# Study of Population Dynamics in a Biological Phosphorous Removal Wastewater Treatment System

by

Pamela B. Morgan

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APPROVED:

Clifford W. Randall

John T. Novak

James G. Ferry

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Committee Chairman: Clifford W. Randall
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**(Abstract)**

This study was an extension of a project conducted by Cech and Hartman (1991) at the Academy of Sciences Laboratories in Ceske Budejouice, Czechoslovakia. During the 1991 study, an unidentified bacterial species dominated a biological phosphorous removal (BPR) system, causing the system to fail. The study indicated that feed composition may have been responsible for the bacteria population shift. The purpose of this study was to examine population shifts of polyphosphorous-removing (PP) bacteria and the unknown bacteria (G bacteria) in a bench-scale sequencing batch reactor (SBR), with emphasis on the effects of feed composition on the populations. The purpose of the study also included characterization and identification of the unknown bacterial species.

Six SBRs were operated for three 8-hour cycles per day, over a time period greater than three sludge ages. Each 8-hour cycle included an influent/anaerobic, anoxic, aerobic, and settling/effluent stage. Different feed mixtures of acetate, glucose, and nutrient broth were fed to the reactors. Chemical and physical parameters were tested during each stage of an 8 hour cycle weekly, in addition to microscopic analysis of PP and G bacteria.

The results of this study indicated that feed composition did not have as significant an effect on PP and G bacteria as hypothesized. G bacteria did not always dominate a system fed a glucose mixture, nor did PP bacteria always dominate a system fed only acetate. In terms of P-removal, bacteria numbers of either PP or G bacteria were not always indicative of P-removal in the reactor. Instead, the size of the PP cells and the amount of phosphorous inside the cells were better indicators of P-removal. G bacteria did not appear to be a controlling factor in PP population size; the reverse appeared to be true. Temperatures above 25C did have an adverse effect on G bacteria, and a positive effect on PP bacteria. No identification in terms of genus and species could be determined for the G bacteria.

Abstract

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# Chapter One: Introduction

With the introduction of biological nutrient removal (BNR) in recent years, much research has been done to gain a better understanding of the population dynamics associated with nutrient-removing bacteria. Although a relatively new technology, biological nutrient removal is growing in popularity as a viable option for wastewater treatment. Biological treatment is beneficial in that it is less expensive than chemical treatment, particularly for those wastewaters high in both nitrogen and phosphorous. As regulations become more stringent with respect to nitrogen and phosphorous, lower cost and single-sludge biological processes will become increasingly beneficial for wastewater treatment.

This project was an extension of a study of biological phosphorous removal systems performed by Cech and Hartman (1991) at the Hydrobiological Institute, Academy of Sciences, Ceske Budejovice, Czechoslovakia. During the course of their studies, they discovered an unidentified bacteria that had interrupted phosphorous removal in their laboratory wastewater treatment systems. Further analysis of the bacterium indicated that the organism was favored when concentrations of glucose to acetate increased in the reactors. Under these conditions, the polyphosphorous (Poly-P) bacteria appeared to be outcompeted by the unknown bacteria, dubbed "G bacteria" because of the reactor from which they were isolated, and phosphorous removal ceased.

The purpose of this research was to study the population dynamics of both Poly-P bacteria and the G-bacteria in a bench-scale biological phosphorous removal system. The bacterial populations were studied both in pure culture and in operating sequencing batch reactors (SBRs) in an effort to best characterize and identify the unknown G-bacteria and to determine its potential role in an activated sludge BPR system.

# Chapter Two: Literature Review

## 2.1 Activated Sludge Microbiology

Activated sludge is a complex mixture of many organisms. As with all biological systems, factors affecting populations of organisms within the sludge include the intrinsic rate of increase of a particular species, food availability, and predation (Hawkes, 1963). Populations within activated sludge are further affected by such factors as temperature, pH, oxygen ($O_2$) availability, and influent characteristics. Influent characteristics may include the form of a particular substrate, the rate at which that substrate is made available (overloading or underloading), toxins introduced into the system, the availability of required nutrients.

In his chapter on "The Ecology of Wastewater" (1963), Hawks describes four primary groups of organisms in activated sludge: bacteria, fungi, protozoa, and metazoa. Of these, bacteria are of chief concern because of their ability to break down organics and their ability to form floc for good sludge settleability. These bacteria are primarily gram negative rods, and include mostly *Achromobacter* (including the genus *Acinetobacter*), *Flavobacterium*, and *Pseudomonas*. Filamentous bacteria may also be present in wastewaters containing complex carbohydrates, however, they are undesirable as they may cause sludge bulking when present in large numbers.

## 2.2 Microbiology of Biological Phosphorous Removal

In recent years, wastewater systems have been designed to remove phosphorous biologically instead of by chemical precipitation. Advantages of this method include lower operating costs, no addition of expensive chemicals, lower amounts of sludge production than with chemical precipitation, no addition of potentially harmful precipitants such as sulfate or chloride, and reduced $O_2$ requirements for aerobic degradation (Winter, 1989; Somiya, et al., 1988; Hao and Chang, 1987; Randall, 1984). Biological phosphorous removal can occur with many bacterial species (Pattarkine, 1991), however, *Acinetobacter* has been reported to be the primary genus responsible for polyphosphorous (PP) storage (Cloete and Steyn, 1988; Lötter and Dubery, 1987; Brodisch, 1985; Hascoet, et al.,1985). *Acinetobacter* are strict aerobes. Under aerobic conditions, these bacteria are capable of accumulating large amounts of PP, which can later be used for energy to sequestor and store organic substrate during anaerobiosis. In this way, *Acinetobacter* have a competitive advantage over other aerobic and facultative bacteria that do not have this capability.

Several factors are required to achieve PP removal. The primary factor is that the bacteria must have alternating anaerobic and aerobic conditions. Polyphosphorous-removing bacteria (PP-bacteria) must undergo P-release before luxury P-uptake can occur (Hascoet, et al., 1985) which requires the absence of electron acceptors, i.e., strict anaerobic conditions. Second, sufficient $O_2$ must be available in the aerobic zone in order for P-uptake to occur. Sufficient quantities of minor nutrients associated with P-removal, such as magnesium, potassium, and manganese, must also be available

(Pattarkine, 1991; Winter, 1989; Davelaar, 1989). Finally, the available carbon source must be in the form of volatile fatty acids (VFAs) for Poly-P metabolism.

## 2.3 PP-removing Bacteria: Biochemistry and Behavior

### 2.3.1. Biochemistry

*Acinetobacter* belong to the family Nesseriaceae. They are Gram negative, oxidase negative rods with an optimum growth temperature of 35-37°C. During log growth phase, they appear as short, plump rods, while during stationary growth they are nearly coccoid (Bergey's Manual, 1984), with average cell dimensions of 0.8 - 1.5 $\mu$m length and 0.6 - 0.8 $\mu$m width (Hao and Chen, 1987). They are classified as chemo-organo-heterotrophs because they utilize volatile fatty acids as both an energy source and a carbon source, and they use oxygen as an electron acceptor. They also are typically characterized as strict aerobes (Bergey's Manual, 1984), however, some species are facultative because they are capable of using $NO_3^-$ as an electron acceptor when no $O_2$ is present (Wentzel, et al., 1985). *Acinetobacter* can survive long periods of time under anaerobiosis, which requires an electron acceptor other than $O_2$ (Davelaar, 1989).

Several species of *Acinetobacter* have been identified in activated sludge, the most abundant of these being *A. iwoffii*, *A johnsonii*, and *A. junii* (Beacham, et al., 1990) (Fig. 1). *Acinetobacter* species have been divided into three groups based on their ability to accumulate phosphorous. These include constitutive accumulators, i.e., those species which accumulate phosphorous at any concentration; conditional accumulators, those

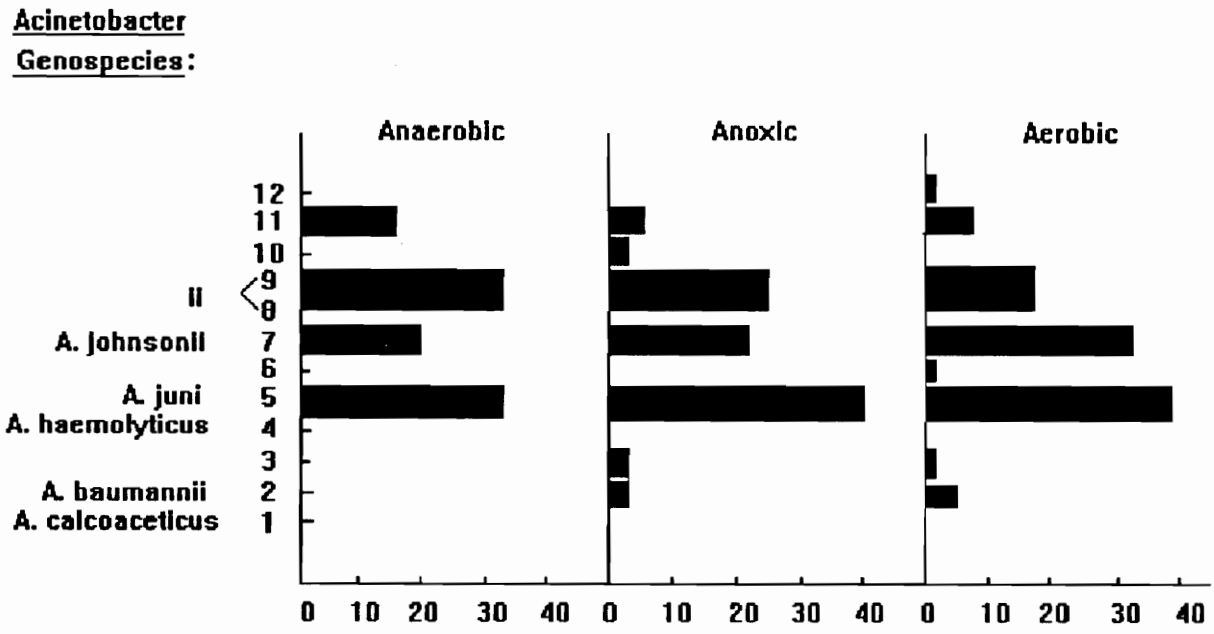



Fig. 1. Distribution of Acinetobacter isolated from different stages in a pilot plant (from A. M. Beacham, et al., 1990).

that accumulate phosphorous when it is available in excess; and non-accumulators, those that do not accumulate phosphorous at all. Of the species studied in a biological nutrient removal plant, 51-61% were identified as constitutive accumulators, 27-39% as conditional accumulators, and 10-12% as non-accumulators, including both clustered and non-clustered cells (Beacham, et al., 1992). It was concluded, therefore, that the bacteria should be studied as a genus and not by species, since no single species is responsible for the phosphorous removed. It should also be noted that in activated sludge, *Acinetobacter* are found primarily in clumps surrounded by extracellular material, as opposed to single cells (Hao and Chang, 1987; Deinema, et al., 1985). This serves to enhance the cell's ability to form settleable floc (Hao and Chang, 1987; Deinema, et al., 1985).

### 2.3.2. Metabolism

The metabolism of *Acinetobacter*, or poly-p bacteria, is summarized by the following: their food source, in the form of volatile fatty acids (VFAs), is broken down via the tricarboxylic acid cycle. Using the fermented fatty acids as electron donors, the fatty acids are oxidized to $CO_2$, using $O_2$ as an electron acceptor. The energy gained is then used for cell repair, reproduction, and growth.

Poly-P bacteria do not possess a fermentative, or glycolytic, pathway to convert available organics into VFAs, therefore they are dependent on other microorganisms to break down complex sugars, i.e. glucose, into the fermented forms they can use (Deinema, et al., 1985; Randall, 1984). This has been demonstrated in a study using acetate (a VFA) and glucose (a complex sugar) as substrates. The study concluded that

a higher amount of tagged carbon was found in cells when fed both acetate and glucose. These results were interpreted as an indication of the PP bacteria's inability to directly utilize glucose as a substrate (Bordacs and Chiesa, 1989). These findings also support biochemical models that have been proposed (Wentzel, et al., 1986), and batch studies performed in the laboratory (Arvin and Kristensen, 1985).

A synergistic relationship exists between fermentative bacteria and the poly-p bacteria due to the PP's inability to utilize complex sugars. This relationship has been demonstrated between two species, *Acinetobacter calcoaceticus* and *Aeromonas puntata* (Brodisch, 1985). When present, *Aeromonas* enhanced phosphorous uptake in poly-p bacteria by breaking down glucose into a usable form for the poly-p bacteria. Although *Aeromonas* itself was capable of removing phosphorous, its primary function was to provide VFAs under anaerobic conditions for the poly-p bacteria. These findings refute previous hypotheses that poly-p bacteria must undergo anaerobiosis as a period of stress to induce phosphorous release, in order to remove phosphorous under subsequent aerobic conditions.

Wentzel (et al., 1986) summarizes *Acinetobacter* metabolism in three steps: the tricarboxylic acid (TCA) cycle, the glyoxylate cycle, and poly-$\beta$-hydroxybutyrate (PHB) synthesis and degradation. The TCA cycle provides energy to the cells in the form of NADH, and FADH. It also supplies intermediates for anabolism, and is controlled by the presence of NAD and ATP. In high concentrations, NAD/NADH and ATP/ADP ratios act to inhibit the TCA cycle, while low ratios stimulate the cycle. The glyoxylate cycle supplies intermediates required by the TCA cycle. These intermediates also serve

to regulate the TCA cycle by their presence or absence. This secondary cycle is required because the oxidation of acetic acid (a 2-carbon compound) to $CO_2$ does not contain enough carbon atoms to complete more than one cycle. By utilizing the glyoxylate cycle, two decarboxylation reactions are bypassed in the TCA cycle (Lotter and Dubery, in Ramadori, 1987) thus avoiding the need for additional carbons.

PHB synthesis occurs when acetate is converted to acetyl-CoA, where it is polymerized in the form of PHB. PHB formation is activated by low NAD/NADH ratios and the presence of acetyl-CoA. This occurs under anaerobic conditions, where no electron acceptors are available to the bacteria. PHB degradation, or hydrolysis, occurs when PHB is de-polymerized into acetyl-CoA. Once in this form, the compound may enter into the TCA cycle. Conditions that induce PHB degradation include high NAD/NADH ratios, low concentrations of available organics, and the presence of an electron acceptor ($O_2$). In addition to PHB metabolism, polyphosphorous (PP) synthesis/degradation may also occur in the cell, and may serve as energy source/sink. PP accumulation occurs when ADP/ATP ratios are low, while PHB accumulation occurs when NAD/NADH ratios are low. Figure 2 illustrates these transformations inside and outside the cell.

PHB is formed when acetic acid is used as a substrate. It should also be noted, however, if other fatty acids such as propionate, lactate, butyrate, or valerate are used as substrate instead of acetate, poly-$\beta$-hydroxy valerate (PHV) accumulation will occur instead (Comeau, et al., in Arun, et al., 1989).

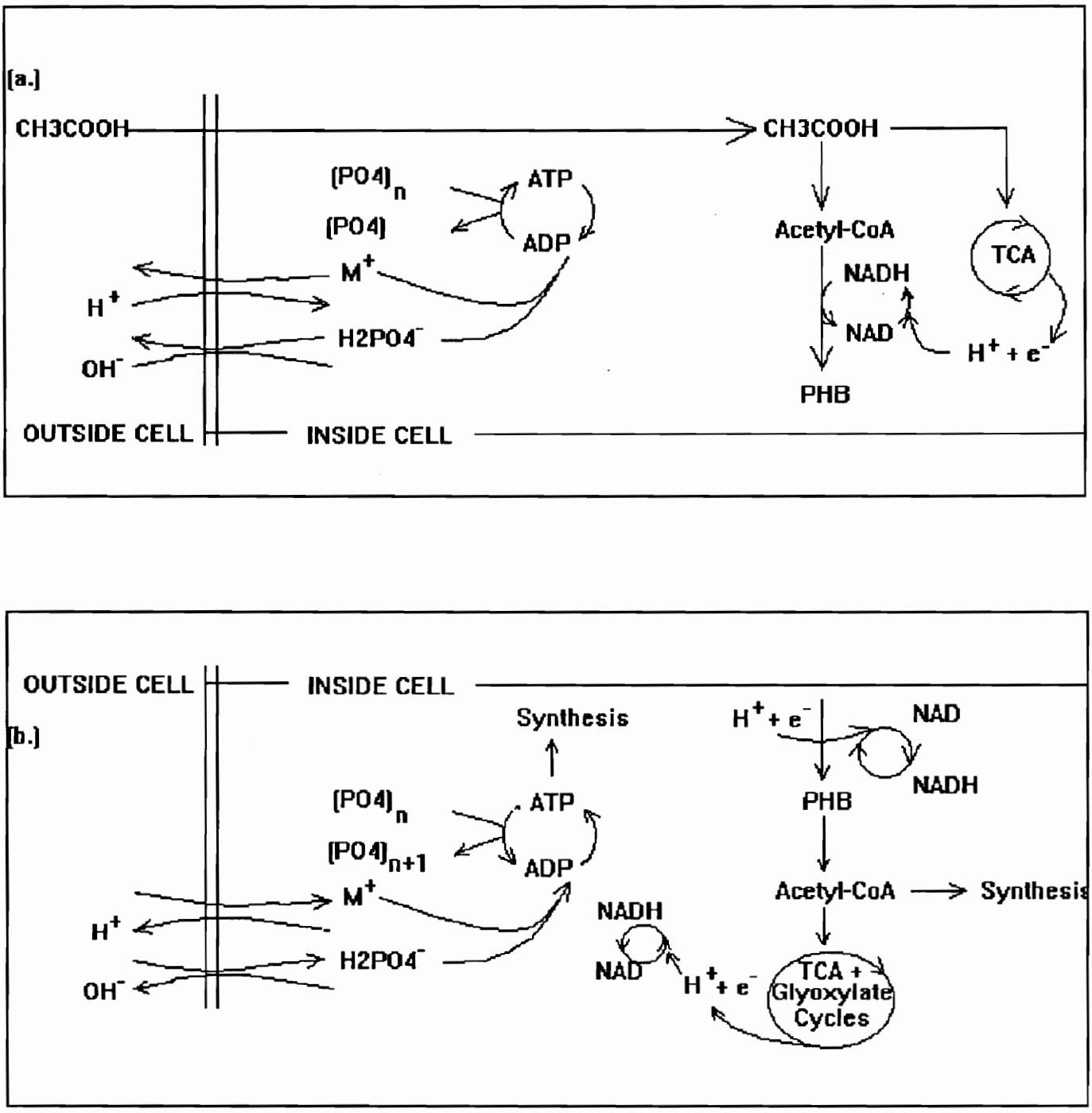



Figure 2. Movement of acetate, poly-p, and cations across cell membrane (a) under anaerobic conditions, and (b) under aerobic conditions (from Wentzel, et al., 1986).

Intracellular P occurs in three forms: ortho-P, $H_2PO_4^-$, and $HPO_4^{-2}$ (Pattarkine, 1991). Because there is a negative charge associated with all these forms of phosphorous, cations such as $Mg^{+2}$, $K^+$, and $Ca^{+2}$ are associated with P uptake and release in order to maintain a redox balance and electroneutrality in the cell. Several studies have determined ratios of the number of cations released per P atom released (mg/mg), summarized by the following table:

| Mg:P | K:P | Ca:P | Study |
|---|---|---|---|
| 0.28 | 0.22 | -- | Yoon and Suziki, 1990 |
| 0.25 | 0.29 | -- | Arvin and Kristensen, 1985 |
| 0.27 | 0.28 | 0.02 | Comeau, et al., 1985[1] |

[1]In Wentzel, et al., 1986.

These cations are required for phosphorous removal/uptake and must be available in sufficient quantities. Pattarkine (1991) demonstrated that $K^+$ and $Mg^{+2}$ must be available at the same time, in concentrations of ≥0.43 mol K/mol P and 0.37 mol Mg/mol P. $Ca^{+2}$ is not required for phosphorous removal, but may be co-transported with P, if available. However, because $Ca^{+2}$ is an essential element for bacterial growth, it is required in trace amounts.

### 2.3.3. Factors Affecting P Release and Uptake

In a conventional activated sludge system, bacterial contain approximately 2.0-3.5 %P in their cells, while in an enhanced BPR system, %P in poly-p bacteria is approximately 8-10 %P (Randall, 1992). To achieve biological P removal in an activated sludge system, poly-p bacteria must undergo P release prior to enhanced P uptake. It has been well documented that the amount of P release to P uptake is a linear (or near linear) relationship (Wentzel, et al., 1986; Hascoet, et al., 1985). Pattarkine (1991) found 1.2 kg P release per kg P uptake for a mean cell retention time (MCRT) range of 8-20 days. What factors affect both P release and P uptake in an activated sludge system?

Substrate has been shown to have an effect on the amount of P release that occurs anaerobically. P release:acetate uptake has been theoretically determined to be 0.50, although experimental values have been found to be between 0.29-0.77 mol P release:acetate uptake (Cech, et al., 1991). P release is significantly higher if acetate, propionate, and lactate are used as substrates rather than glucose (Arvin and Kristensen, 1985); however, this could reflect that fermentation may be the limiting step in substrate availability for poly-p utilization. In terms of total organic carbon (TOC), the amount of P release per unit mass soluble TOC has been found to be 0.221 mg P/mg TOC (Somiya, et al., 1988). The chemical oxygen demand (COD) utilized during P release has been determined to be approximately one mg COD utilized per 0.22 mg P released, following an initial 20-40 mg/L COD utilized prior to any P release (Pattarkine, 1991).

P release can be triggered by the presence of organic acids, $H_2S$, $CO_2$, and low pH (Davelaar, 1989). The amount of P release also can be increased by increasing the food

to microorganism (F/M) ratio, up to 0.044 mg TOC/mg MLSS (Somiya, et al., 1988). There is a limit, of course, to the amount of releasable P in a cell, and a limit to the storage capacity of that cell. P release will not occur in cells during stationary growth phase (Deinema, et al., 1985). The rate of P release can be increased by the addition of $CO_2$ and by increasing the amount of acetate and ethanol. The addition of ethanol serves as an extra hydrogen donor to create a reducing environment suitable for lipid synthesis that acetate alone cannot achieve (Deinema, et al., 1985).

Studies have shown that P release is also inhibited in the presence of $NO_3$, resulting in the subsequent disruption of P uptake under aerobic conditions (Davelaar, 1989; Hascoet, et al., 1985). Wentzel, et al. (1986) identified three groups of *Acinetobacter* in terms of nitrogen reduction: those that can reduce $NO_3$ to $NO_2$, those that can reduce $NO_3$ to $N_2$, and those that are incapable of $NO_3$ reduction. During the anaerobic phase, if nitrates are present, bacteria incapable of $NO_3$ reduction will demonstrate P release, while those that can reduce $NO_3$ will begin slow uptake of P. During the anaerobic stage, this results in a rapid decrease in $NO_3$, a decrease in PHB formation, and a slow increase or decrease in soluble P, depending on the population's capabilities. It has been shown that up to 50% of Acinetobacter spp. are capable of partial $NO_3$ reduction; fewer are capable of complete $NO_3$ reduction (Lotter, 1985). Another study had shown, however, that poly-p bacteria are capable of successfully competing with denitrifiers for acetate, and are able to release P with $NO_3$ concentrations as high as 40 mg/L, although not as effectively as with no $NO_3$ present (Iwema and Meunier, 1985, in Wable, 1992).

The rate of P uptake is a function of available storage capacity in the cell and the concentration of extracellular P, as well as factors such as temperature and pH, under aerobic conditions (Somiya, et al., 1988; Hao and Chang, 1987). Optimum temperature for P uptake is approximately 33°C; optimum pH for growth is 7.5, while optimum pH for P uptake is 7.0 (Hao and Chang, 1988). In addition to $NO_3$, copper has also been found to inhibit P uptake at concentrations >1 mg/L (Hascoet, et al., 1985). P uptake is also inhibited if there is acetate carried over from the anaerobic/anoxic stage into the aerobic stage (Pattarkine,1991). It should be noted that filamentous growth may also be promoted if excess substrate is available during the aerobic stage, either in the form of soluble substrate, or particulate form immeshed in biological floc (Wanner and Novak, 1990).

Arun (et al., 1989) best summarized the basic characteristics of the primary bacterial species responsible for phosphorous removal. Polyphosphorous-removing bacteria have: the ability to store high energy poly-p under aerobic conditions to use for energy under anaerobiosis; the ability to store these polymers which serves as a competitive advantage over non-energy storing bacteria during the aerobic stage when substrate is unavailable; and the ability to maintain a redox balance inside the cell permitting polymers to be stored by the bacteria.

### 2.4 Biochemistry and Behavior of G-bacteria

Recent studies have indicated that there exist non-fermenting microorganisms that can metabolize substrate during anaerobiosis without poly-p release. These

microorganisms have been referred to as "G" bacteria because of the reactor they were originally isolated from. The designation is appropriate, however, because they have a unique ability to use glucose under anaerobiosis. G-bacteria are Gram negative cocci, approximately twice the size of poly-p bacteria, and are commonly found as tetrads, pairs, or irregular masses (Cech and Hartman, 1990). They are readily identified and distinguished from poly-p bacteria using the Neisser staining method, after which they appear as clear cells surrounded by a deep blue cell wall (Cech, et al., 1991). Table 1 summarizes all biochemical data to date that is known of the bacteria.

Studies performed by Cech and Hartman (1991; 1990) have found that these bacteria can utilize substrates such as acetate, formate, and glucose both anaerobically and aerobically. In laboratory systems, the bacteria have demonstrated an ability to outcompete Poly-p bacteria as they remove substrate anaerobically. This is particularly evident when glucose is used as substrate. G-bacteria have also been found to outcompete Poly-p's even when sufficient acetate for the poly-p bacteria is available. Only if the feed solution contained 100% acetate did the PP bacteria successfully outcompete the G-bacteria over a long period of time.

As G-bacteria begin to dominate an activated sludge system, the performance of the P-removing bacteria deteriorates. Studies have shown that ratios of P release to acetate uptake fall to zero as poly-p numbers decrease and G-bacteria numbers increase.

| Parameter | Test Result | Parameter | Test Result |
|---|---|---|---|
| Cell diameter, $\mu m$ | 1-2 | Amino Acid Decarboxylases: | |
| Cell length, $\mu m$ | 2-3 | L-Arginin | - |
| Gram Stain | - | L-Lysin | - |
| Gram Stain after KOH Treatment | + | Red. $NO_3 \rightarrow NO_2$ | + |
| Growth On: | | $H_2S$ | - |
| Sheep's Blood Agar | - | Glucose: | |
| MacConkey Agar | - | Gas Production | +/- |
| Formate | + | Acid Production | +/- |
| Acetate | + | Urea | + |
| Oxidase | + | ONPG | + |
| Starch | - | Motility | - |
| Casein | - | Citrate | +/- |
| Tween 80 | - | VP | - |
| DNA | - | Gelatin | - |
| Esculin | - | Catalase | + |

Table 1: Known biochemical characteristics for "G-bacteria" (from Cech and Hartman, 1991)

These studies further indicated that G-bacteria are found in many sludges that are fed acetate, particularly under experimental conditions. Thus, the presence of these bacteria in activated sludge treatment systems is of concern, particularly as to what conditions promote G-bacterial growth.

# Chapter Three: Methods and Materials

## 3.1 Overview

This chapter is divided into two sections. The first section describes the design and operation of the bench-scale reactors used in this study, including sampling procedures and analyses used during the primary experiments. The second will describe the biochemical analyses that were performed, including both biochemical test kits and additional experiments that were performed.

## 3.2 Experimental Design

Four bench-scale sequencing batch reactors (SBRs) were used to conduct the experiments (Fig. 3). Each reactor operated on an 8-hour cycle, repeated three times a day. Each cycle included a two hour anaerobic stage, a two hour anoxic stage, a three hour aerobic stage, and a one hour settling/withdrawal period. The design parameters included a hydraulic retention time (HRT) of 2.67 days, and a sludge age ($\theta_c$) of 15 days. Table 2 summarizes influent and effluent flows during each eight hour cycle.

Influent feed solutions consisted of different percentages of acetate, glucose, and/or nutrient broth dissolved in 1 L of distilled water (Table 3). Initially, these percentages were determined on a molar basis. Later on in the research, these percentages were based on total organic carbon (TOC) equivalents for each carbon source, totalling 315 mg/L TOC.

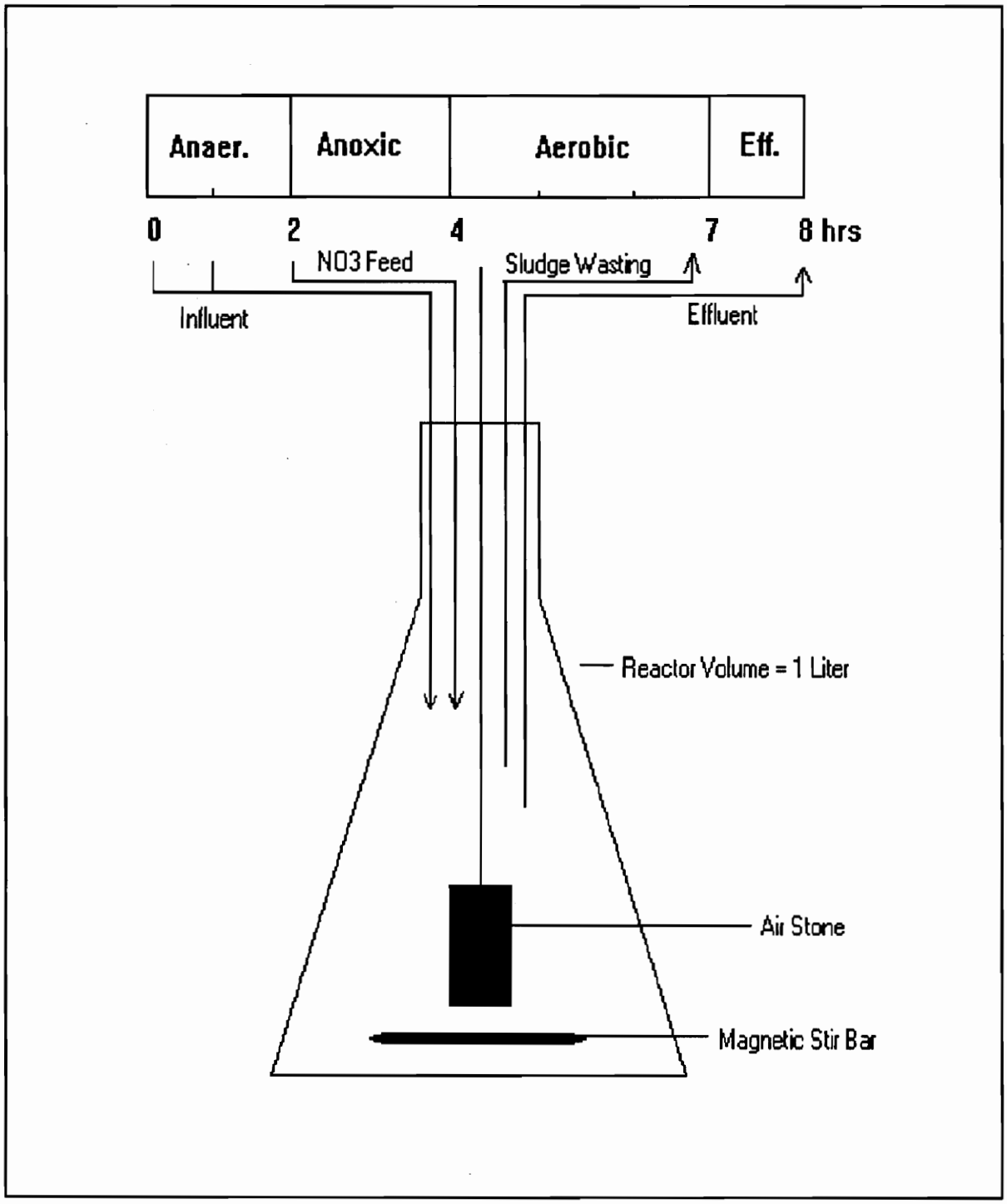



Fig. 3. Sequencing batch reactor (SBR) design.

Methods and Materials

| Time (hrs) | Stage | Flow (ml) | Cum. Flow (ml) |
|---|---|---|---|
| 0 | Anaerobic | + 100 | 100 |
| 1 | Anaerobic | + 100 | 200 |
| 2 | Anoxic | + 7.23 | 207.5 |
| 6.9 | Aerobic | - 22.3 | 184.5 |
| 7.9 | Settle/Withdrawal | - 171.5 | 0 |

Table 2. Reactor flow scheme during one 8-hour cycle.

| Day | Reactor | Constituent | g/L | Percent Feed |
|---|---|---|---|---|
| Solution A: | | | | |
| 1-58 | A | Acetate | 16.400 | 100%[1] |
| 59-131 | A | Glucose | 12.006 | 50%[2] |
| | | Acetate | 6.950 | 50% |
| 1-58 | B | Acetate | 16.400 | 100%[1] |
| 1-40 | C | Acetate | 16.400 | 100%[1] |
| 41-69 | C | Acetate | 24.460 | 100%[2] |
| 1-40 | D | Glucose | 1.487 | 25%[1] |
| | | Acetate | 12.300 | 75% |
| 41-69 | D | Glucose | 4.194 | 25%[2] |
| | | Acetate | 18.008 | 75% |
| 69-114 | D | Nutrient Broth | 4.004 | 25%[2] |
| | | Glucose | 4.194 | 25% |
| | | Acetate | 6.004 | 50% |
| 1-73 | E | Nutrient Broth | 8.008 | 50%[2] |
| | | Acetate | 12.006 | 50% |
| 1-45 | F | Nutrient Broth | 12.012 | 75%[2] |
| | | Acetate | 6.004 | 25% |
| Solution B: | | | | |
| N/A | A - F | $NH_4Cl$ | 37.4 | N/A |
| N/A | A - F | $Na_2HPO_4$ | 71.0 | N/A |
| N/A | A - F | $KH_2PO_4$ | 27.2 | N/A |
| N/A | A - F | $MgCl*6H_2O$ | 40.6 | N/A |

[1]Molar Basis
[2]Total Organic Carbon Equivalent

Table 3. Feed composition of solutions A and B.

Methods and Materials

Concentrated stock solutions of each feed were added to a second solution prepared with tap water, which contained minor nutrients required for bacterial growth. The two solutions were added at a ratio of 1 part solution A to 2 parts solution B, producing a mixture with a final TOC of ~315 mg/L.

A nitrate feed was added to each reactor at the beginning of each anoxic stage. The concentration of $NaNO_3$ was calculated to be a 1:1 molar ratio for acetate to nitrate, and a 4:1 ratio for glucose to nitrate from the following equations:

$$NaC_2H_3O_2 + NaNO_3 \rightarrow 2CO_2 + H_2O + \tfrac{1}{2}N_2\uparrow + H^+ + 2Na^+$$

$$NaC_6H_{11}O_6 + 4NaNO_3 \rightarrow 6CO_2 + 6H_2O + 2N_2\uparrow + 4Na^+$$

These ratios approximated COD:$NO_3$ ratios. The molar ratio for nutrient broth was assumed to be 2:1. Actual $NaNO_3$ concentrations were calculated based on the amount of TOC entering the anoxic stage, which was then converted into equivalent amounts of influent organic carbon. These concentrations were decreased, when necessary, to achieve zero mg/L $NO_3$-N at the end of the anoxic stage.

### 3.3 Sampling Procedure

Weekly samples were taken at the beginning of each stage from each reactor during a full 8-hour cycle . Dissolved oxygen (DO) and pH were measured using a YSI Model 57 Oxygen Meter (Yellow Springs Instrument Co., Inc., Yellow Springs, Ohio) and

a Fisher Accumet® Model 610A pH meter. The samples were filtered through a glass fiber filter (Whatman) using an acid washed filter apparatus. Samples were then analyzed for nitrates ($NO_3^-$), nitrites ($NO_2^-$), and phosphorous ($PO_4^{-3}$) using a Dionex 2010i ion chromatograph (Dionex Corporation, Sunnyvale, California). Total suspended solids (TSS) and volatile suspended solids (VSS) were determined for aerobic and effluent samples. The remaining sample was then preserved with concentrated $H_2SO_4$ at a pH<2 and refrigerated until further analysis.

### 3.4 Sample Analysis

Table 4 summarizes the tests performed on each sample. Sample analyses were performed as per procedures outlined by Standard Methods for the Analysis of Water and Wastewater (1991).

Total organic carbon (TOC) was determined using a Dohrmann® Carbon Analyzer (Vertex Corp., Santa Clara, CA). TOC is a measure of the amount of covalently bonded carbon in an organic compound. Its measurement is based on the conversion of these organic compounds to single carbon units which are oxidized to $CO_2$ by ultra-violet radiation. An infra-red detector produces an electrical output which is integrated and scaled by a processor which prints out the amount of $CO_2$ measured in mg/L. Pre-filtered samples were acidified and purged with $CO_2$ to eliminate

| | Inf. | Anaer. | Anox. | Aer. | Eff. | APHA Method Procedure Method |
|---|---|---|---|---|---|---|
| D.O. | | • | • | • | • | N/A |
| pH | • | • | • | • | • | N/A |
| TSS | | | | • | • | 2540 D. TSS Dried @ 100°C |
| VSS | | | | • | • | 2540 E. VSS Dried @ 500 °C |
| Total P | | | | • | | 4500-P, B and E Ascorbic Acid W/ Sample Prep. |
| Sol. P | • | | | • | | 4500-P, B and E |
| $PO_4$-P | • | • | • | • | • | 4110 B. IC W/ Chemical Suppression of Eluent Conductivity |
| $NO_2$-N | • | • | • | • | • | 4110 B. |
| $NO_3$-N | • | • | • | • | • | 4110 B. |
| $NH_3$-N | • | • | • | • | • | 4500-$NH_3$ B, E. Titrimetric W/ Distillation |
| Total TKN | | | | • | | 4500$N_{org}$-B, Macro-Kjeldahl |
| Sol. TKN | • | | | • | | 4500$N_{org}$-B. |
| TOC | • | • | • | • | • | 5310.C, Persulfate-UV Oxidation |

Table 4. Weekly sampling procedure and analysis.

interferences of other carbon forms, such as $CO_3^{-2}$, and $HCO_3^-$ prior to analysis. TOC was measured in mg/L TOC.

### 3.5 Microbial Counting Procedure

Raw samples obtained from each stage during an eight hour cycle were used to prepare slides. Samples were first homogenized using a glass homogenizer to break up bacterial floc. A glass syringe was then used to place 0.005 ml of sample onto a microscopic slide. The sample was allowed to air dry; the slide was then heat-fixed and Neisser stained. Samples were diluted with distilled water to achieve a bacterial count of less than 200 baceria per one counting square under x1000 magnification prior to homogenizing.

A modified Neisser staining method was used to differentiate Poly-p and G-bacteria. The following details the procedures outlined by Cech and Hartman (1991) for Neisser staining: a 2:1 mixture of methylene blue and crystal violet is applied to the slide for 15 seconds. The slide is rinsed with distilled water. Chrysoidin Y solution is then applied for 45 seconds. The slide is rinsed thoroughly, allowed to air dry, and stored in a closed container. Under an oil immersion lens, Poly-P bacteria appear as solid colored, brown/black cells, while G-bacteria are clear cells, with deep blue cell walls. Bacterial counts were made using a counting grid under an oil immersion objective lens. Five to ten random areas were counted until a standard deviation of $\leq 0.30$ was achieved. The area

of each 0.005 ml sample was determined using the counting grid under a x4 objective. The actual bacterial count per ml for that sample was then calculated using the following formula:

$$X_{actual} = [X * A *(100/4)^2/V]$$

X = # bacteria

A = area of 0.005 mL sample

V = volume, 0.005 ml

### 3.6 Biochemical Analyses

Three bacterial identification systems were used to characterize the G-bacteria. These systems included the Analytical Profile Index (API), the Flow Laboratories System for Non-fermenting Bacteria, and the Biolog system. G-bacteria were isolated using a streak plate method. Raw sludge samples were streaked onto glucose agar. Isolated bacterial colonies were removed and streaked again. This method was repeated several times until a pure culture was achieved. Slides of the culture were Neisser stained and API tested for verification. Polyphosphorous bacteria were isolated in a similar way, using an acetate agar. All cultures for both G-bacteria and poly-P bacteria were grown at 25°C.

In addition to identification systems, toxicity tests were also performed. Preliminary toxicity testing began with cross-streaking pure cultures of G and PP bacteria on a nutrient agar and a yeast extract agar. In this test, inhibition is indicated by a lack of cell growth in the "inhibited" species at the intersection of the two streaks. Further testing was to include the addition of several concentrations of pure G bacteria to pure cultures of PP bacteria into a broth. Variations in growth was to be measured in terms of turbidity, however, the G bacteria were too slow-growing and PP bacteria too numerous, with the result that no conclusions could be drawn in terms of any variation in turbidity.

A mixed liquor sample was taken from the reactors and centrifuged. The supernatant was collected and purified using a 0.22 $\mu$m sterile filter. The filtrate was placed on pure cultures of polyphosphorous bacteria and incubated at 25°C to determine its effect on bacterial growth.

# Chapter Four: Results

## 4.1 Overview

This section summarizes the results obtained from weekly sampling of each reactor. It includes topics such as population shifts, the effects of feed solutions, temperature effects, and other characteristics indicated by the data. Raw data are located in Appendix A and B.

## 4.2 Definition of P-removal

It should be noted that P-removal was defined as the removal of $\geq$10 mg/l $PO_4$, measured from the end of the anaerobic stage to the end of the aerobic stage. During initial periods of sludge acclimation, background $PO_4$ concentrations in the reactor were often significantly higher than those of the influent $PO_4$. Thus differences between influent and effluent $PO_4$ did not always indicate whether net P-removal actually occurred. In addition, $PO_4$ release often occurred during the one hour settling period due to the onset of anaerobic conditions, thus increasing the amount of $PO_4$ measured in the effluent. Because this did not occur at all times, $PO_4$ removal was always measured at the end of the aerobic stage for consistency.

## 4.3 Population dynamics and subsequent P-removal

Figure 4 (a-f) illustrates the changes in bacterial populations of both PP bacteria and G bacteria in the aerobic stage of each reactor through time. During periods of P-

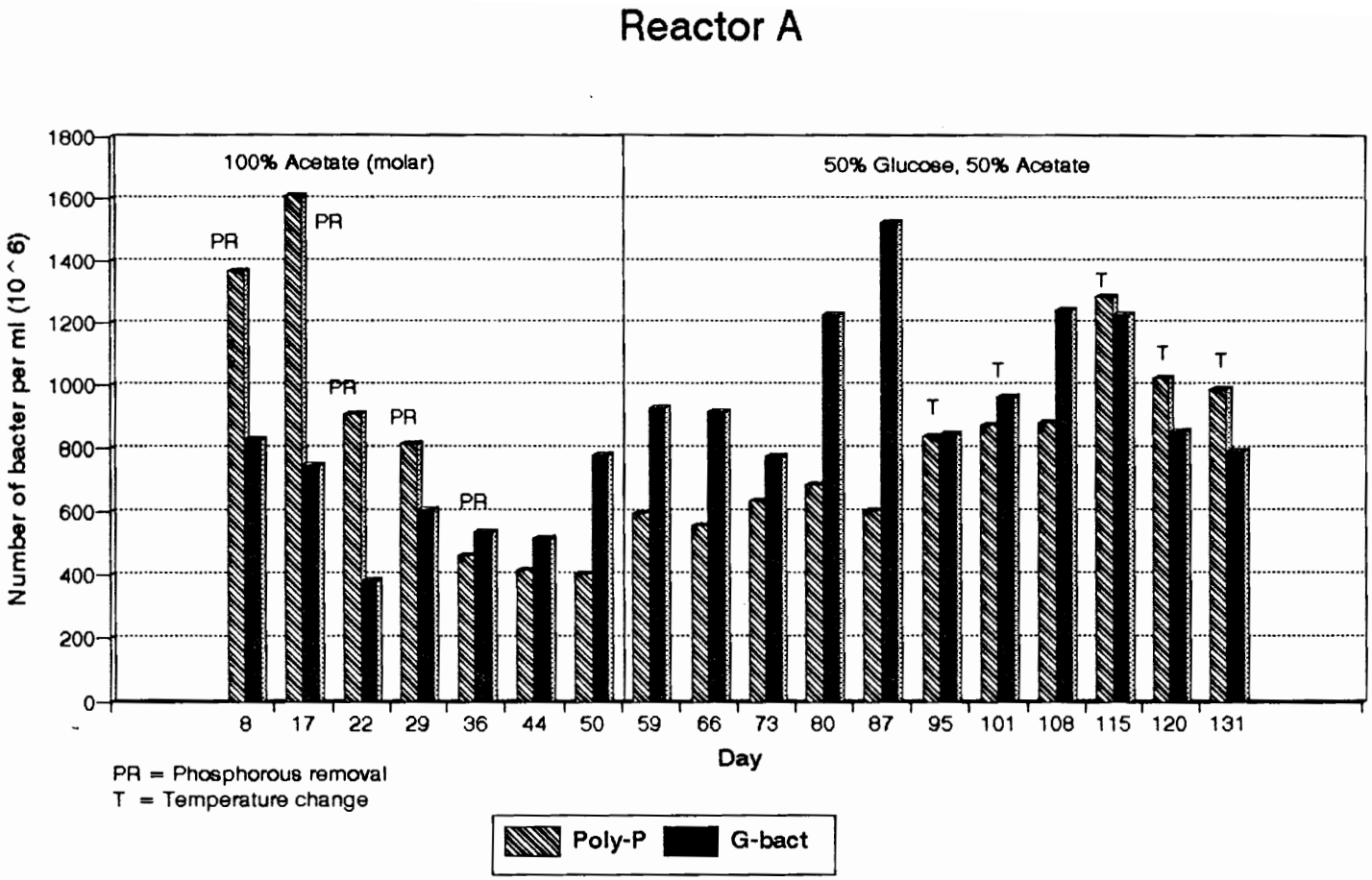
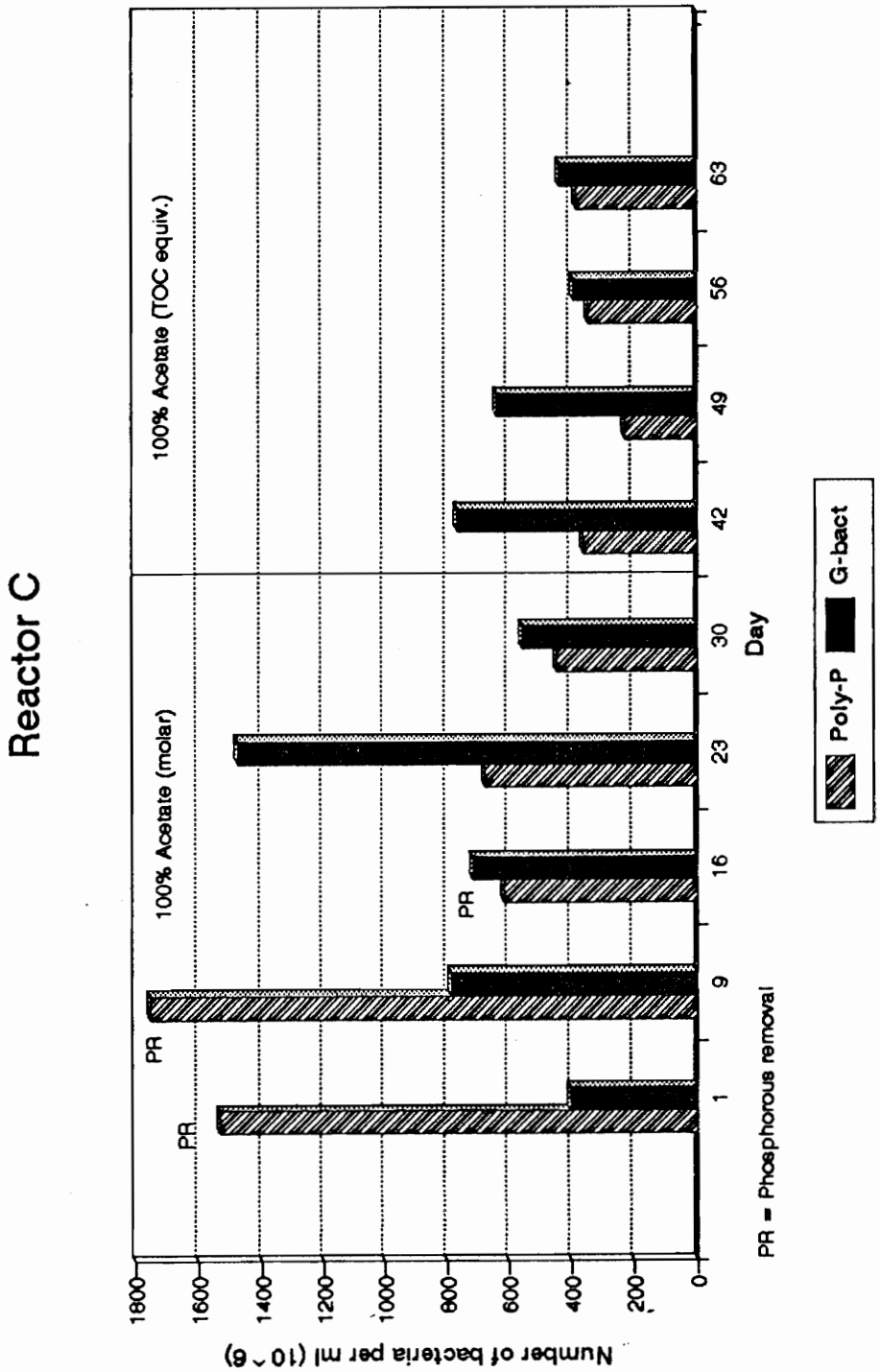
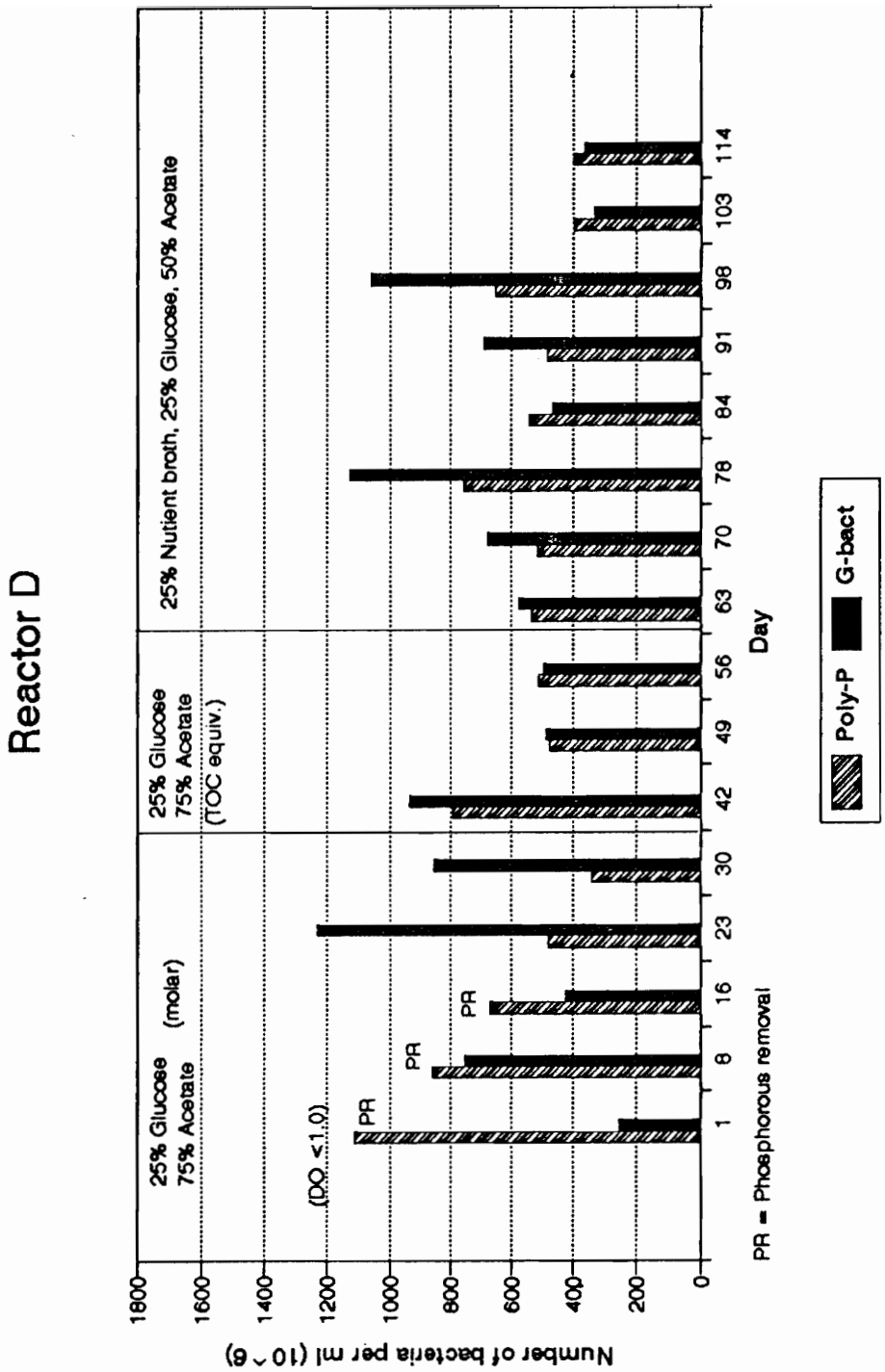
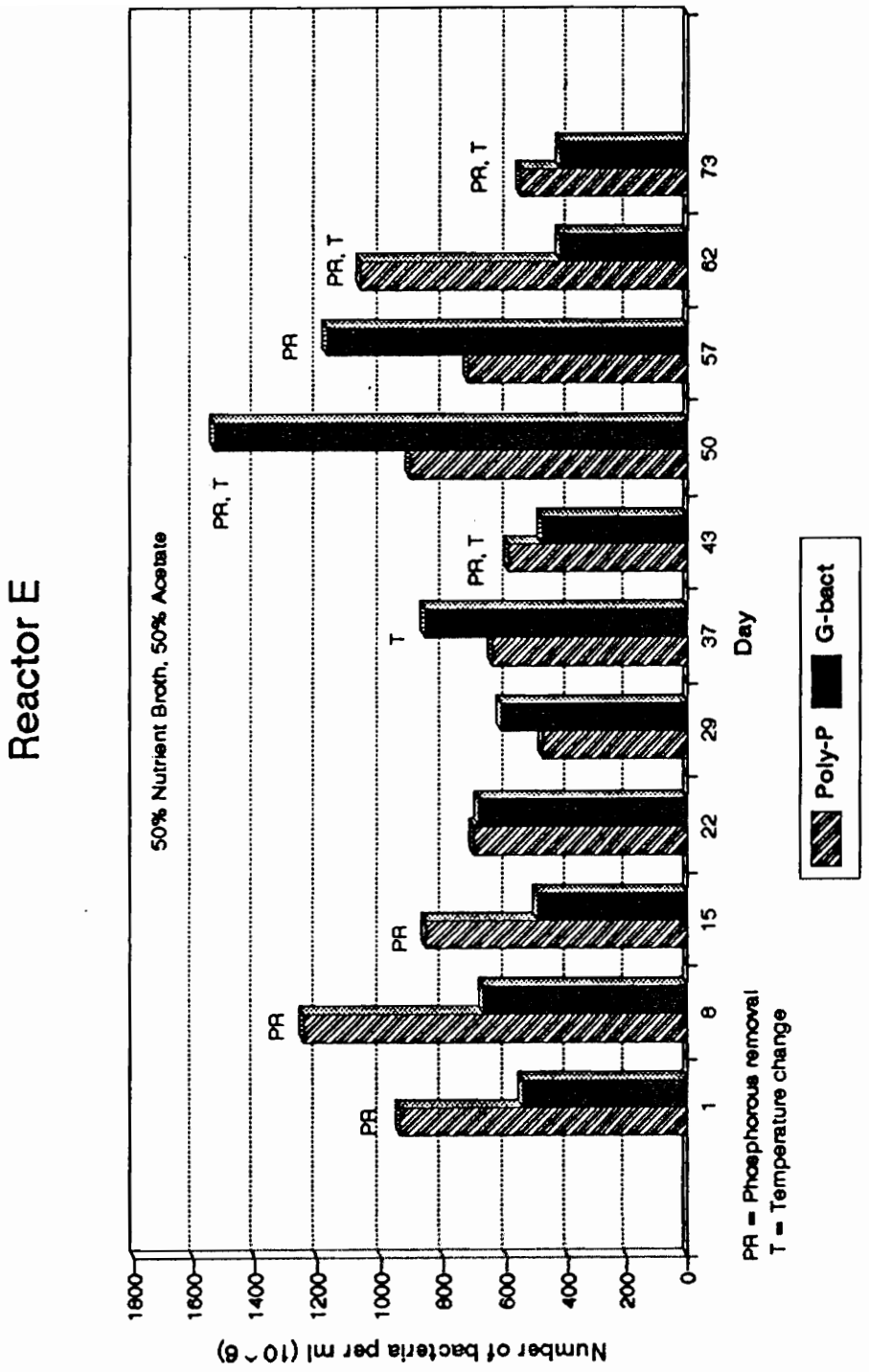


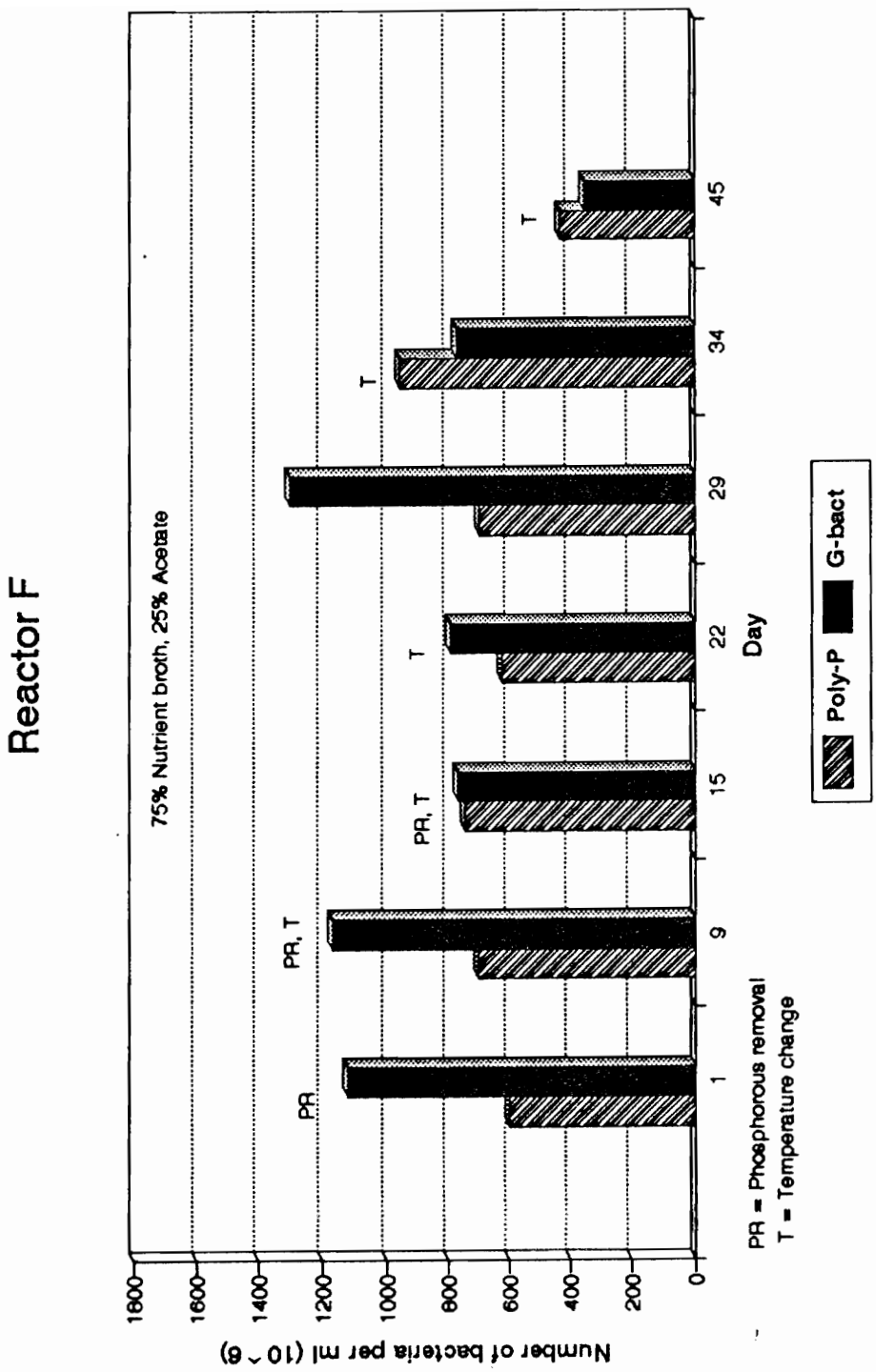

Fig. 4 (a-f). Number of PP and G bacteria during the aerobic stage in each reactor through time. Note that in reactor A, the D.O. on days 29, 36, and 66 was below 4.0 mg/l dissolved oxygen.

Reactor B
100% Acetate (molar)
Number of bacteria per ml (10^6)
1800
1600
1400
1200
1000
800
600
400
200
0
8
17
22
29
36
44
50
Day
Poly-P
G-bact


Reactor C
100% Acetate (molar)
100% Acetate (TOC equiv.)
PR
PR
PR
Number of bacteria per ml (10^6)
1800
1600
1400
1200
1000
800
600
400
200
0
1
9
16
23
30
42
49
56
63
Day
PR = Phosphorous removal
Poly-P
G-bact


Reactor D
25% Glucose
75% Acetate
(molar)
25% Glucose
75% Acetate
(TOC equiv.)
25% Nutient broth, 25% Glucose, 50% Acetate
(D.O. <1.0)
PR
PR
PR
Number of bacteria per ml (10^6)
1800
1600
1400
1200
1000
800
600
400
200
0
1
8
16
23
30
42
49
56
63
70
78
84
91
98
103
114
Day
PR = Phosphorous removal
Poly-P
G-bact


Reactor E
50% Nutrient Broth, 50% Acetate
Number of bacteria per ml (10^6)
1800
1600
1400
1200
1000
800
600
400
200
0
PR
PR, T
T
1
8
15
22
29
37
43
50
57
62
73
Day
PR = Phosphorous removal
T = Temperature change
Poly-P
G-bact


Reactor F
75% Nutrient broth, 25% Acetate
Number of bacteria per ml (10^6)
1800
1600
1400
1200
1000
800
600
400
200
0
PR
PR, T
PR, T
T
T
T
1
9
15
22
29
34
45
Day
PR = Phosphorous removal
T = Temperature change
Poly-P
G-bact

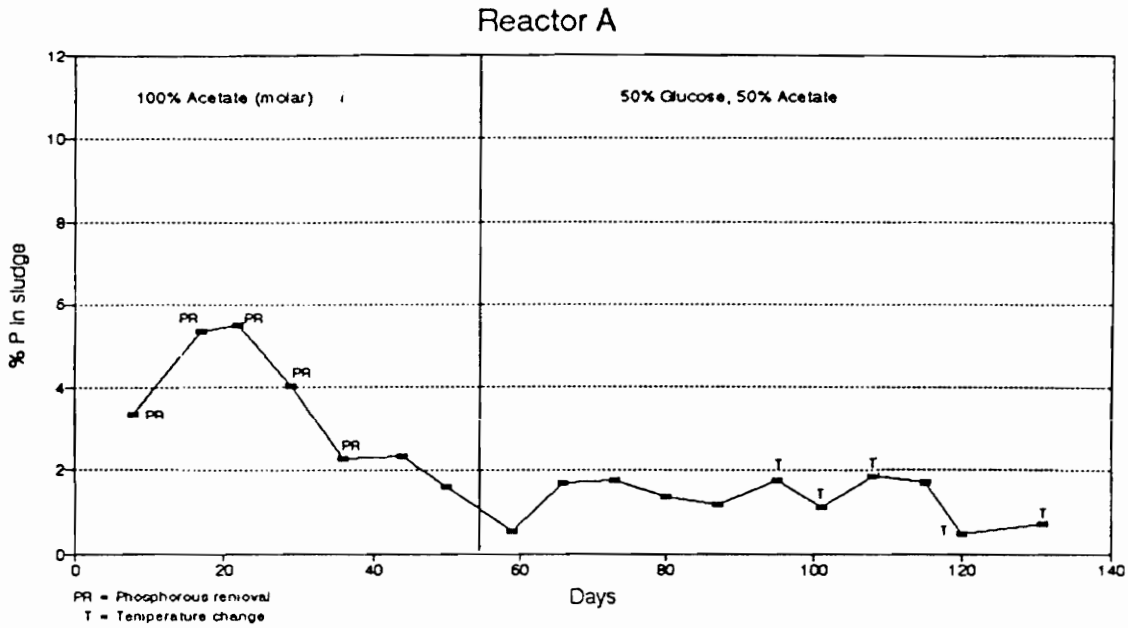
removal, neither PP nor G bacteria consistently dominated, although PP bacteria did outnumber G bacteria 15 out of 22 total days when P-removal was observed. Raw bacterial numbers also did not necessarily indicate reactor performance. High numbers of PP bacteria did not guarentee P-removal, with or without G bacteria domination. Day 62 of reactor F displays the highest population of PPs found in the reactor. No P-removal occurred, despite relatively low numbers of G bacteria. Day 115 of reactor A shows a large population of PP's (>1200 x 10^6), with a near-equal population of G's, yet no P-removal occurred. Moreover, days with relatively low PP numbers (<700 x 10^6) were associated with P-removal, whether G bacteria were significantly higher (Days 1,9, reactor F), significantly lower (Day 16, reactor D), or nearly equal (Day 73, reactor E).

Under microscopic examination, a relationship appears to exist between the size of the PP bacteria and the ability to remove PP. This was particularly apparent during days of P-removal and days without P-removal in reactor E (Fig. 4e). Days 1-15 contained relatively few PP bacteria (with the exception of day 8), yet all days had P-removal. Under the microscope, these PP bacteria were very large (2-3 um in length), as opposed to days without P-removal when the bacteria were typically $\leq 1$ $\mu$m, such as days 22-29. Day 22 had a greater or equivalent population of PP's to days with P-removal (days 43, 57, and 73), yet no P-removal occurred. Under the microscope, these bacteria were very small, appearing only as small, black dots, $\leq 1$ $\mu$m in length. Cech and Hartman (1991) describe G bacteria as 1-2 times larger than PP bacteria. During periods of P-removal, however, the G bacteria appeared much smaller than the PP's. In

addition, they were also smaller than G bacteria found in systems during no P-removal (1-2 $\mu$m as opposed to 2-3 $\mu$m in size). This trend was apparent in all of the reactors.

As the ability to remove P was lost in each reactor, % P in the sludge also decreased (Fig. 5, a-f). From day 1, all reactors removed phosphorous until the % P dropped below 2-3% P. Following this decline, some reactors did eventually exceed 2-3% P, but did not regain the ability to remove phosphorous (see days 29, 44, reactor B; day 78, reactor D). The minimum amount of P in sludges that were removing excess phosphorous was approximately 2%. The only days that do not fall above 2% are days 43 and 62 in reactor B. This, however, appears to reflect an error in the amount of total P measured in the sample. In general, all reactors exhibited a significant decrease in % P as the ability to remove P was lost; those that did regain P-removal never reached a % P higher than 4% -- a very low %P in sludge for biological phosphorous removal systems.

Through time, all of the reactors lost the ability to release phosphorous, with the exception of reactor E. To determine a relationship between the number of PP and G bacteria and the ability/inability to remove phosphorous, Figs. 6 (a-f) were developed, showing the amount of $PO_4$ uptake versus the number of PP:G bacteria. All of the reactors indicate higher P-uptake with higher PP:G ratios, except reactor F. In this reactor, P uptake was higher when PP:G was low. This was the only time such a trend was found. Note that the $R^2$ value was very low and no significance can be attributed to the apparent trend. All three indicated a strong positive correlation between P-uptake and the PP:G ratio.



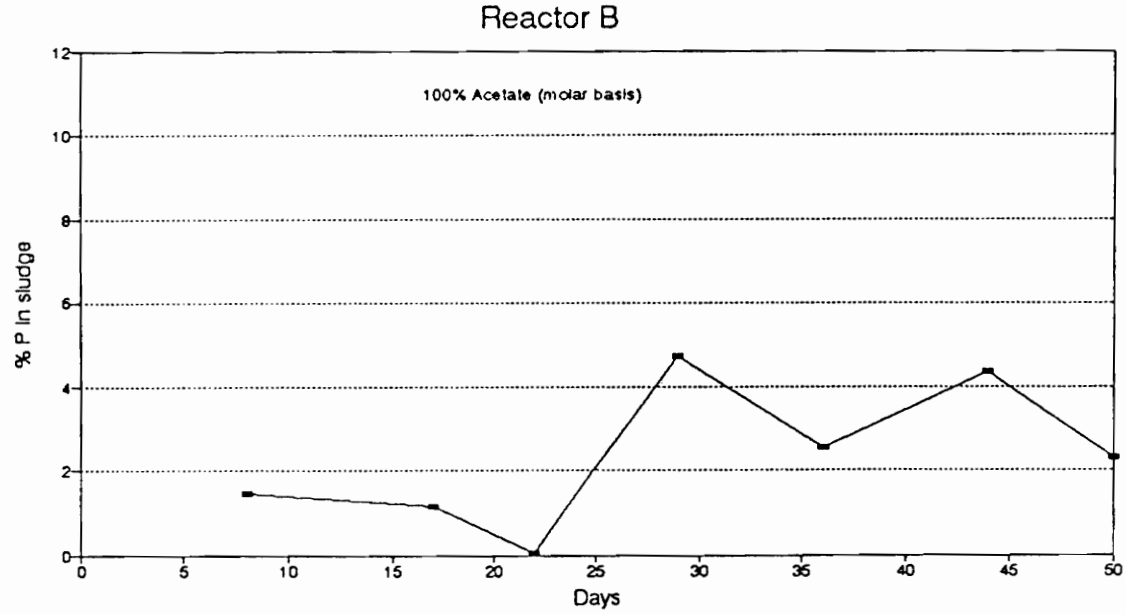
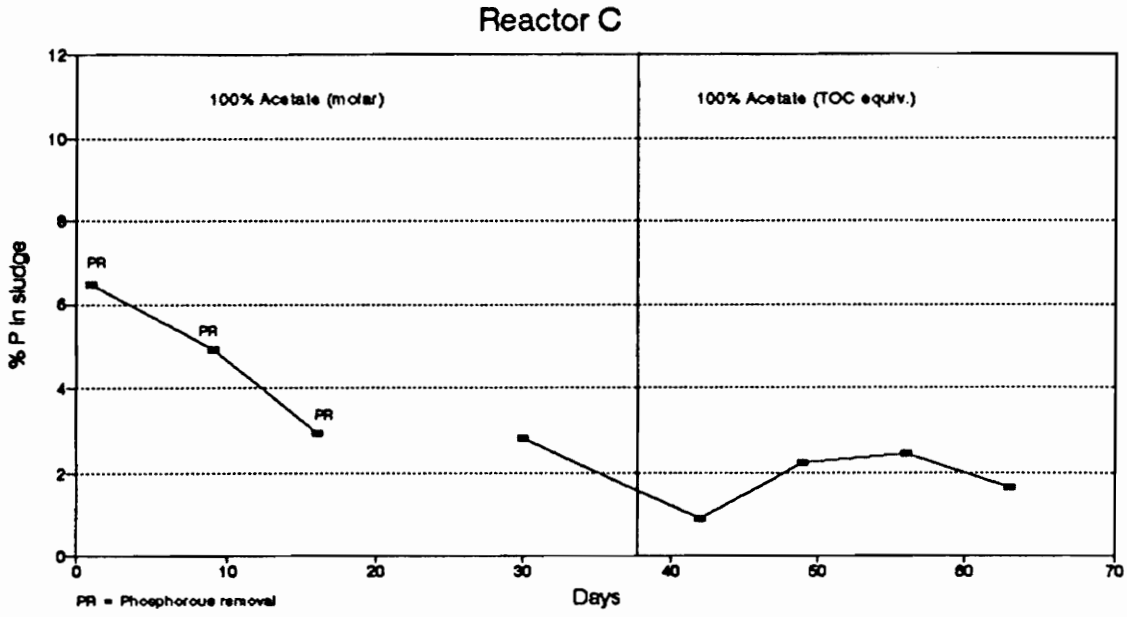
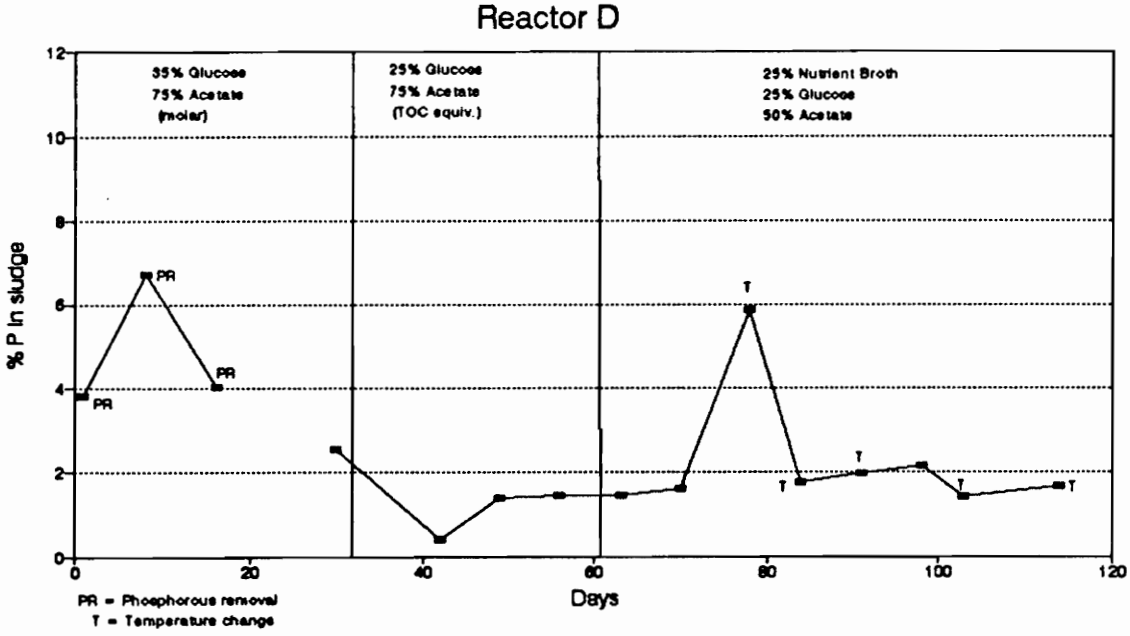
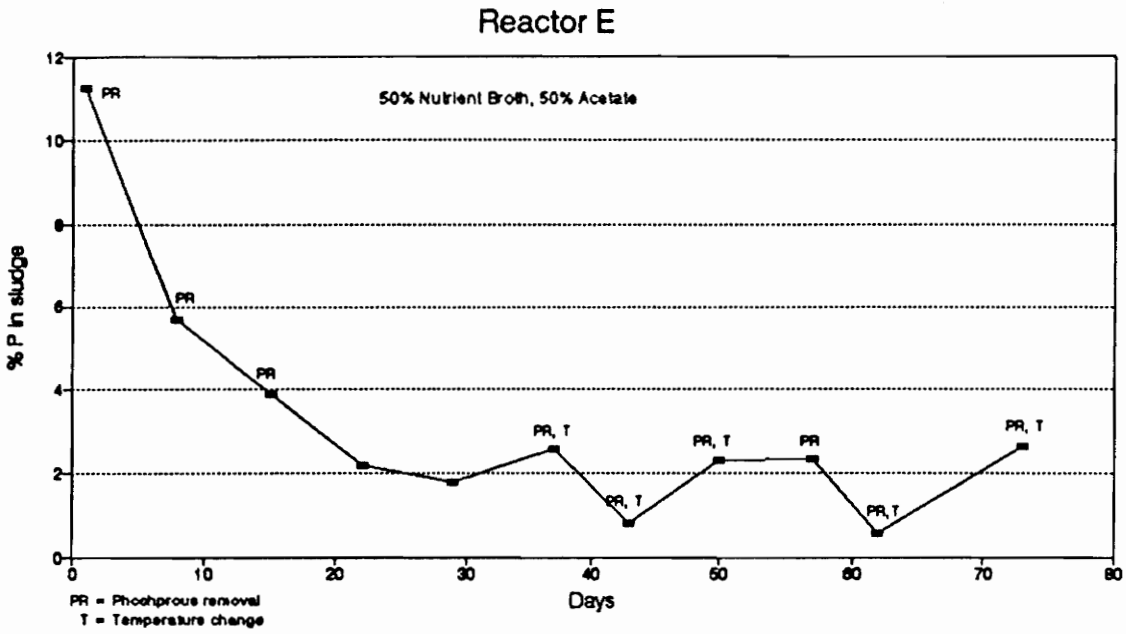
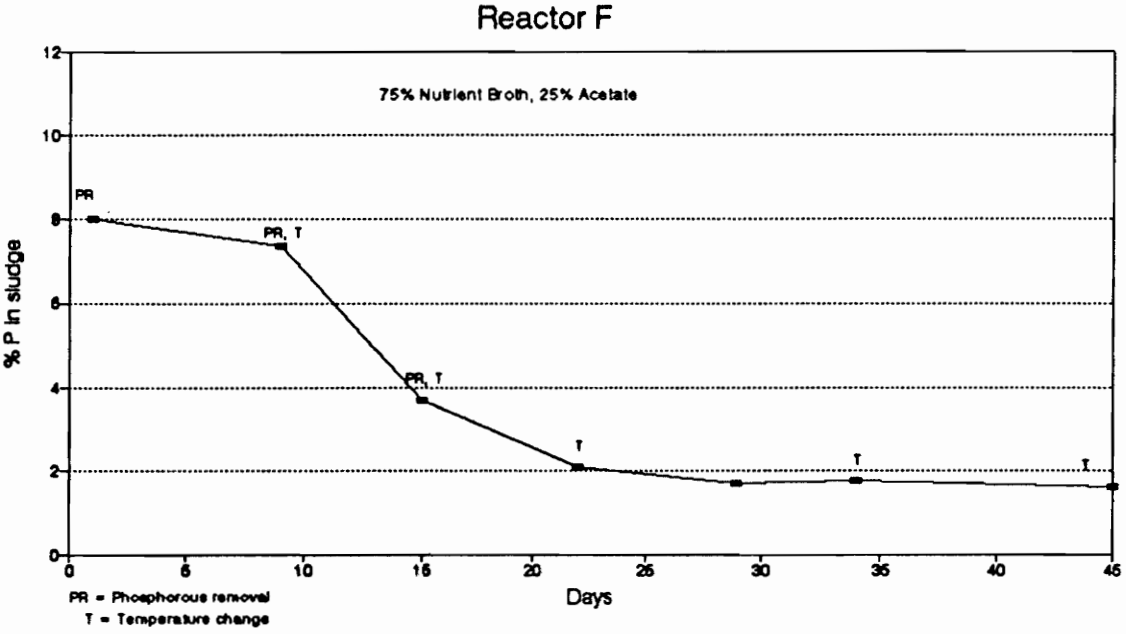



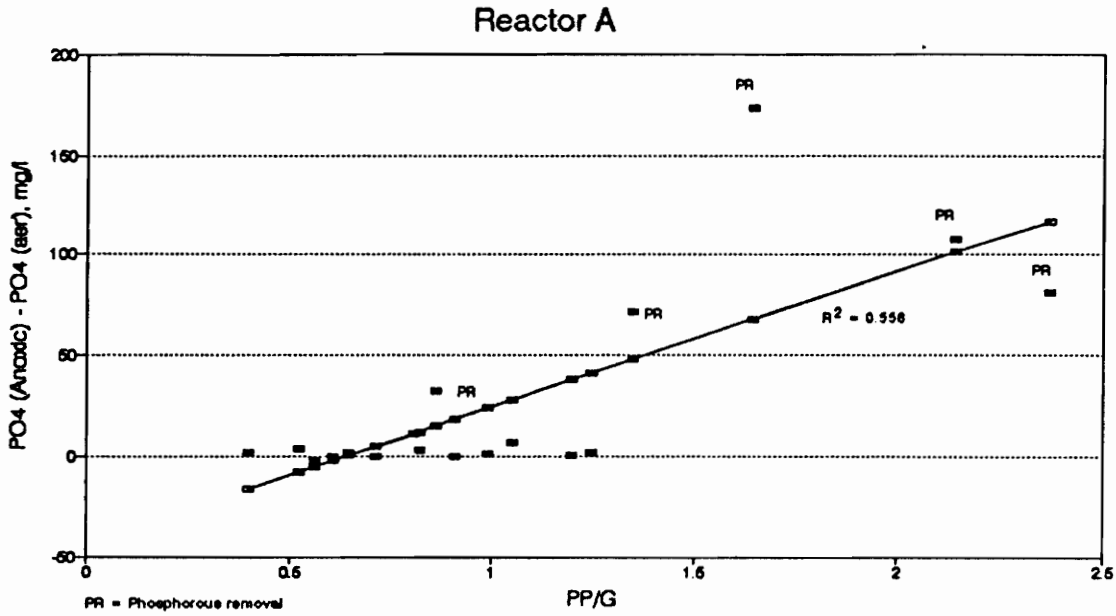

Fig. 5 (a-f). Percent phosphorous measured in the sludge during the aerobic stages of reactors A-F.


Reactor C
100% Acetate (molar)
100% Acetate (TOC equiv.)
% P in sludge
PR
PR
PR
0
2
4
6
8
10
12
0
10
20
30
40
50
60
70
Days
PR = Phosphorous removal


Reactor D
35% Glucose
75% Acetate
(molar)
25% Glucose
75% Acetate
(TOC equiv.)
25% Nutrient Broth
25% Glucose
50% Acetate
% P in sludge
PR
PR
PR
T
T
T
T
T
0
2
4
6
8
10
12
0
20
40
60
80
100
120
Days
PR = Phosphorous removal
T = Temperature change


Reactor E
50% Nutrient Broth, 50% Acetate
% P in sludge
Days
PR = Phosphorous removal
T = Temperature change
PR
PR, T


Reactor F
75% Nutrient Broth, 25% Acetate
% P in sludge
Days
PR = Phosphorous removal
T = Temperature change
PR
PR, T
T



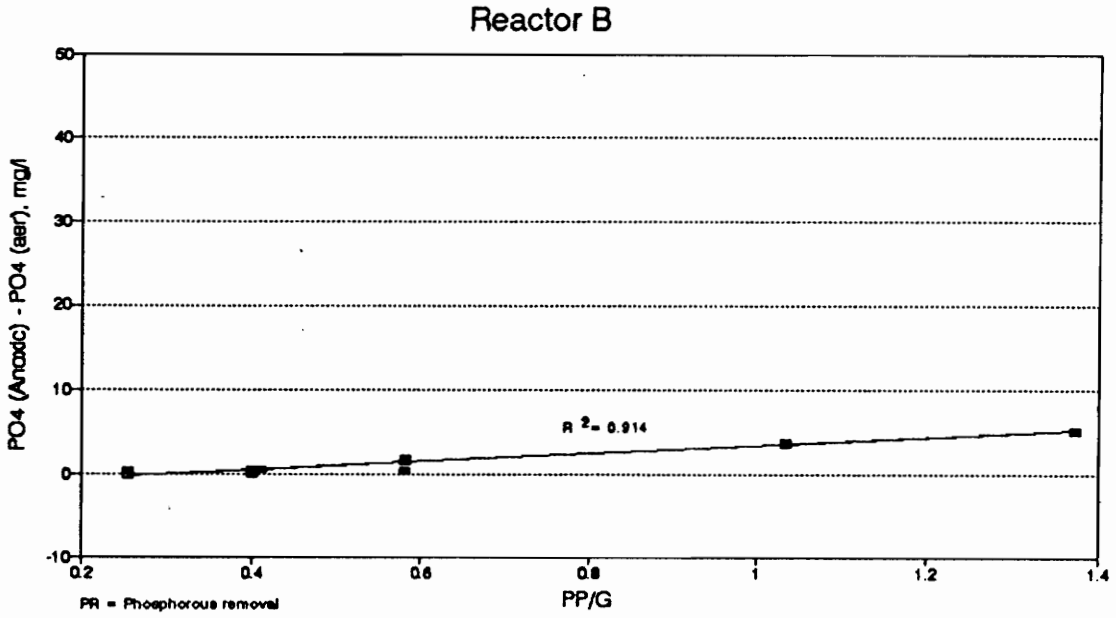
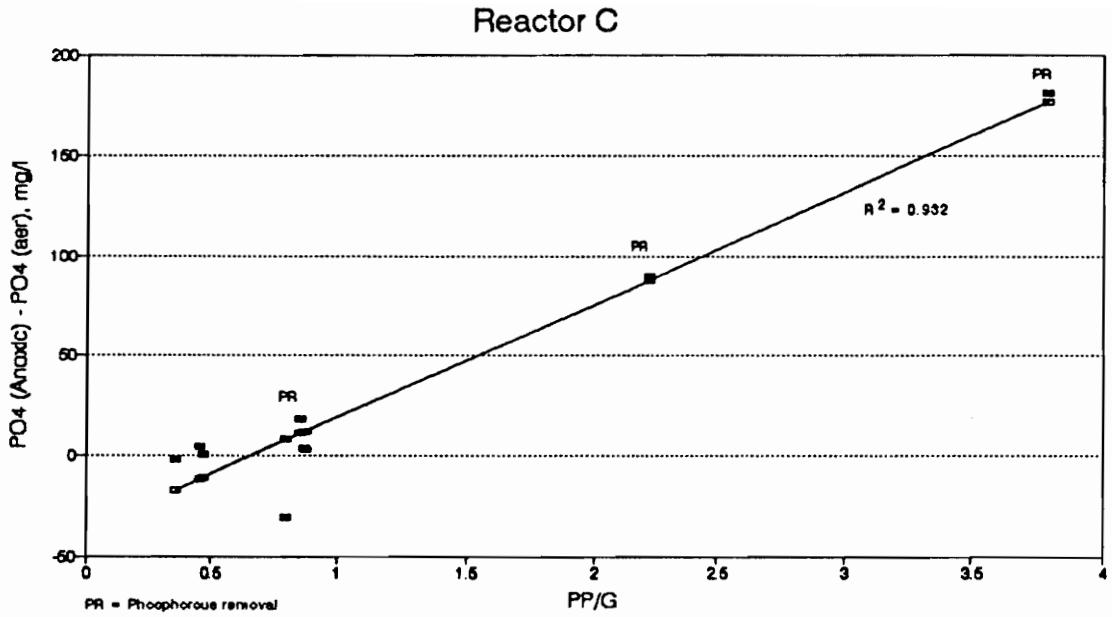
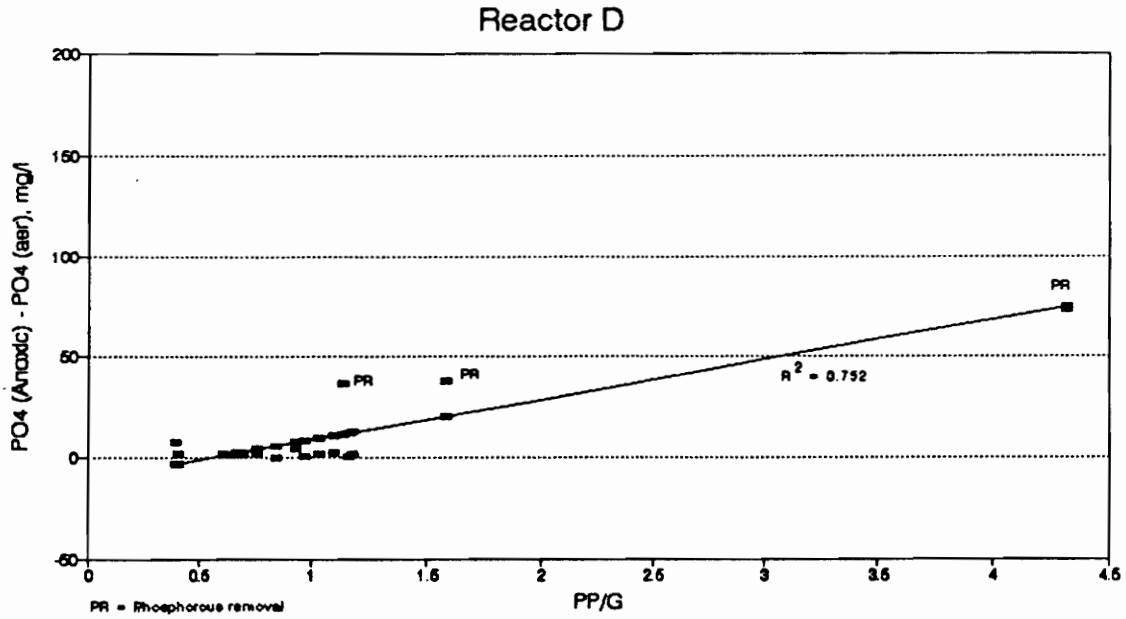
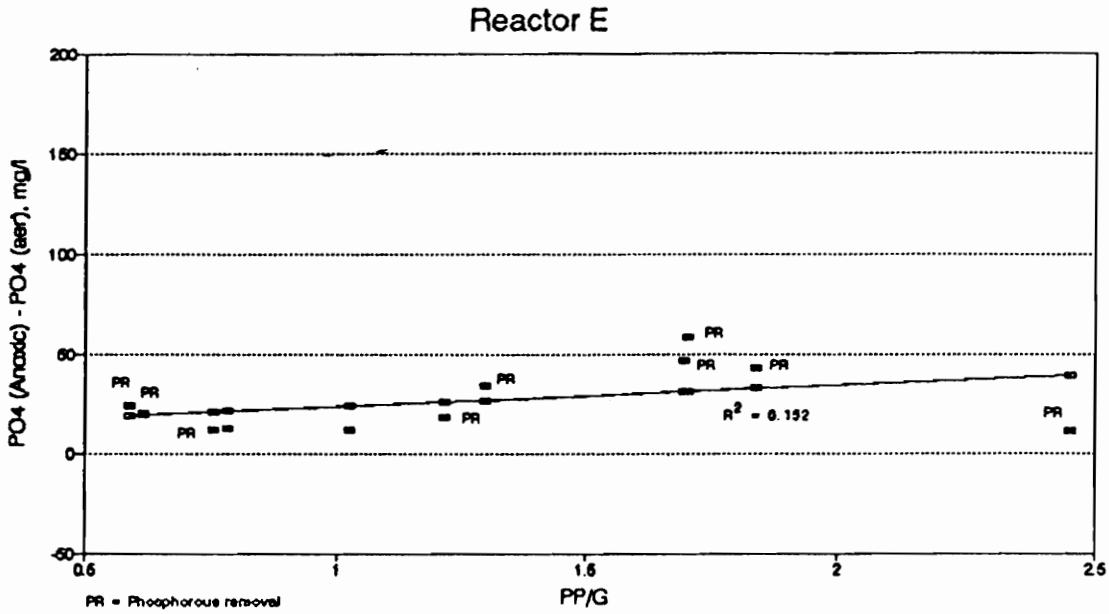
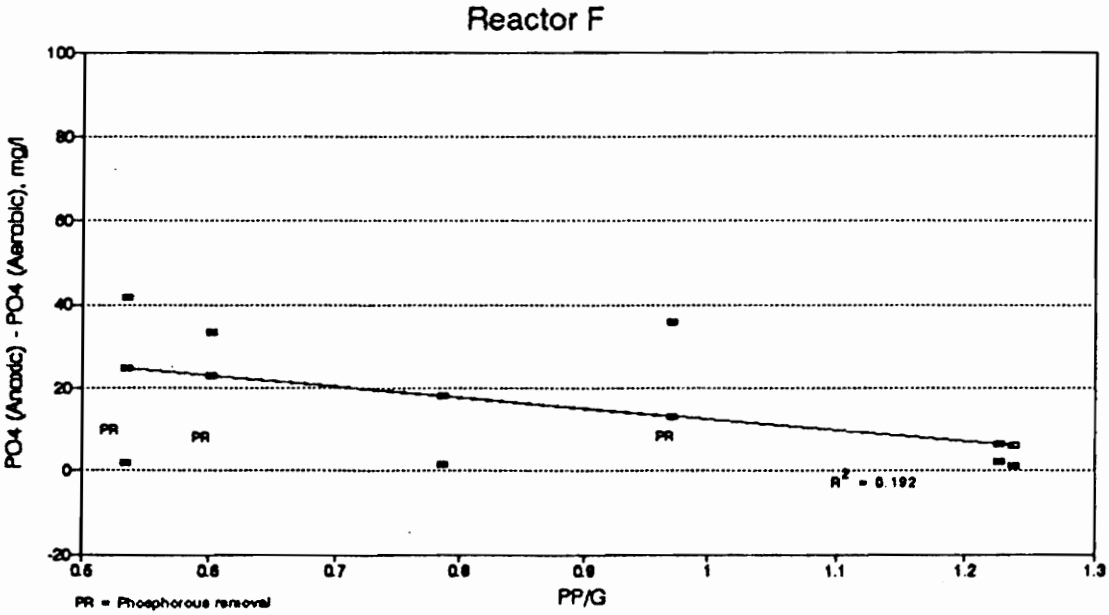




Fig. 6 (a-f). The amount of soluble phosphorous uptake as a function of PP and G population. PP and G numbers obtained from the aerobic stage of each reactor.


Reactor C
PO4 (Anoxic) - PO4 (aer), mg/l
PP/G
PR = Phosphorous removal
R 2 = 0.932
PR


Reactor D
PO4 (Anoxic) - PO4 (aer), mg/l
PP/G
PR = Phosphorous removal
R 2 = 0.752
PR


Reactor E
PO4 (Anoxic) - PO4 (aer), mg/l
200
150
100
50
0
-50
0.5
1
1.5
2
2.5
PP/G
PR
R² = 0.152
PR = Phosphorous removal


Reactor F
PO4 (Anoxic) - PO4 (Aerobic), mg/l
100
80
60
40
20
0
-20
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3
PP/G
PR
R² = 0.192
PR = Phosphorous removal

The above observations were based soley on PP and G numbers found in the aerobic zone. Because P-uptake depends on prior P-release, and because both depend on the number of PP available during the appropriate reactor stages, the number of PP and G bacteria during each stage of operation in the reactor were examined for each sampling day. However, no apparent trends existed between the number of PP or G bacteria during anaerobic, anoxic, or aerobic stages, with or without P-removal, in any of the reactors.

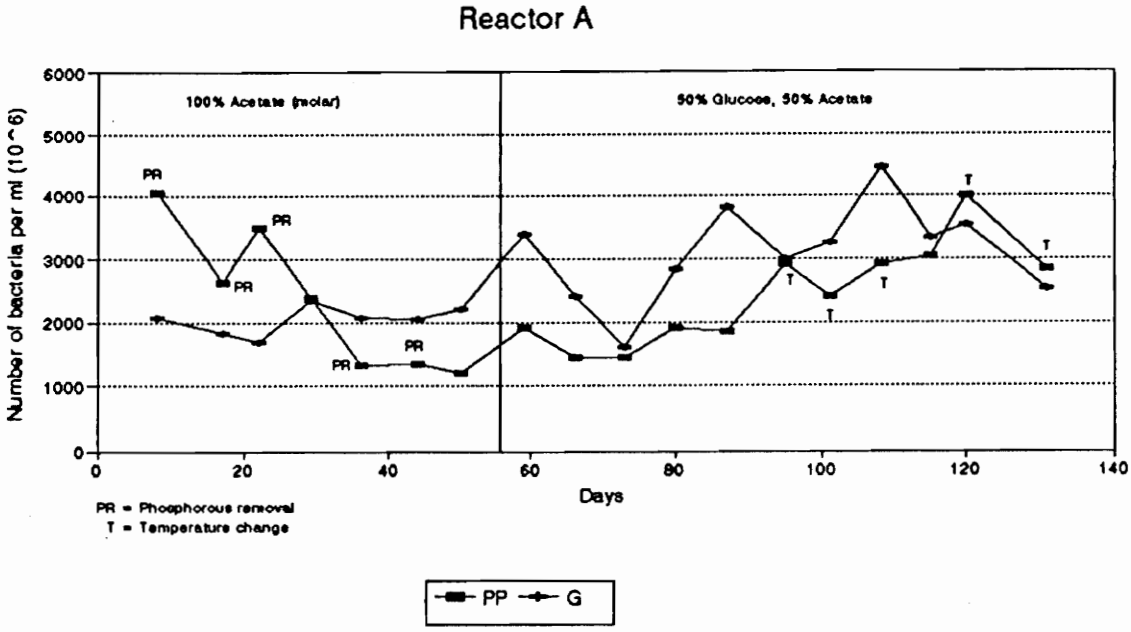
### 4.4 Effects of feed composition on PP and G populations

A total of six reactors were maintained throughout the experiment. Of these, two were fed a 100% acetate solution throughout their operation. The only change in feed occurred when the amount of sodium acetate ($NaC_2H_5O_2$) was changed from a molar equivalent of 200 mmol/l acetic acid (after Cech and Hartman, 1990) to a TOC equivalent amount of acetate equalling 315 mg/l TOC, although the actual amount of $NaC_2H_5O_2$ (in grams) changed little. The remaining four reactors were fed solutions containing different percentages of glucose and/or nutrient broth, totaling 315 mg/l TOC. Table 3, page 21, summarizes these feed changes.

Because the numbers of PP and G bacteria varied widely throughout each stage in the reactors with no apparently consistent peak stage (ie. within the aerobic stage), the total number of PP and G bacteria were determined for each 8-hour sampling day to better estimate overall population size. These numbers, including all five stages, were then plotted versus time, and are shown in Fig. 7 (a-f).

Reactors A, B, and C were fed only acetate during all or half of their operation. All three showed a sharp decline in PP's. Because the number of G bacteria also declined, particularly in reactors B and C, it initially appeared as though toxic concentrations of acetate had caused a decline in bacterial growth. However, after day 50 in reactor C, populations of both PP and G bacteria began to increase. Although a slight feed change did occur 15 days prior to the observed increase, it was considered inconsequential because the feed changes did not significantly change the amount of acetate entering into the reactor, and because of the time lapse between feed change and population shift. Examining all six reactors, it is clear that this decline and subsequent rise in population was consistent for all of the reactors, despite feed composition. It should be noted that in all cases (where applicable), the populations of both PP and G bacteria began to climb on or within 2-3 days of day 50. These result, therefore, suggest population shifts occurred regularly in the reactors, and that feed toxicity did not play a role in these shifts.

A 50% glucose/acetate feed was introduced to reactor A, 58 days into operation. From Fig. 4a, it appears as though the increase in glucose initiated an increase in both G and PP bacteria. Recall that glucose is readily used by G bacteria, but PP bacteria are considered to be incapable of using complex sugars, and must rely on other organisms to convert them to VFAs. In reactor D, both G and PP bacteria increased when the amount of acetate was decreased from 75% to 50% acetate, with glucose at 25%.



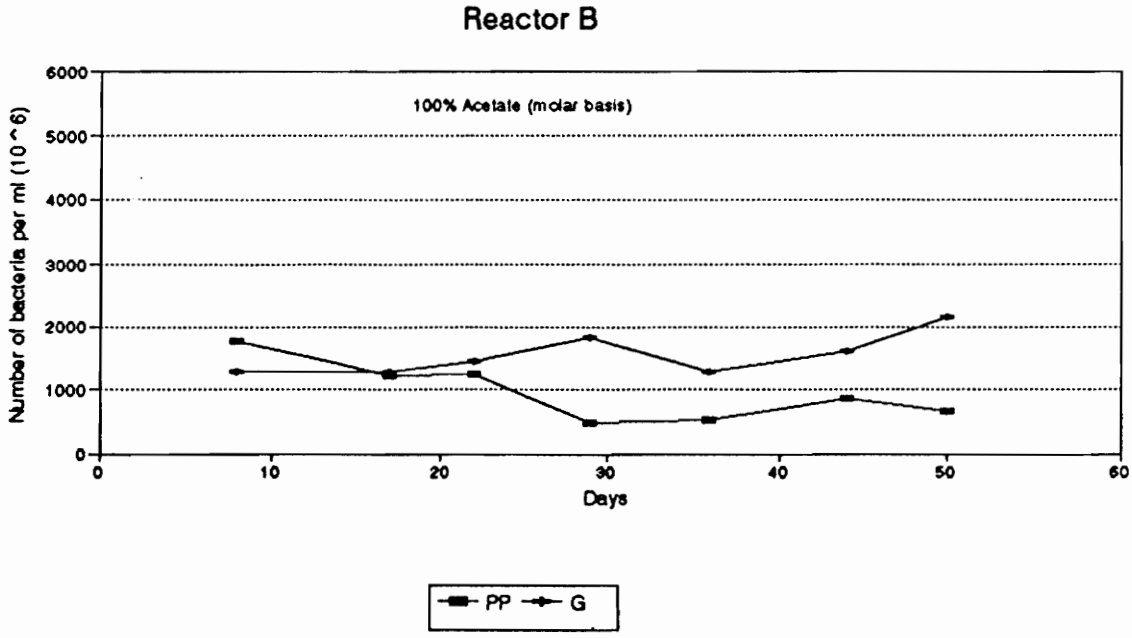
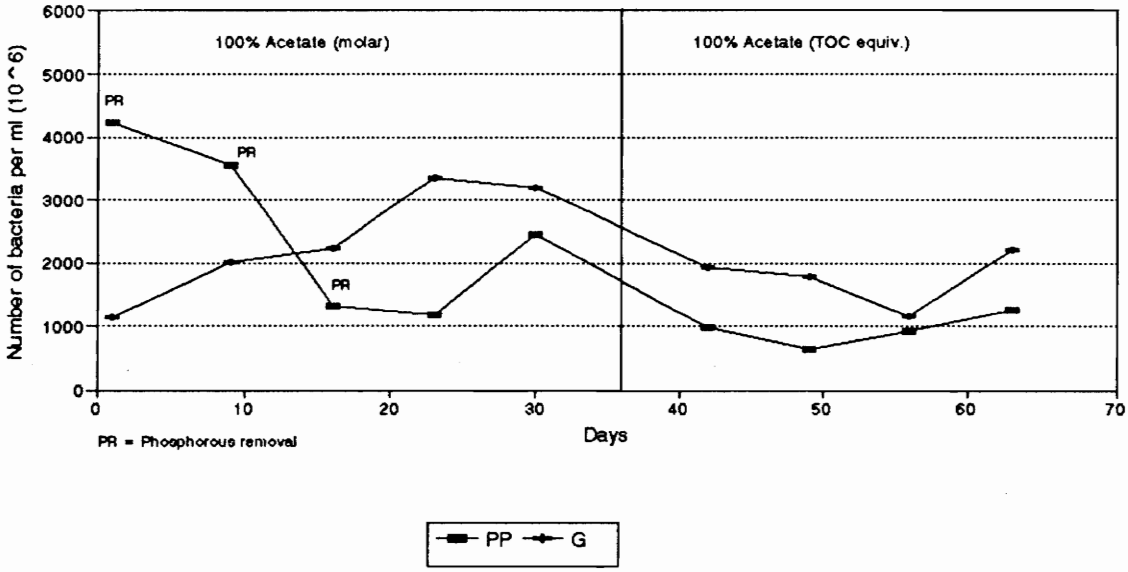
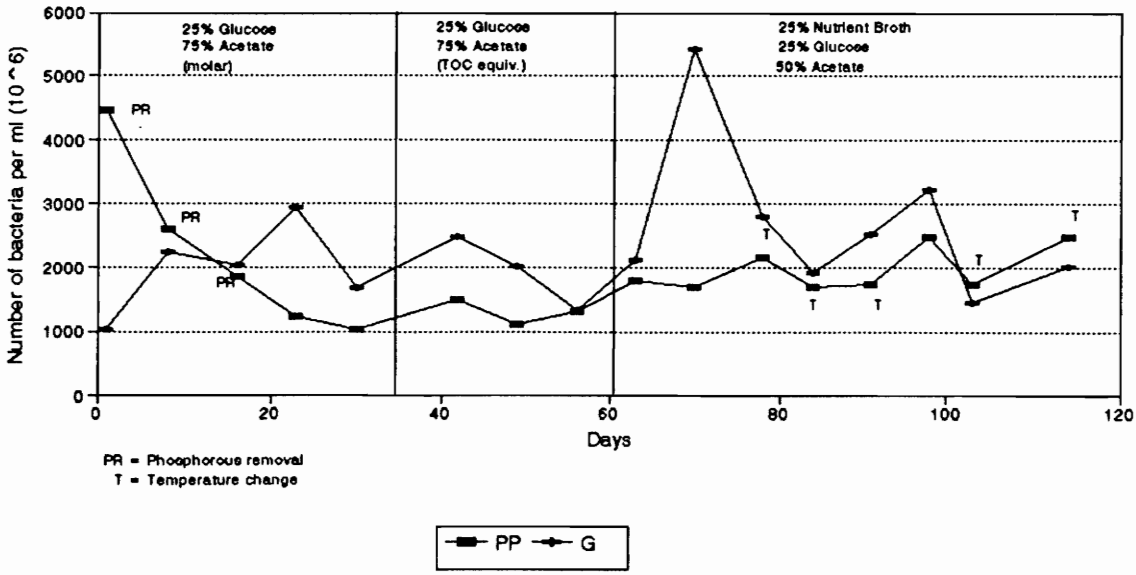




Fig. 7 (a-f). Total number of PP and G bacteria identified through all five stage of operation as a function of time.

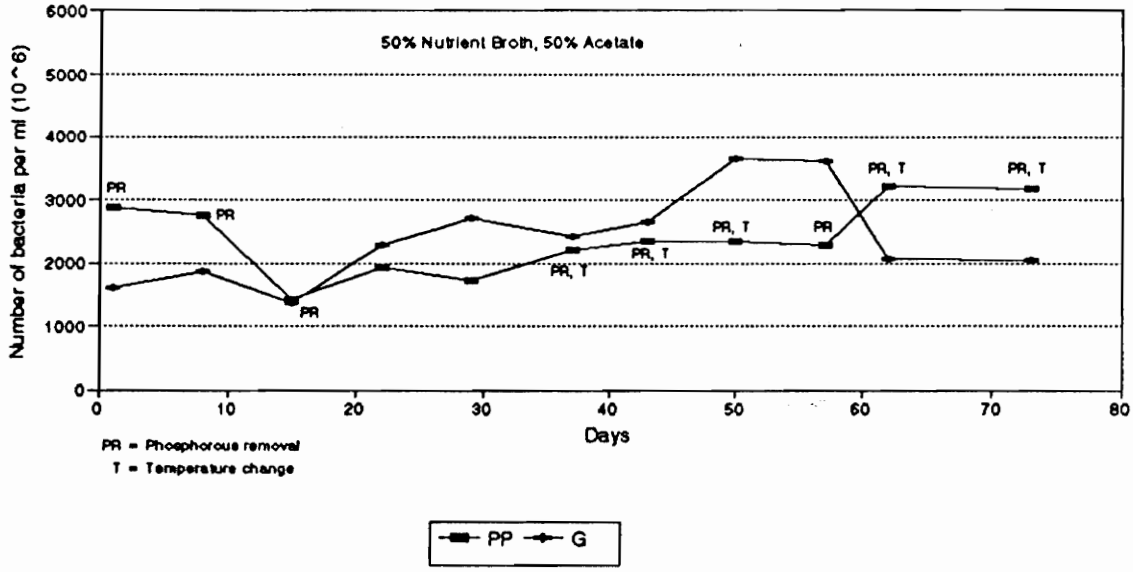
## Reactor C



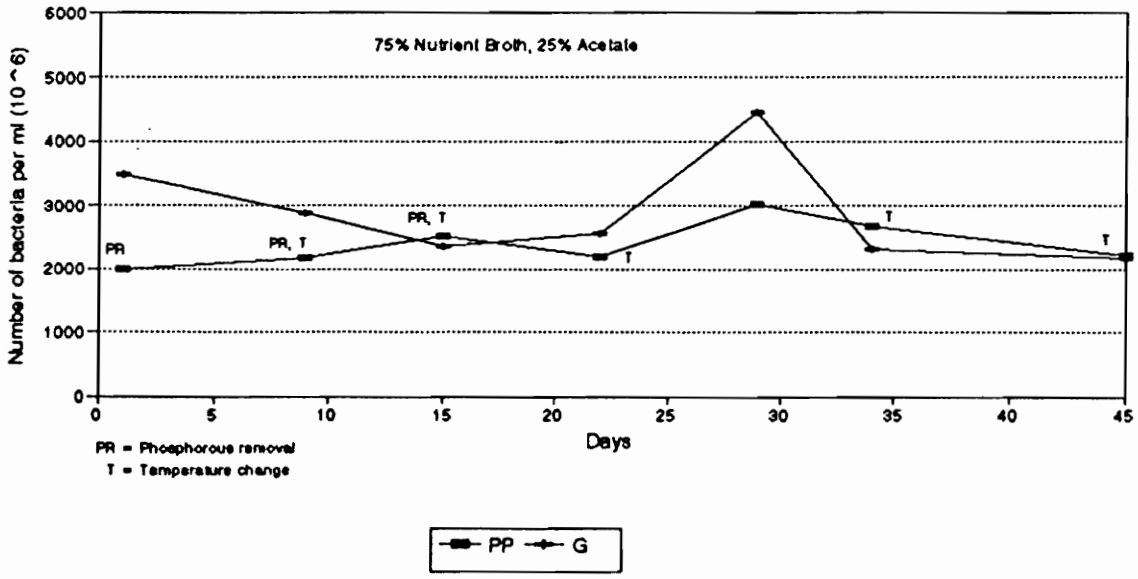

## Reactor D



## Reactor E




## Reactor F



The population increase beyond day 50 was consistent in both reactors, although reactor A had a larger overall bacterial population with higher concentrations of available glucose.

With the introduction of nutrient broth, the same patterns of decline and recovery continued in the reactors. Reactor E was fed 50% nutrient broth:acetate. Without available glucose, G bacteria numbers were lower than reactor A with 50% glucose, yet nearly the same as those in reactor D with 25% glucose. In reactor F, only 25% acetate was available, with 75% nutrient broth. The number of PP and G bacteria fluctuated between 2,000 and 3,000 bacteria/ml*(10^6), which was somewhat higher than in the other reactors containing nutrient broth. It also did not display the characteristic sharp decline in PP bacteria, only in G bacteria. Despite the relatively high numbers of PP bacteria, P-removal was not maintained. It should also be noted that the sludge used to start up reactor F had unusually high initial numbers of G bacteria.

Overall, the addition of nutrient broth did not appear to significantly enhance either PP or G bacteria populations. It was available, however, when only one reactor of six regained the ability to remove phosphorous. According to the label, the nutrient broth contained 3 g Bacto® beef extract and 5 g Bacto® peptone (DIFCO laboratories). The addition of glucose did appear to stimulate G bacterial growth at concentrations greater than 25% glucose, although these increases did eventually follow the same trends in both PP and G populations in all the reactors beyond day 50.

### 4.5 Temperature effects on bacterial populations

Temperature experiments were conducted during the last six days of operation of reactors A, D, E, and F. The first three weeks of the experiment were conducted between 25-27°C, the fourth week at 20°C, and the last two weeks at 30°C. Because pure cultures of G bacteria grew only at temperatures between 20-25°C, it was assumed that higher temperatures would negatively affect populations of G bacteria in the reactors.

In reactor A, PP numbers increased nearly to those of G bacteria for the first time since initial operation (Fig. 7a). The bacteria were also larger, containing sufficient phosphorous in the cells to stain distinctively as PP bacteria. However, the number of G bacteria did not significantly decrease as expected, although they did appear to be in decline at 30°C. In reactor D, the number of PP declined at 20-25°C, yet increased at 30°C, while the G bacteria rose and fell throughout the temperature changes (Fig. 7d). Again, PP bacteria were much larger and stained well during periods of higher temperature in reactor D. The same trends were found in reactors E and F, although in reactor F, the increase in PP at 30°C was not as prominent as in the other reactors.

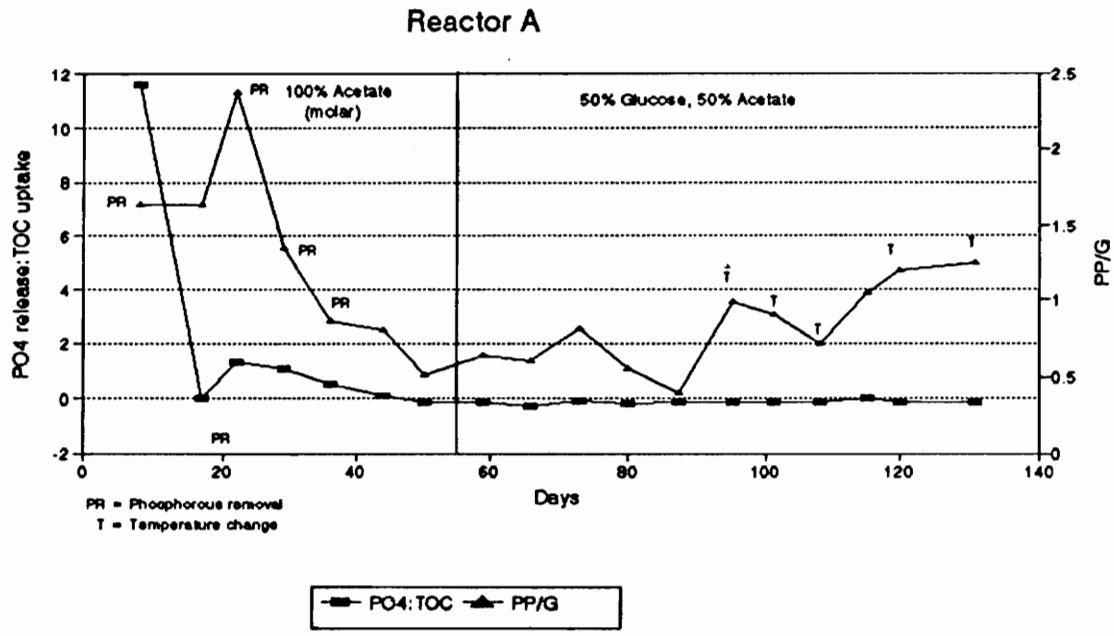
Overall, all reactors displayed some kind of PP increase at higher temperatures, particularly at 30°C. The number of G bacteria fluctuated between 25-27°C, yet began to decline at 30°C in all reactors. In addition, all reactors but reactor A showed a sharp increase in G bacteria during the fourth week when temperatures were restored to 20°C. Most notably, in all cases, PP bacteria were larger and stained well when temperatures increased.

### 4.6 Effects of PP and G populations on TOC removal

In their 1992 study, Cech and Hartman determined that a relationship existed between the molar ratio of phosphorous released to acetate uptake, and the number of G bacteria in an SBR. Their studies indicated that as the number of G bacteria increased, the ratio of $PO_4$ released:acetate uptake decreased. To further study this relationship, Figs. 8 (a-f) were developed, showing $PO_4$ release:TOC uptake and the ratio of PP to G bacteria through time. P release was measured as the difference between the initial and anoxic $PO_4$ (mg/l), and TOC uptake as the difference between influent and anoxic TOC (mg/l). Acetate was not directly measured during this study.

In all of the reactors fed 100% acetate (B, C, and part of A), a relationship did appear to exist between $PO_4$ release:TOC uptake, and the number of PP and G bacteria. As predicted by Cech and Hartman, low $PO_4$:TOC ratios were associated with high numbers of G bacteria, and vice versa. Reactors fed nutrient broth showed similar trends, with the exception of reactor E (Figs. 8e and f). Reactor E began to display the opposite trend following temperature changes in the reactor.

With the introduction of a 25% glucose:75% acetate feed solution, $PO_4$:TOC ratios also rose and fell with PP:G ratios as predicted. Once the amount of glucose reach 50%, or the amount of acetate dropped to 25%, however, these relationships ceased. In both cases, $PO_4$:TOC stayed nearly the same while the PP:G ratios ranged between 0.5-1.5. It should be noted that $PO_4$:TOC in reactor A remained at approximately zero, while $PO_4$:TOC in reactor D was approximately - 0.1, suggesting greater TOC utilization in reactor D.



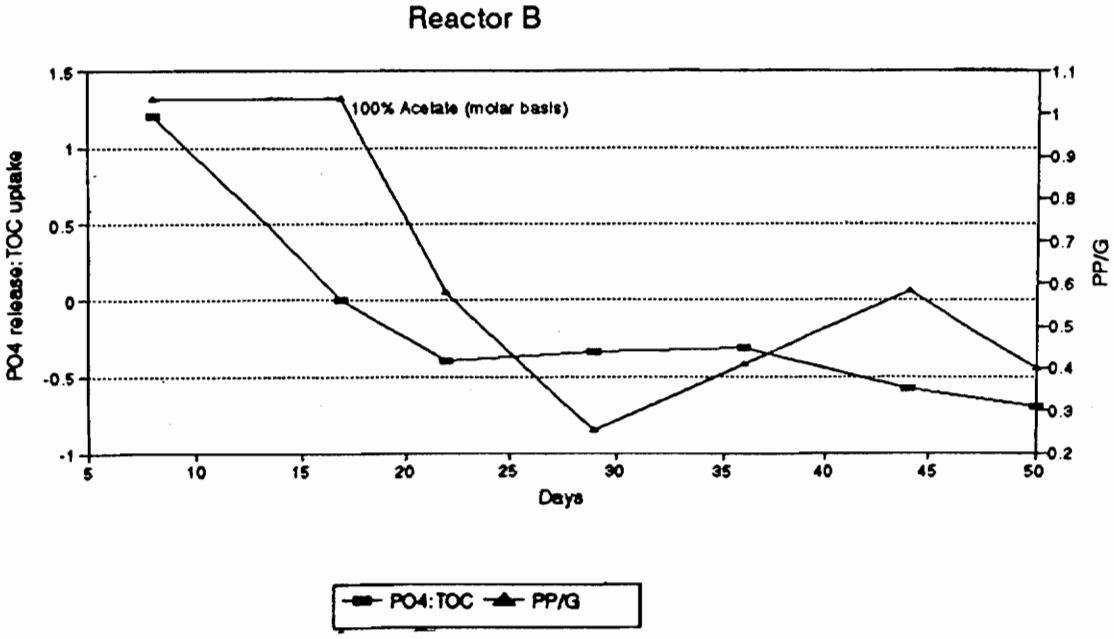
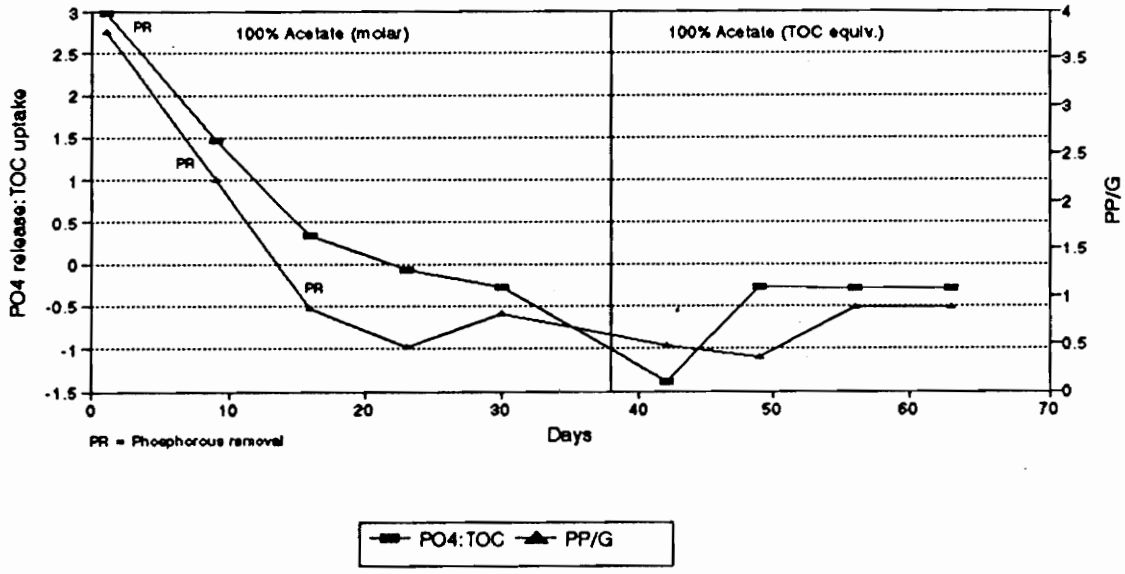
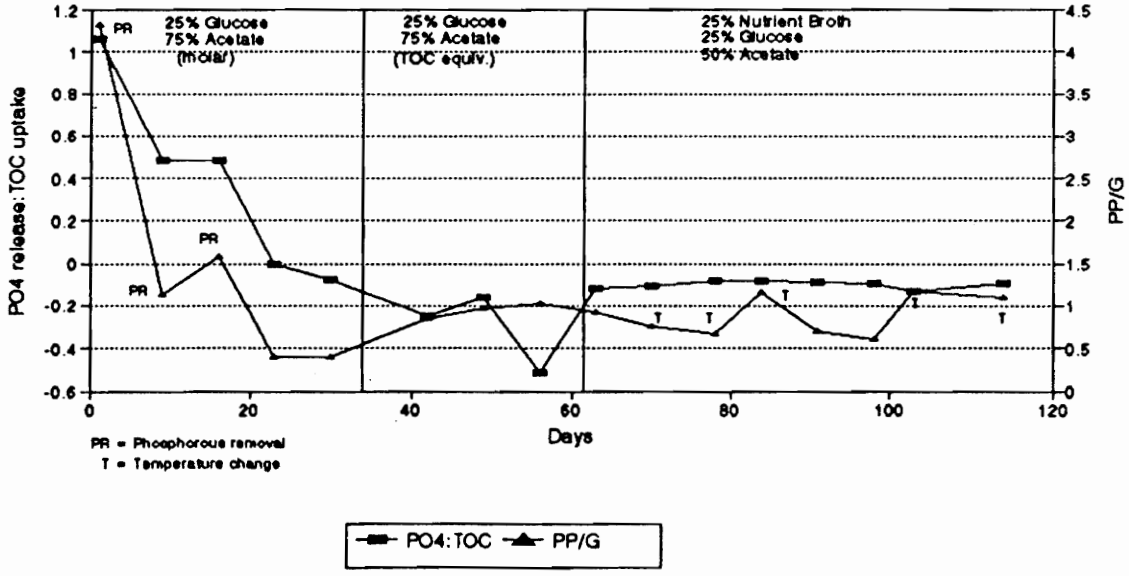




Fig. 8 (a-f). Amount of $PO_4$ release:TOC uptake as a function of PP and G bacteria. PP and G bacteria from aerobic stage only.

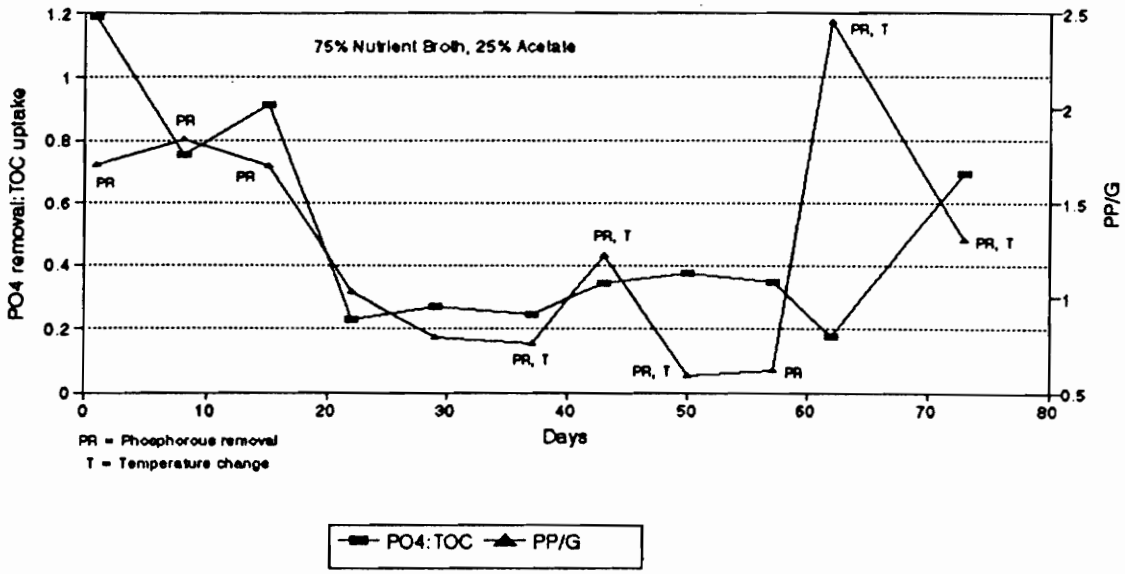
## Reactor C



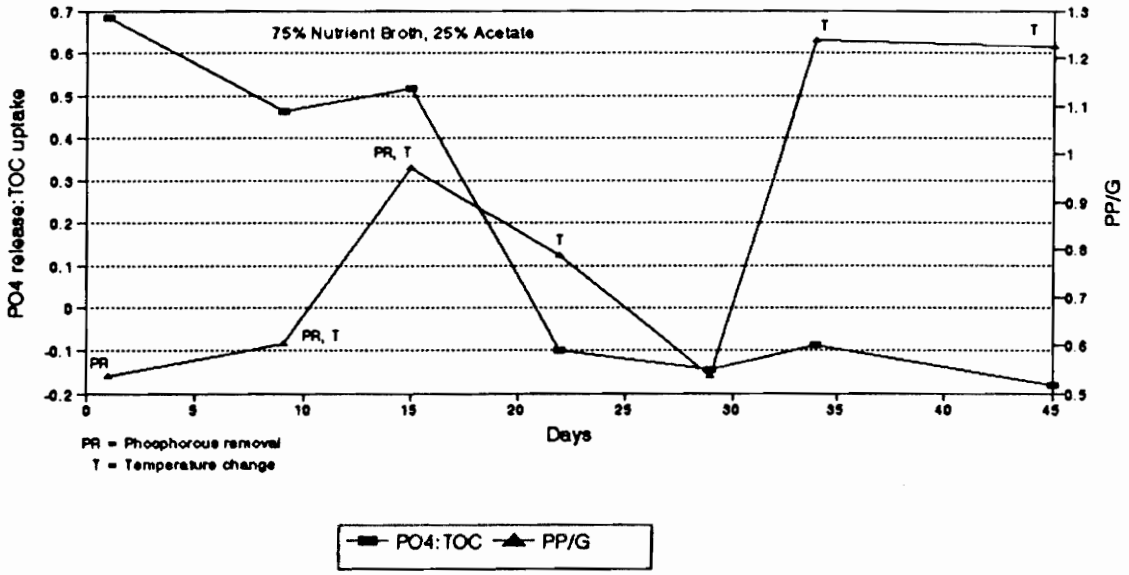

## Reactor D



## Reactor E



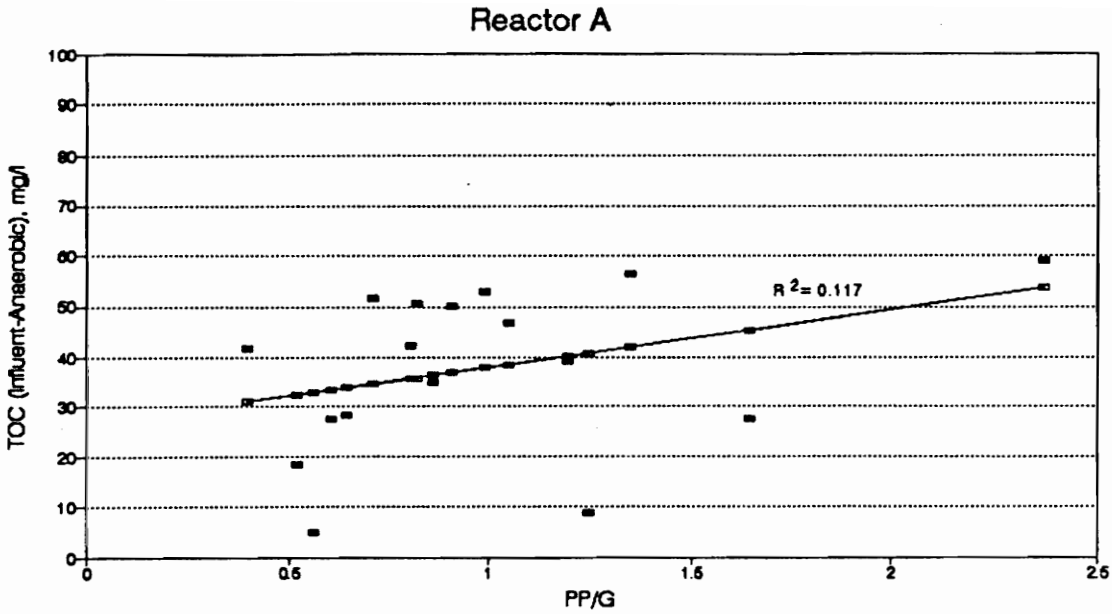

## Reactor F



During data collection, it appeared as though the amount of TOC uptake during the first two hours of operation began to decrease through time in the reactors. To establish a relationship between the number of PP and G bacteria and TOC utilization, Figs. 9 (a-f) were developed. Reactors A, C, D, and E did indicate some correlation between the amount of TOC utilized and the number of PP bacteria. An increase in TOC uptake occurred, to some extent, with an increase in PPs. However, because $R^2$ values were so low (0.68-0.047), the significance of this relationship is questionable. It should also be noted that reactors B and F indicated the opposite trend, although it is believed that this may have been a function of the small number of data points available for each reactor.

### 4.7 Effects of PP and G bacteria on effluent characteristics

Under the microscope, it appeared as though changes in the number and character of the bacteria had changed with time, particularly with respect to an increase in the number of G bacteria in the effluent. To determine whether the settleability of the sludge was affected by the amount of G bacteria in the reactor, TSS was plotted as a function of PP:G bacteria. These results are summarized in Appendix C. No relationship between the number of PP or G bacteria and sludge settleability was indicated by the data.



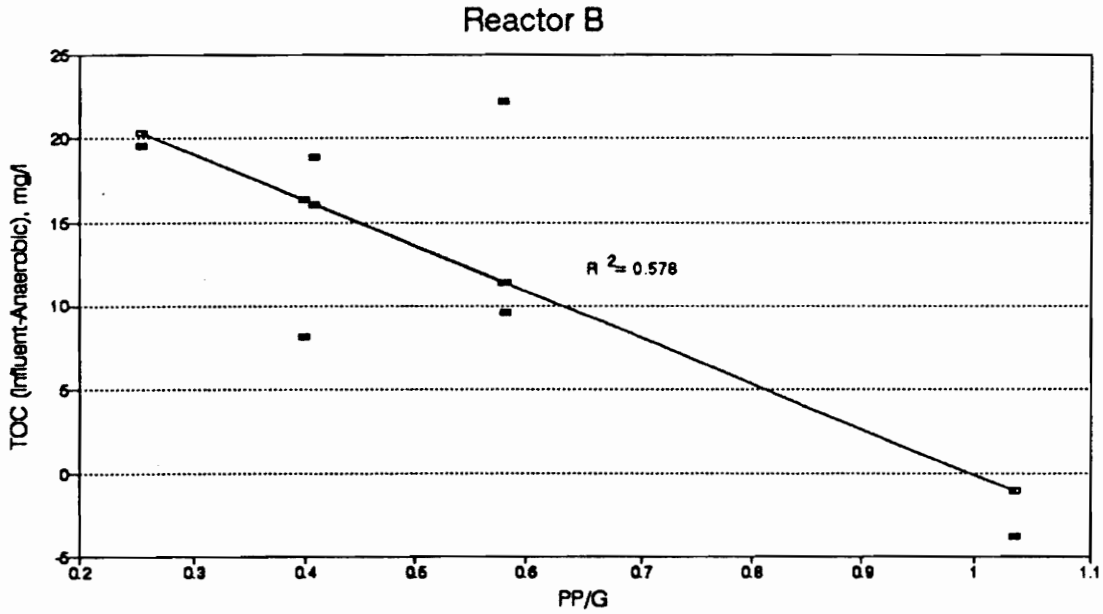
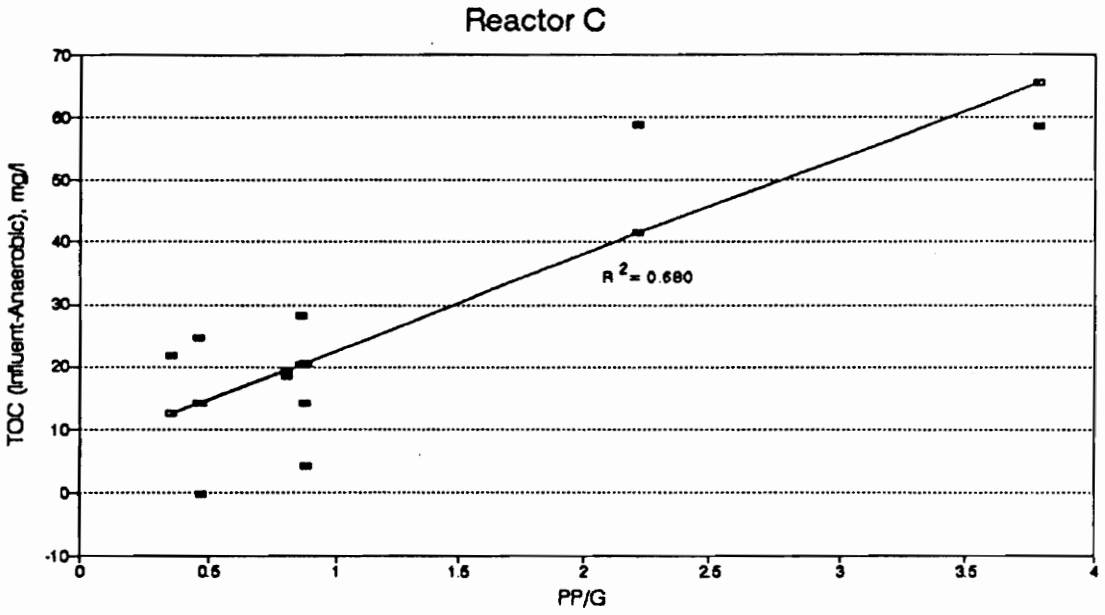
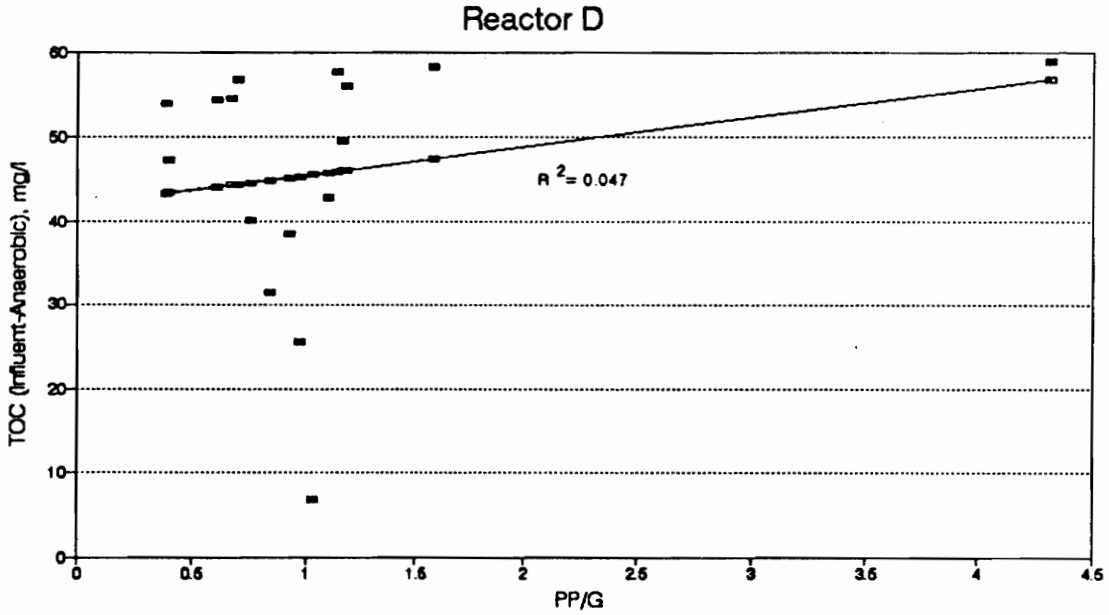
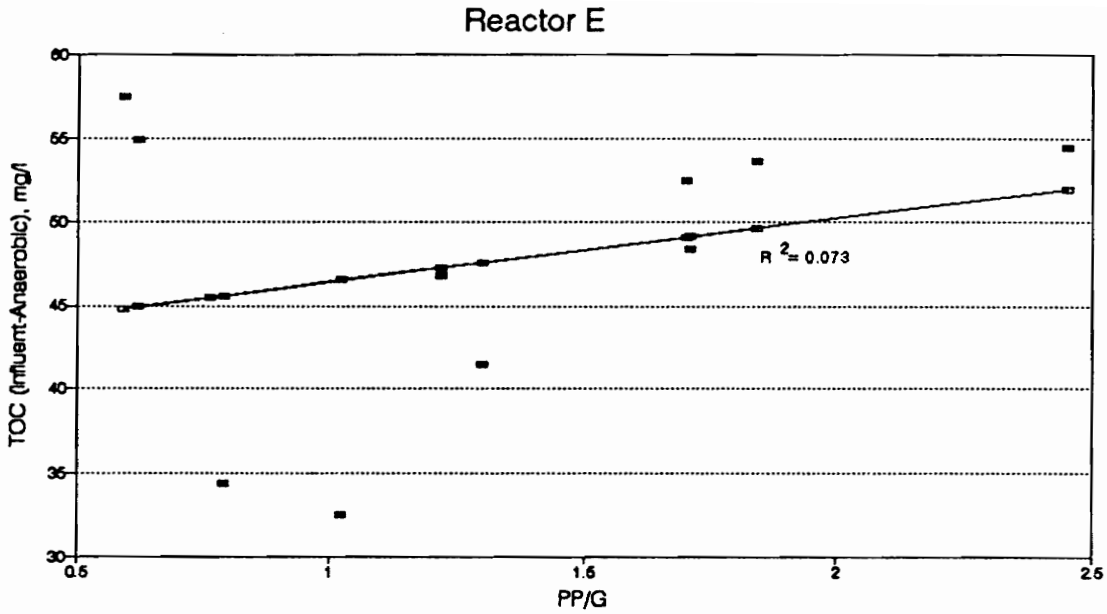
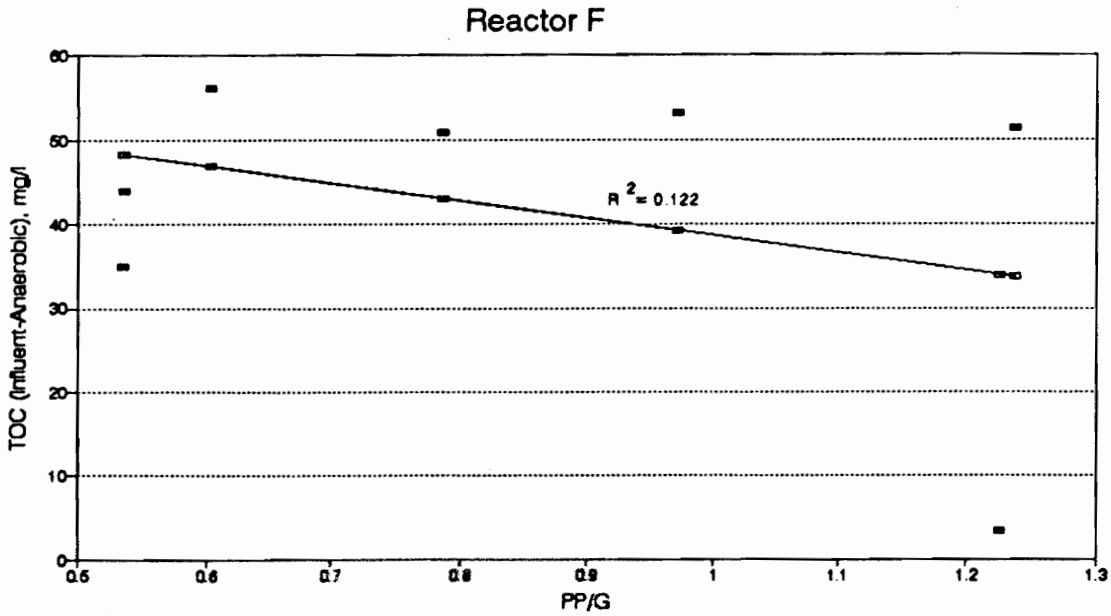




Fig. 9 (a-f). Amount of TOC uptake versus the number of PP and G bacteria identified in the aerobic stage of each reactor.


Reactor C
TOC (Influent-Anaerobic), mg/l
PP/G
R 2= 0.680
70
60
50
40
30
20
10
0
-10
0
0.5
1
1.5
2
2.5
3
3.5
4


Reactor D
TOC (Influent-Anaerobic), mg/l
PP/G
R 2= 0.047
60
50
40
30
20
10
0
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5


Reactor E
TOC (Influent-Anaerobic), mg/l
PP/G
R 2= 0.073
60
55
50
45
40
35
30
0.5
1
1.5
2
2.5


Reactor F
TOC (Influent-Anaerobic), mg/l
PP/G
R 2= 0.122
60
50
40
30
20
10
0
0.5
0.6
0.7
0.8
0.9
1
1.1
1.2
1.3

### 4.8 Pure culture analyses and results

Three biochemical identification systems were used in an effort to identify the genus and/or species of the G bacteria. Because strains may vary slightly, some of the parameters yielded different results in some instances. These variations were taken into account during the identification process.

Results from the API system yielded two identification numbers for the G bacteria, 2-214-156 and 3-214-156. Two numbers were obtained due to a positive ONPG reaction using the API system, and a negative ONPG by Cech and Hartman. Only one number coded to a bacterial identification, with rather poor correlation (ID code number 2-214-004). This number identified the following *Pseudomonas* groups: *Ps. aeruginosa, Ps. putida*, and *Ps. fluorescens*. Using identification tables from Flow Laboratories, the following matches were made, again, with relatively poor correlation: *Pasteurella multocida* (11 of 14 matches), *Pasteurella canis* (11 of 14 matches), *Ps. paucimobilis* (9 of 14 matches), and *Ps. vesicularis* (8 of 14 matches).

The Biolog system utilized a computer data base to identify the bacteria. The program stated that no acceptable correlation could be found using both the medical and the environmental data bases. It did, however, identify the four best matches: *Brucella abortus* (SIM = 0.591), *Hydrophaga flava* (SIM = 0.113), *Moracella atlantae* (SIM = 0.042), and *Vibrio fisheri* (SIM = 0.018). Table 5 summarizes all test results obtained from each system for the G bacteria.

API System:

| Parameter | Test Results | Cech, Hartman |
|---|---|---|
| N2 gas prod. | – | |
| Reduce NO3>NO2 | – | + |
| H2S | – | – |
| Glucose: | + | |
| Gas from glucose | – | +/– |
| Acid from Glucose | + | +/– |
| Mannitol | +/– | |
| Urea | + | + |
| DNase | – | |
| ONPG (beta-galactosidase) | – | + |
| Glucose: | | |
| Oxidation | + | |
| Fermentation | – | |
| Motility | – | – |
| Arginine dihydrolase | + | |
| Citrate | + | +/– |
| Tryptophane deaminase | – | |
| Indole | – | |
| VP | – | – |
| Gelatin | – | – |
| Inositol | – | |
| Sorbitol | – | |
| Rhamnose | +/–, – | |
| Sucrose | – | |
| Melibiose | + | |
| Amygdalin | – | |
| L+ Arabinose | + | |
| Lysine decarboxylase | – | |
| Ornithine decarboxylase | – | |
| Catalase: | + | + |
| Mannitol | + | |
| Inositol | + | |
| Sorbitol | + | |

Flow Laboratories Non-Fermenter System:

| Parameter | Test Results | Cech, Hartman |
|---|---|---|
| Xylose | + | |
| Lactose | – | |
| Maltose | – | |
| Acetamide | – | |
| Esculin | – | – |
| Pyocyanin | – | |
| 42C Growth Tolerance | – | |

Other Parameters:

| Parameter | Test Results | Cech, Hartman |
|---|---|---|
| Cell diameter, um | 1–2 | |
| Cell length, um | 2–3 | |
| Pigment Formation | | |
| Gram Stain | +/– | – |
| Gram stain after KOH treatment | | + |
| Growth on: | | |
| Sheep's blood agar | | – |
| MacConkey agar | | – |
| Formate | | + |
| Acetate | | + |
| Oxidase | + | + |
| Starch | | – |
| Casein | | – |
| Tween 80 | | – |
| DNA (Deoxyribonuclease) | | – |
| Amino acid decarboxylases: | | – |
| L-Arginin | | – |
| L-Lysin | | – |

API System:

| Parameter | Test Results | Cech, Hartman |
|---|---|---|
| N2 gas prod. | +/– | |
| Reduce NO3>NO2 | – | + |
| H2S | – | – |
| Glucose: | + | + |
| Gas from glucose | – | +/– |
| Acid from Glucose | + | +/– |
| Mannitol | +, – | |
| Urea | + | + |
| DNase | +/– | |
| ONPG (beta-galactosidase) | – | + |
| Glucose: | | |
| Oxidation | + | |
| Fermentation | – | |
| Motility | – | – |
| Arginine dihydrolase | + | |
| Citrate | + | +/– |
| Tryptophane deaminase | – | |
| Indole | – | |
| VP | – | – |
| Gelatin | – | – |
| Inositol | – | |
| Sorbitol | – | |
| Rhamnose | – | |
| Sucrose | – | |
| Melibiose | + | |
| Amygdalin | – | |
| L+ Arabinose | + | |
| Lysine decarboxylase | – | |
| Ornithine decarboxylase | – | |
| Catalase: | | |
| Mannitol | | |
| Inositol | | |
| Sorbitol | | |

Flow Laboratories Non-Fermenter System:

| Parameter | Test Results | Cech, Hartman |
|---|---|---|
| Xylose | + | |
| Lactose | – | |
| Maltose | – | |
| Acetamide | – | |
| Esculin | – | |
| Pyocyanin | | |
| 42C Growth Tolerance | | |

Table 5. Summary of biochemical characteristics identified for pure cultures of G bacteria and G bacteria cultures isolated from reactor B.

Other selected experiments were also run during the study. G bacteria were grown on three agars to determine if particular nutrient requirements existed. Results showed that in the presence of glucose, G bacteria were capable of growing with or without peptone, potassium, or magnesium. The bacteria were then grown at selected temperatures to determine relative effects on growth. The bacteria grew very slowly (3-4 weeks) at 20°C, while at 25°C, evidence of growth was seen in 2-3 days in partially sealed tubes on glucose agar; on yeast extract agar, the bacteria grew slowly despite any temperature changes. If the test tubes were not partially sealed with tape, growth occurred in 2-3 weeks despite temperature or agar type. No growth occurred at 30°C.

To determine whether the G bacteria were capable of anaerobic growth, the bacteria were grown in fully sealed test tubes purged with nitrogen gas. The experiment was conducted twice, using both a glucose and a formate broth. No growth occurred during either experiment. Finally, toxicity experiments that were conducted indicated that PP bacteria were not inhibited by the G bacteria. In fact, it appeared as though the G bacteria were too slow-growing to effectively compete at all with the PP's in a yeast extract agar.

In summary, it should be noted that growth rate was significantly influenced by the type of organic substrate available to the bacteria in the agar media. Although growth rates were not specifically determined, it was found that the bacteria grew rapidly on glucose agar (always within one day to one week), while on other agars it would take at least 2-3 weeks to detect any growth, despite favorable temperatures or partial sealing.

# Chapter 5: Discussion

## 5.1 Overview

This section will analyze the results presented in the previous section. Conclusions were drawn, where possible, to establish a relationship between PP bacteria, G bacteria, and their impact on population dynamics within an SBR designed for enhanced P-removal. Topics are presented in the same format as in the Results chapter.

## 5.2 Population dynamics and phosphorous removal

The primary focus of this experiment was to determine the relationship between G bacteria and PP bacteria, and the effects on the operation of an SBR with enhanced biological P-removal. Previous studies suggested that G bacteria were the controlling factor, particularly under conditions where glucose was present in the feed. From these studies, and from preliminary work with the bacteria, it was hypothesized that:

- G bacteria would dominate a BPR system in the presence of glucose
- PP bacteria would dominate a BPR system in the presence of acetate
- Temperature would adversely affect G bacteria populations above 25-27°C

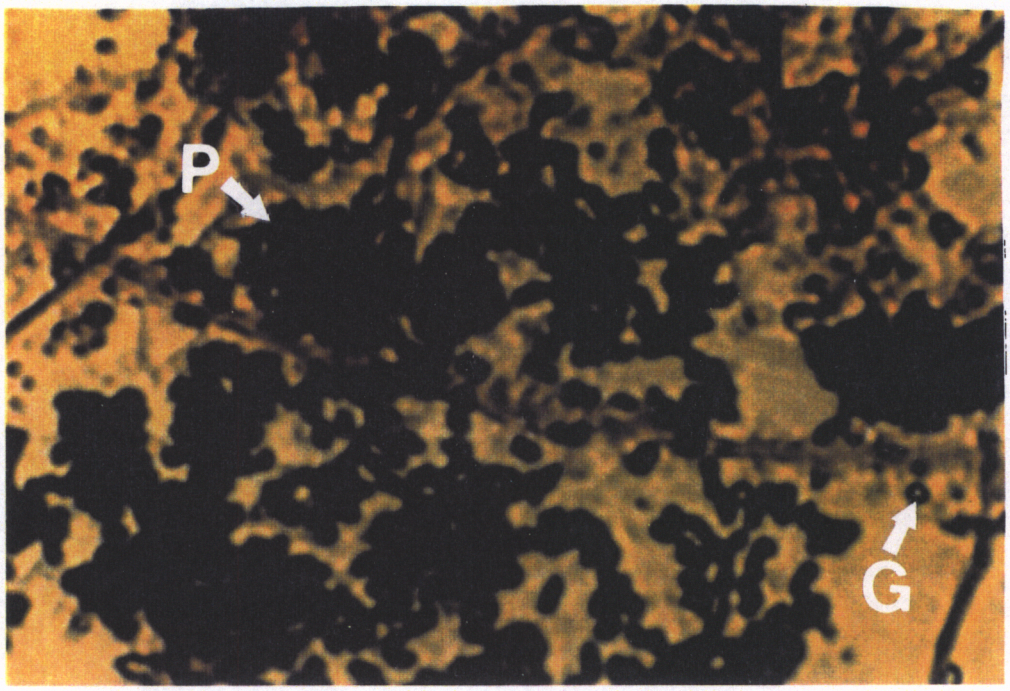
Many of the results of this experiment, however, did not support these hypotheses. For instance, the number of G bacteria in the reactors did not appear to affect PP numbers. In particular, high or low numbers of G bacteria were not an

indication of whether P-removal would (or could) occur. Furthermore, the number of PP bacteria did not always indicate whether P-removal would occur in the reactors. What did indicate P-removal was the size of the PP bacteria. In all reactors, P-removal was associated with large, well Neisser-stained PP bacteria, while small, poorly stained bacteria were indicative of P-removal loss. Figure 10 (a, b) illustrate these differences in size, shape, and staining appearance. It should be noted that the population of these larger PP bacteria were an indication of P-removal, however, due to the staining method and counting method used, both large and small PP were counted. In addition, some bacteria were identified as PP bacteria, by size, shape and arrangement, but because they lacked sufficient phosphorous to stain correctly, these bacteria were not counted. Thus, identification and enumeration of PP bacteria may have lead to erroneous results in the sense that there is a significant difference between the number of PP bacteria and the number of P-removing PP bacteria.

Percent phosphorous in the sludge also did not indicate a definite relationship between the number of PP and G bacteria in the reactors. In all reactors, a sharp drop in %P occurred, followed by the loss of P-removal, within the first weeks of operation. Only reactor E regained P-removal, maintaining %P at approximately 2.5%, discounting errors. Results from reactor E suggest that a minimum of 2.0% P is required for P-removal. Unfortunately, no other reactors resumed P-removal to support this conclusion.

In all reactors, once the initial decrease occurred, %P in the reactors remained constant. Changes in feed composition, temperature, and PP or G populations did not

(a)




(b)

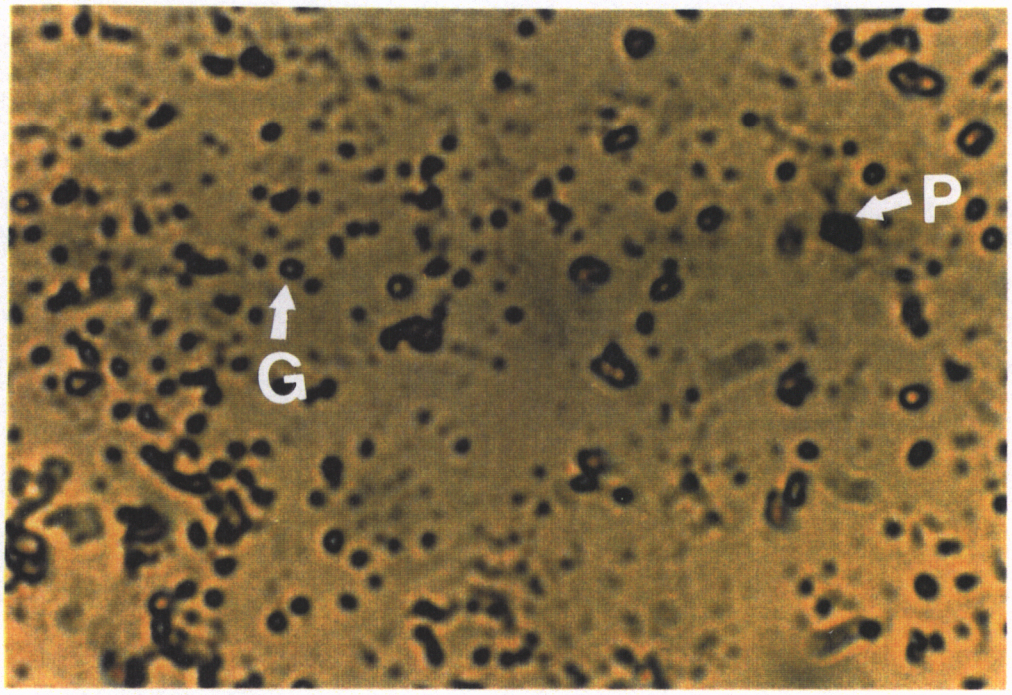



Fig. 10 (a, b). Difference in appearance between (a) phosphorous-removing PP and (b) non-phosphorous removing PP bacteria. Note the presence of G bacteria in both samples.

Discussion

affect %P once it had reached a steady value of approximately 2.0%. This suggested again that G bacteria were not a controlling factor in P-removal, or in PP population size. If a relationship had existed, variations in G bacteria numbers would have coincided with changes in %P. Furthermore, these results suggest that %P was not a function of PP numbers, and further support the hypothesis that the size, not the number, of PP is indicative of P-removal.

In their 1992 study, Cech and Hartman concluded that the molar ratio of phosphate release to acetate uptake depended on the ratio of PP to G bacteria. The results of this experiment contradicted their conclusion in many instances. The correlation between $PO_4$ release:TOC uptake versus PP: G was very poor for three out of six reactors ($R^2 \leq 0.75$). These reactors included 100% acetate feed, in addition to mixtures of glucose, acetate, and nutrient broth feeds. In one instance, the number of G bacteria was so large, even with P-removal, that an inverse relationship between $PO_4$ release:TOC uptake versus PP: G occurred. Once P-removal was lost, the relationship between $PO_4$ release:TOC uptake versus PP: G no longer held. Without P-removal, the number of PP and G bacteria had little/no effect on $PO_4$ release:TOC uptake. This was particularly evident in reactors A and D over an extended period of time. Because these reactors had very different feeds, and because those reactors with good correlation included reactors with or without 100% acetate feed, feed composition did not appear to have as significant an effect as expected, particularly with those reactors fed a glucose/acetate mix versus those fed 100% acetate. Perhaps a more correct conclusion would be that the ratio of $PO_4$ release:TOC uptake depended on the

ratio of PP:G bacteria when P-removal was occurring, and was unaffected by PP:G when P-removal no longer occurred. If the number of G bacteria was high and P-removal still occurred, this relationship, again, did not appear to apply.

### 5.3 Effects of feed composition on PP and G populations

Feed composition did not have as significant an affect on PP and G populations as initially expected. Because PP bacteria are considered incapable of metabolizing glucose, it was assumed that an increase in the amount of glucose would greatly increase G bacteria populations. Pure culture studies in this experiment indicated rapid growth when glucose was available. It was therefore expected that G bacteria populations would sharply increase in the reactors, especially since PP were unable to use the glucose portion of the feed solution until other bacteria (including G's) could break down the complex sugars into VFA's. At 25% glucose/acetate feed, little affect occurred. However, at 50% glucose, both PP and G bacteria increased in the reactors. Initially, it appeared as though the G bacteria were producing VFA's, thereby increasing both populations of bacteria. The significance of this increase is questionable, however, because all six reactors displayed similar trends after approximately three sludge ages. Nutrient broth appeared to have little overall effect on PP and G populations, although it was present in the only reactor that regained P-removal. The only ingredients in nutrient broth were beef extract and peptone. Peptone is a required nutrient for some glucose-utilizing bacteria (Bergey's Manual, 1986), however, its role in P-removal is undetermined.

Despite feed composition, temperature, and PP and G populations, all reactors underwent subsequent highs and lows nearly every three sludge ages. These results contradict conclusions made by Cech and Hartman in their 1992 study. In that study, they concluded that G bacteria would dominate the system if a glucose/acetate mixture was available; PP would dominate if the feed contained only acetate. However, their results displayed the same population shifts obtained during this experiment. In particular, the number of G bacteria decreased as PP increased when fed 100% acetate, and also when fed approximately 30% glucose:acetate. If G bacteria were to dominate the system in the presence of glucose, their numbers should not have decreased while fed glucose and acetate. Instead, their results and the results of this experiment appeared to indicate that PP and G bacteria continually fluctuate, regardless of feed. G bacteria appear "opportunistic" -- if the number of PP is low, they take advantage of the available substrate; if the number of PP is high, or the PP are large and actively removing phosphorous, the G bacteria do not grow as vigorously; they appear much smaller than normal, and are generally fewer in number. These results did not indicate that G bacteria are a controlling factor, but that they are a result of PP population size and function.

### 5.4 Temperature effects on PP and G populations

Pure culture studies indicated that the G bacteria were highly sensitive to temperature. They grew extremely slow at room temperature (20°C) -- up to 3 weeks in some cases. At 25°C, the G bacteria grew within days, and at 30°C, they did not grow

at all. If PP populations were a function of G populations as hypothesized, then a rise in temperature should stimulate PP bacteria by decreasing the number of G bacteria, and as a result, stimulate P uptake and removal. Up to 25-27°C, temperature did stimulate, or improve PP populations in that more larger, well-stained PP's were identified in all the reactors. At this temperature, however, G bacteria populations continued to fluctuate. Only at 30°C did the G bacteria begin to steadily decline. Despite the PP's improved appearance, P-removal did not occur in 3 of 4 reactors. Thus, temperature had more of an effect on PP performance than it did on G bacteria populations. These results may also suggest that the loss of phosphorous removal was not a function of G bacteria populations.

### 5.5 Effects of PP and G populations on TOC removal

In their 1992 study, Cech and Hartman determined that as the number of G bacteria increased, the ratio of $PO_4$ release to acetate uptake decreased. In all reactors fed 100% acetate, this relationship was consistent throughout operation, using TOC uptake as a measure of acetate uptake. In reactors fed a 25% glucose/acetate mixture, the ratio decreased, indicating greater TOC utilization. This would be expected, as G bacteria utilize substrate that the PP bacteria cannot, with no associated $PO_4$ release and uptake. However, when glucose was increased to 50%, or acetate decreased to 25%, this relationship ceased. PP and G bacteria populations fluctuated with no change in $PO_4$:TOC. These results appear to be a function of several factors, including the loss of $PO_4$ uptake and release in the PP bacteria. In addition, substrate utilization, whether it

be acetate or glucose, had much less of an effect on PP and G populations than initially anticipated. This may be a result of slower growth rates for the G bacteria, and/or the result of other microbes in the reactors fermenting glucose to VFA's for PP utilization, stimulated by higher amounts of complex carbon sources available.

Reactors fed nutrient broth also showed a decrease in $PO_4$:TOC with an increase in G bacteria, except for reactor E. Reactor E displayed this trend until temperature changes occurred. Because reactor E was removing phosphorous at the time, these results may reflect the difference between the number of PP versus the number of large, P-removing PP. Although low in number, most of the PP identified in the reactor were large bacteria that stained well. But because of their low numbers, (1) they did not utilize a large amount of substrate and (2) more substrate was available for the G bacteria. In addition, higher temperatures may have stimulated all microbial growth in the reactors, especially those which would not have contributed to $PO_4$ release.

The results of this study did indicate a decrease in the amount of TOC utilized during the first two hours of anaerobiosis with an increase in the number of G bacteria. Although the significance of the relationship may be questionable ($R^2 \leq 0.68$), these results may be an indication of the G bacteria's slow growth rate, particularly at lower temperatures (at or below 20°C).

### 5.6 Pure culture analyses

The results of this study identified several characteristics that help characterize the newly discovered "G bacteria" strain. The bacteria grow readily on any type of

glucose media. Other agars, such as minimal agar, yeast extract agar, and nutrient agar, were acceptable, but required significantly more growing time, even at an optimal temperature of 25°C.

The G bacteria grew so well and so rapidly on glucose agar, that it was often used as an initial identification tool for new isolates. This initial identification procedure was then followed by innoculation on MacConkey agar. No growth on MacConkey agar was a second identification tool to help isolate G bacteria from other species. For isolation and storage purposes, the use of yeast extract agar is recommended for more rapid isolation. Few other bacteria will grow on yeast extract agar, thus making isolation more selective with fewer transfers.

Toxicity testing provided no indication of G bacteria producing toxins to inhibit the growth of PP bacteria. Pure cultures of PP and G bacteria were cross-streaked on nutrient and yeast extract agars. The G bacteria did not inhibit PP growth, as would have been indicated at the crossing of the PP and G streaks had the G bacteria produced toxins. Further tests actually indicated otherwise: that PP bacteria grew so rapidly, G bacteria could not successfully compete for available substrate in a nutrient or yeast extract agar. Cultures containing both PP and G bacteria were so thick with PP bacterial growth, that no measurable difference could be detected in tubes innoculated with different concentrations of G bacteria. The only competitive advantage of the G bacteria over PP was that the G bacteria did not require minor nutrients, such as Mg and K (or peptone), that PP's do for phosphorous uptake and removal. The actual advantage of this, however, is unknown.

Discussion

Though the biochemical tests did not yield any identification in terms of genus and species for the G bacteria, the tests suggested a strong similarity between the G bacteria and the genus, *Pseudomonas*. Because of these similarities, some of the genus' most common characteristics were studied, perhaps indicating something about the G bacteria as well.

*Pseudomonas* metabolism utilizes $O_2$ as a terminal electron acceptor, with all species possessing the tricaboxylic acid (TCA) cycle. The genus grows optimally at 28°C, and most species require no organic growth factors. Most notably, however, is that many species accumulate PHB. The genus is important because they are widespread, nutritionally and biochemical versatile, and relatively easy to grow and maintain. At moderate temperatures, with pH around 7.0, and organics and $O_2$ available, these bacteria grow well even under nutrient poor conditions. Their most notable difference from the G bacteria is that *Pseudomonas* are gram negative rods. Because of their similarity to the G bacteria, many of these characteristics may also apply to G bacteria, particularly their ubiquitous nature, although this is purely speculation.

The results of this study indicate that G bacteria are typically slow-growing, aerobic bacteria that proliferate only under specific condition. These include temperatures around 25°C, with at least some $O_2$ available, in a glucose substrate. Without these conditions, the bacteria appeared to be too slow-growing to effectively compete with, and dominate, other bacterial populations in activated sludge systems. They are ubiquitous in wastewater, but appear to "dominate" only when other bacterial species (such as the PP) decline. More specifically, the success of the G bacteria was

more a function of PP bacterial growth than the PP's a function of G bacteria, except when conditions directly favored G bacteria growth such as the availability of a glucose-based medium.

# Chapter 6: Conclusions

This study examined the population dynamics of polyphosphorous-removing bacteria, such as *Acinetobacter,* and an unidentified bacteria, referred to as "G-bacteria." From the results of this study, the following conclusions were drawn:

1. The number of G bacteria in a BPR system did not appear to affect PP populations in terms of P-uptake and removal in an active P-removal system.

2. The number of PP bacteria was not necessarily an indication of P-removing ability; the size of the cell, and the amount of P in the cell during all reactor stages were more indictative of P-removing capability.

3. G bacteria did not appear to inhibit PP populations; instead, PP bacteria appeared to have an adverse affect on G bacteria during periods of P-removal in the systems. However, cross-streak analysis showed that neither bacteria was toxic to the other.

4. High temperatures (above 30°C) had an adverse effect on G bacteria growth. Optimum temperature for growth was ~25°C for the G bacteria.

5. Feed composition had only a moderate effect on PP and G populations, despite availability of glucose and/or acetate in the systems.

6. G bacteria could not be identified in terms of genus or species using conventional biochemical identification systems, such as API and Flow Labs Non-fermenting Bacteria system.

# 7.0 Suggestions for Further Research

Although the G bacteria did not appear to play a dominant role in PP populations in a bench scale system, further characterization of the bacteria may be useful, especially with respect to the bacteria's behavior in a full scale plant. Even though the bacteria appears to require specific conditions to flourish, their behavior in a full scale plant may be different. It should be noted that the bacteria were first identified in a fully operating plant, and the bacteria were also found in significant quantities in a pilot scale system which served as starter activated sludge for this study.

Most importantly, further research is needed to properly identify the G bacteria in terms of genus and species. This identification would greatly enhance existing knowledge of the bacteria, and aid in characterizing its behavior in a BPR activated sludge system.

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# Appendix A:

# Summary of Raw Chemical Data

Appendix A: Raw data for reactors A-F

| Date | Day | Reactor | Stage | D.O. | pH | TSS | VSS | Total P | Tot Sol P | PO4-P | %P | NO2-N | NO3-N | NH3-N | TKN | Total TKN | %N | Sol TOC | Temp (C) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2/3/93 | 5 | A | Influent | | 7.43 | | | | | 28.3 | | 0.00 | 0.67 | | | | | 317.00 | | |
| | 5 | A | Anaerobic | 0.17 | 7.60 | | | | | 163.0 | | 0.00 | 0.11 | | | | | 8.64 | | |
| | 5 | A | Anoxic | 0.10 | 7.50 | | | | | 194.5 | | 0.00 | 0.04 | | | | | 4.57 | | |
| | 5 | A | Aerobic | 6.60 | 6.47 | 3924 | | | | 46.0 | | 0.00 | 0.26 | | | | | 4.41 | | |
| | 5 | A | Effluent | 0.60 | 6.70 | 8 | | | | 45.3 | | 0.00 | 0.21 | | | | | 5.05 | | |
| | 5 | B | Influent | | 7.52 | | | | | 27.9 | | 0.00 | 0.67 | | | | | 318.00 | | |
| | 5 | B | Anaerobic | 0.30 | 6.00 | | | | | 23.3 | | 0.00 | 0.05 | | | | | 38.80 | | |
| | 5 | B | Anoxic | 0.15 | 7.62 | | | | | 23.6 | | 0.00 | 0.03 | | | | | 38.80 | | |
| | 5 | B | Aerobic | 6.40 | 6.46 | 880 | | | | 21.5 | | 0.00 | 0.03 | | | | | 7.80 | | |
| | 5 | B | Effluent | 2.60 | 6.50 | 46 | | | | 24.5 | | 0.00 | 0.02 | | | | | 6.89 | | |
| Date | Day | Reactor | Stage | D.O. | pH | TSS | VSS | Total P | Tot Sol P | PO4-P | %P | NO2-N | NO3-N | NH3-N | TKN | Total TKN | %N | Sol TOC | Temp (C) | Comments |
| 2/6/93 | 8 | A | Influent | | 7.43 | | | | 23.0 | 29.0 | | 0.00 | 0.69 | 7.36 | | | | 316.40 | | |
| | 8 | A | Anaerobic | 0.15 | 7.34 | | | | | 188.0 | | 0.00 | 0.12 | 0.00 | | | | 38.00 | | |
| | 8 | A | Anoxic | 0.18 | 7.41 | | | | | 213.8 | | 0.00 | 0.14 | 0.00 | | | | 49.10 | | |
| | 8 | A | Aerobic | 6.80 | 6.76 | 3142 | 2767** | 134* | 40.6 | 42.9 | 3.37% | 0.00 | 0.01 | 0.00 | | | | 3.46 | | *Samples fr from 2/8 |
| | 8 | A | Effluent | 0.50 | 6.70 | 32 | | | | 43.4 | | 0.00 | 0.01 | 0.00 | | | | 4.19 | | ** Est. @ 88% of TSS |
| | 8 | B | Influent | | 7.34 | | | | 30.3 | 28.8 | | 0.00 | 0.67 | 6.13 | | | | 315.20 | | |
| | 8 | B | Anaerobic | 0.17 | 7.71 | | | | | 27.7 | | 0.00 | 0.03 | 0.00 | | | | 68.40 | | |
| | 8 | B | Anoxic | 0.15 | 7.75 | | | | | 26.1 | | 0.00 | 0.03 | 0.00 | | | | 69.60 | | |
| | 8 | B | Aerobic | 6.30 | 6.31 | 872 | 800** | 39.29* | 27.1 | 22.2 | 1.43% | 0.00 | 0.06 | 0.00 | | | | 58.30 | | |
| | 8 | B | Effluent | 2.00 | 6.06 | 168 | | | | 20.3 | | 0.00 | 0.01 | 0.00 | | | | 6.22 | | |
| Date | Day | Reactor | Stage | D.O. | pH | TSS | VSS | Total P | Tot Sol P | PO4-P | %P | NO2-N | NO3-N | NH3-N | TKN | Total TKN | %N | Sol TOC | Temp (C) | Comments |
| 2/17/93 | 17 | A | Influent | | 7.39 | | | | | 30.56 | | 0 | 0.49 | | | | | 297 | | |
| | 17 | A | Anaerobic | 0.22 | 7.43 | | | | | 103 | | 0 | 0 | | | | | | | |
| | 17 | A | Anoxic | 0.17 | 7.54 | | | | | 121 | | 0 | 0 | | | | | | | |
| | 17 | A | Aerobic | 6.40 | 6.74 | 2208 | 1550 | 100.2 | 17.16 | 13.9 | 3.36% | 0 | 0.04 | | | | | 4.05 | | |
| | 17 | A | Effluent | 0.56 | 6.69 | 30.6 | 16.7 | | | 10.1 | | 0 | 0.04 | | | | | 2.96 | | |
| | 17 | B | Influent | | 7.37 | | | | | 30.56 | | 0 | 0.49 | | | | | 295 | | |
| | 17 | B | Anaerobic | 0.15 | 6.07 | | | | | 27.5 | | 0 | 0.05 | | | | | | | |
| | 17 | B | Anoxic | 0.2 | 6.17 | | | | | 29.1 | | 0 | 0.07 | | | | | | | |
| | 17 | B | Aerobic | 7.3 | 6.61 | 636 | 365 | 34.26 | 27.62 | 23.9 | 1.14% | 0 | 0.05 | | | | | 4.77 | | |
| | 17 | B | Effluent | 1.1 | 6.44 | 40 | 30.9 | | | 26 | | 0 | 0.06 | | | | | 6.93 | | |
| Date | Day | Reactor | Stage | D.O. | pH | TSS | VSS | Total P | Tot Sol P | PO4-P | %P | NO2-N | NO3-N | NH3-N | TKN | Total TKN | %N | Sol TOC | Temp (C) | Comments |
| 2/18/93 | 1 | C | Influent | | 7.29 | | | | 31.47 | 32.1 | | 0 | 0.65 | 8.69 | 7.67 | | | 305.2 | | |
| | 1 | C | Anaerobic | 0.32 | 7.11 | | | | | 161 | | 0 | 0.02 | 0 | | | | 6.435 | | |
| | 1 | C | Anoxic | 0.21 | 7.02 | | | | | 202 | | 0 | 0.01 | 0 | | | | 5.415 | | |
| | 1 | C | Aerobic | 3.82 | 6.33 | 3620 | 1947 | 147.8 | 22.17 | 20.8 | 6.46% | 0 | 0.06 | 0 | | 108.69 | 5.31 | 5.667 | | |
| | 1 | C | Effluent | 0.35 | 6.38 | 16 | 20 | | | 18.5 | | 0 | 0.008 | 0 | 5.52 | | | 5.665 | | |
| | 1 | D | Influent | | 7.31 | | | | 33.7 | 34.9 | | 0 | 0.72 | 10.22 | 60.1 | | | 173.9 | | |
| | 1 | D | Anaerobic | 0.3 | 6.73 | | | | | 103 | | 0 | 0.04 | 0 | | | | 7.636 | | |
| | 1 | D | Anoxic | 0.37 | 6.81 | | | | | 140 | | 0 | 0.03 | 0 | | | | 11.21 | | |
| | 1 | D | Aerobic | 6.4* | 7.5 | 3113 | 1913 | 138.3 | 66.5 | 66.5 | 3.61% | 0 | 0.009 | 0 | | 308.49 | 10.9 | 5.732 | | * D.O.<4.0 |
| | 1 | D | Effluent | 0.25 | 7.45 | 28 | 8 | | | 75.6 | | 0 | 0.14 | 0 | 0 | | | 7.296 | | |

Appendix A: Raw data for reactors A-F

| Date | Day | Reactor | Stage | D.O. | pH | TSS | VSS | Total P | Tot Sol P | PO4-P | %P | NO2-N | NO3-N | NH3-N | TKN | Total TKN | %N | Sol TOC | Temp (C) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2/22/93 | 22 | A | Influent | | 7.21 | | | | | 31.43 | | 0 | 0.29 | | | | | 304.6 | | |
| | 22 | A | Anaerobic | 0.23 | 7.32 | | | | | 74.65 | | 0 | 0.01 | | | | | 3.02 | | |
| | 22 | A | Anoxic | 0.2 | 7.51 | | | | | 90.56 | | 0 | 0.009 | | | | | 3.579 | | |
| | 22 | A | Aerobic | 5.1 | 8.43 | 2005 | 1460 | 91.19 | 11.2 | 9.92 | 5.46% | 0 | 0.01 | | | | | 1.929 | | |
| | 22 | A | Effluent | 0.25 | 8.45 | 32.5 | 22.5 | | | 8.09 | | 0 | 0.02 | | | | | 2.639 | | |
| | 22 | B | Influent | | 7.16 | | | | | 31.29 | | 0 | 0.29 | | | | | 308.3 | | |
| | 22 | B | Anaerobic | 0.25 | 7.76 | | | | | 20.12 | | 0 | 0.009 | | | | | 46.67 | | |
| | 22 | B | Anoxic | 0.32 | 7.98 | | | | | 20.47 | | 0 | 0.009 | | | | | 51.14 | | |
| | 22 | B | Aerobic | 7.2 | 8.49 | 670 | 620 | 18.86 | 17.08 | 20.01 | 0.267% | 0 | 0.009 | | | | | 7.715 | | |
| | 22 | B | Effluent | 0.4 | 8.46 | 60 | 45 | | | 21.73 | | 0 | 0.02 | | | | | 8.466 | | |

| Date | Day | Reactor | Stage | D.O. | pH | TSS | VSS | Total P | Tot Sol P | PO4-P | %P | NO2-N | NO3-N | NH3-N | TKN | Total TKN | %N | Sol TOC | Temp (C) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2/26/93 | 9 | C | Influent | | 7.19 | | | | 26.12 | 31.43 | | 0 | 0.319 | 7.97 | 8.43 | | | 313.5 | | |
| | 9 | C | Anaerobic | 0.2 | 6.46 | | | | | 138.8 | | 0 | 0.005 | 0 | | | | 3.535 | | |
| | 9 | C | Anoxic | 0.2 | 7.66 | | | | | 121.8 | | 0.071 | 0.039 | 0 | | | | 2.929 | | |
| | 9 | C | Aerobic | 7.63 | 8.67 | 2033 | 1393 | 97.14 | 29.69 | 32.26 | 4.91% | 0 | 0.194 | 0 | | 119.57 | 8.5 | 2.829 | | |
| | 9 | C | Effluent | 0.35 | 8.9 | 29 | 20 | | | 28.4 | | 0 | 0.194 | 0 | 0.767 | | | 3.131 | | |
| | 9 | D | Influent | | 6.34 | | | | 31.04 | 29.43 | | 0 | 0 | 2.15 | 9.2 | | | 189 | | |
| | 9 | D | Anaerobic | 0.16 | 6.96 | | | | | 76.26 | | 0 | 0.032 | 0 | | | | 4.217 | | |
| | 9 | D | Anoxic | 0.15 | 7.27 | | | | | 56.04 | | 0 | 0.009 | 2.24 | | | | 2.826 | | |
| | 9 | D | Aerobic | 7.32 | 8.53 | 2153 | 1313 | 109.1 | 21.3 | 18.42 | 6.69% | 0 | 0.009 | 0 | | 124.94 | 9.46 | 2.146 | | |
| | 9 | D | Effluent | 0.55 | 8.56 | 32 | 32 | | | 20.83 | | 0 | 0.0187 | 0 | 0.767 | | | 2.626 | | |

| Date | Day | Reactor | Stage | D.O. | pH | TSS | VSS | Total P | Tot Sol P | PO4-P | %P | NO2-N | NO3-N | NH3-N | TKN | Total TKN | %N | Sol TOC | Temp (C) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3/1/93 | 29 | A | Influent | | 7.24 | | | | | 29.64 | | 0 | 0 | | | | | 275.5 | | |
| | 29 | A | Anaerobic | 0.2 | 7.6 | | | | | 108.72 | | 0 | 0.056 | | | | | 6.196 | | |
| | 29 | A | Anoxic | 0.2 | 7.63 | | | | | 99.21 | | 0 | 0.013 | | | | | 3.661 | | |
| | 29 | A | Aerobic | 1.0* | 8.29 | 1673 | 1267 | 82.5 | 31.4 | 28.05 | 4.03% | 0 | 0.009 | | | | | 2.499 | | *D.O. <4.0 |
| | 29 | A | Effluent | 0.4 | 8.3 | 38 | 8 | | | 27.97 | | 0 | 0.011 | | | | | 3.308 | | |
| | 29 | B | Influent | | 7.17 | | | | | 30.01 | | 0 | 0 | | | | | 283.1 | | |
| | 29 | B | Anaerobic | 0.16 | 7.99 | | | | | 23.29 | | 0 | 0.02 | | | | | 46.96 | | |
| | 29 | B | Anoxic | 0.15 | 7.96 | | | | | 23.22 | | 0 | 0.008 | | | | | 40.9 | | |
| | 29 | B | Aerobic | 6 | 8.43 | 687 | 620 | 58.64 | 29.52 | 22.7 | 4.73% | 0 | 0.014 | | | | | 7.07 | | |
| | 29 | B | Effluent | 1.5 | 8.44 | 92 | 64 | | | 25.17 | | 0 | 0.004 | | | | | 9.141 | | |

| Date | Day | Reactor | Stage | D.O. | pH | TSS | VSS | Total P | Tot Sol P | PO4-P | %P | NO2-N | NO3-N | NH3-N | TKN | Total TKN | %N | Sol TOC | Temp (C) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3/5/93 | 16 | C | Influent | | 7.34 | | | | 32.41 | 30.3 | | 0 | 0.207 | 4.29 | 9.56 | | | 291.2 | | |
| | 16 | C | Anaerobic | | 8.11 | | | | | 66.1 | | 0 | 0.015 | 0 | | | | 33.98 | 24 | |
| | 16 | C | Anoxic | 0.1 | 8.07 | | | | | 66.1 | | 0 | 0.011 | 0 | | | | 27.5 | | |
| | 16 | C | Aerobic | 6.69 | 8.57 | 1347 | 1173 | 69.9 | 35.69 | 46 | 2.92% | 0 | 0.015 | 0 | 1.53 | 85.85 | 7.19 | 2.616 | | |
| | 16 | C | Effluent | 0.76 | 8.56 | 36 | 44 | | | 46.5 | | 0 | 0.016 | 0 | | | | 2.819 | 24 | |
| | 16 | D | Influent | | 7.03 | | | | 32.32 | 29.5 | | 0 | 0 | 1.23 | 14.18 | | | 191.8 | | |
| | 16 | D | Anaerobic | | 7.3 | | | | | 69 | | 0 | 0.023 | 0 | | | | 3.378 | 26 | |
| | 16 | D | Anoxic | 0.14 | 7.32 | | | | | 74 | | 0 | 0.008 | 0 | | | | 1.905 | | |
| | 16 | D | Aerobic | 5.76 | 8.23 | 1413 | 1133 | 78.84 | 33.03 | 35.8 | 4.04% | 0 | 0.008 | 0 | 0.77 | 85.85 | 7.51 | 3.149 | | |
| | 16 | D | Effluent | 0.8 | 8.25 | 88 | 32 | | | 39.5 | | 0 | 0.012 | 0 | | | | 2.311 | 26 | |

Appendix A: Raw data for reactors A-F

| Date | Day | Reactor | Stage | D.O. | pH | TSS | VSS | Total P | Tot Sol P | PO4-P | %P | NO2-N | NO3-N | NH3-N | TKN | Total TKN | %N | Sol TOC | Temp (C) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3/8/93 | 36 | A | Influent | | 7.1 | | | | | 31.03 | | 0 | 0.189 | | | | | 299.2 | | |
| | 36 | A | Anaerobic | 0.07 | 7.75 | | | | | 33.87 | | 0 | 0.081 | | | | | 26.87 | 22.5 | |
| | 36 | A | Anoxic | 0.1 | 8 | | | | | 35.27 | | 0 | 0.008 | | | | | 8.255 | | |
| | 36 | A | Aerobic | 3.6* | 8.31 | 1727 | 1531** | 58.1 | 23.3 | 23.31 | 2.27% | 0 | 0.007 | | | | | 2.184 | | *D.O.<4.0 |
| | 36 | A | Effluent | 0.1 | 8.32 | 24 | | | | 21.42 | | 0 | 0.011 | | | | | 2.413 | 23 | **Est. @ 88% of TSS |
| | 36 | B | Influent | | 7.15 | | | | | 31.33 | | 0 | 0.188 | | | | | 289.4 | | |
| | 36 | B | Anaerobic | 0.1 | 7.91 | | | | | 24.03 | | 0 | 0.009 | | | | | 49.4 | 22.5 | |
| | 36 | B | Anoxic | 0.11 | 8.04 | | | | | 25.19 | | 0 | 0.01 | | | | | 46.92 | | |
| | 36 | B | Aerobic | 7.6 | 8.42 | 940 | 822** | 46.5 | 24.58 | 24.34 | 2.50% | 0 | 0.012 | | | | | 9.601 | | |
| | 36 | B | Effluent | 0.05 | 8.36 | 102 | | | | 26.51 | | 0 | 0.007 | | | | | 8.915 | 22 | |

| Date | Day | Reactor | Stage | D.O. | pH | TSS | VSS | Total P | Tot Sol P | PO4-P | %P | NO2-N | NO3-N | NH3-N | TKN | Total TKN | %N | Sol TOC | Temp (C) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3/12/93 | 23 | C | Influent | | 7.15 | | | | | 31.04 | | 0 | 0.298 | 6.25 | 4.6 | | | 294.3 | | |
| | 23 | C | Anaerobic | 0.2 | 7.67 | | | | | 34.02 | | 0 | 0.014 | 0 | | | | 39.26 | | |
| | 23 | C | Anoxic | 0.1 | 7.8 | | | | | 32.8 | | 0 | 0.013 | 0 | | | | 34.63 | | |
| | 23 | C | Aerobic | 7.5 | 8.43 | 1247 | 1177 | NO DATA | NO DATA | 28.98 | — | 0 | 0.01 | 0 | 0 | 74.35 | 6.32 | 3.679 | | |
| | 23 | C | Effluent | 0.1 | 8.42 | 48 | 36 | | | 28.88 | | 0 | 0.019 | 3.37* | | | | 4.426 | | |
| | 23 | D | Influent | | 7.12 | | | | | 31.73 | | 0 | 0.639 | 7.05 | 6.13 | | | 218.2 | | |
| | 23 | D | Anaerobic | 0.1 | 7.03 | | | | | 34.14 | | 0 | 0.02 | 0 | | | | 8.461 | | |
| | 23 | D | Anoxic | 0.1 | 7.16 | | | | | 35.09 | | 0 | 0.008 | 0 | | | | 8.131 | | |
| | 23 | D | Aerobic | 7.72 | 8.11 | 1227 | 1147 | NO DATA | NO DATA | 27.84 | — | 0 | 0.011 | 0 | 0.77 | 73.58 | 6.35 | 2.167 | | |
| | 23 | D | Effluent | 0.1 | 8.11 | 32 | 32 | | | 28.54 | | 0 | 0.014 | 0 | | | | 3.082 | | |

| Date | Day | Reactor | Stage | D.O. | pH | TSS | VSS | Total P | Tot Sol P | PO4-P | %P | NO2-N | NO3-N | NH3-N | TKN | Total TKN | %N | Sol TOC | Temp (C) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3/16/93 | 44 | A | Influent | | 7.26 | | | | | 26.86 | | 0 | 0.704 | | | | | 298.2 | | |
| | 44 | A | Anaerobic | 0.07 | 7.67 | | | | | 32.23 | | 0 | 0.038 | | | | | 27.32 | | |
| | 44 | A | Anoxic | 0.1 | 7.78 | | | | | 35.82 | | 0 | 0.03 | | | | | 16.19 | | |
| | 44 | A | Aerobic | 7.18 | 8.33 | 1614 | 1500 | 62.34 | 27.38 | 24.71 | 2.33% | 0 | 0.014 | | | | | 2.833 | | |
| | 44 | A | Effluent | 0.08 | 8.29 | 56 | 56 | | | 23.35 | | 0 | 0.011 | | | | | 10.16 | | |
| | 44 | B | Influent | | 7.41 | | | | | 26.74 | | 0 | 0.695 | | | | | 300.7 | | |
| | 44 | B | Anaerobic | 0.08 | 7.88 | | | | | 22.02 | | 0 | 0.009 | | | | | 32.75 | | |
| | 44 | B | Anoxic | 0.1 | 7.91 | | | | | 22.57 | | 0 | 0.009 | | | | | 53.21 | | |
| | 44 | B | Aerobic | 7.88 | 8.49 | 573 | 547 | 53.28 | 29.3 | 20.38 | 4.38% | 0 | 0.017 | | | | | 11.5 | | |
| | 44 | B | Effluent | 2.15 | 8.37 | 28 | 36 | | | 22.16 | | 0 | 0.009 | | | | | 2.908 | | |

| Date | Day | Reactor | Stage | D.O. | pH | TSS | VSS | Total P | Tot Sol P | PO4-P | %P | NO2-N | NO3-N | NH3-N | TKN | Total TKN | %N | Sol TOC | Temp (C) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3/19/93 | 30 | C | Influent | | 7.21 | | | | 28.31 | 23.89 | | 0 | 0.639 | 8.58 | 21.46 | | | 299.4 | | |
| | 30 | C | Anaerobic | 0.1 | 7.74 | | | | | 23.13 | | 0 | 0.011 | 0 | | | | 46.83 | | |
| | 30 | C | Anoxic | 0.1 | 7.79 | | | | | 25.33 | | 0 | 0.007 | 0 | | | | 47.73 | | |
| | 30 | C | Aerobic | 6.9 | 8.22 | 1047 | 973 | 56.26 | 28.9 | 56.1 | 2.61% | 0 | 0.011 | 0 | 1.53 | 69.75 | 7 | 6.408 | | |
| | 30 | C | Effluent | 0.25 | 8.16 | 40 | 36 | | | 24.52 | | 0 | 0.016 | 0 | | | | 6.201 | | |
| | 30 | D | Influent | | 7.17 | | | | 30.88 | 25.83 | | 0 | 0.698 | 7.97 | 7.67 | | | 236.4 | | |
| | 30 | D | Anaerobic | 0.12 | 7.09 | | | | | 23.6 | | 0 | 0.013 | 0 | | | | 16 | | |
| | 30 | D | Anoxic | 0.1 | 7.32 | | | | | 23.77 | | 0 | 0.012 | 0 | | | | 9.752 | | |
| | 30 | D | Aerobic | 6.7 | 8.01 | 1134 | 1040 | 57.08 | 30.69 | 22.2 | 2.54% | 0 | 0.009 | 0 | 1.53 | 68.69 | 6.27 | 3.216 | | |
| | 30 | D | Effluent | 0.2 | 7.73 | 8 | 4 | | | 22.16 | | 0 | 0.014 | 0 | | | | 3.988 | | |

Appendix A: Raw data for reactors A-F

| Date | Day | Reactor | Stage | D.O. | pH | TSS | VSS | Total P | Tot Sol P | PO4-P | %P | NO2-N | NO3-N | NH3-N | TKN | Total TKN | %N | Sol TOC | Temp (C) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3/22/93 | 50 | A | Influent | | 7.43 | | | | | 22.98 | | 0 | 0.694 | | | | | 304.3 | | |
| | 50 | A | Anaerobic | 0.07 | 7.85 | | | | | 23.99 | | 0 | 0.014 | | | | | 46.44 | 21 | |
| | 50 | A | Anoxic | 0.09 | 7.73 | | | | | 24.38 | | 0 | 0.02 | | | | | 40.32 | | |
| | 50 | A | Aerobic | 5.46 | 8.11 | 1047 | 994 | 36.49 | 20.46 | 20.94 | 1.61% | 0 | 0.012 | | | | | 5.882 | 21.5 | |
| | 50 | A | Effluent | 0.05 | 7.98 | 44 | 48 | | | 20.54 | | 0 | 0.01 | | | | | 8.532 | | |
| | 50 | B | Influent | | 7.27 | | | | | 22.91 | | 0 | 0.702 | | | | | 305.6 | | |
| | 50 | B | Anaerobic | 0.08 | 7.76 | | | | | 19.43 | | 0 | 0.015 | | | | | 35.89 | 21 | |
| | 50 | B | Anoxic | 0.07 | 7.76 | | | | | 18.08 | | 0 | 0.012 | | | | | 54.08 | | |
| | 50 | B | Aerobic | 7.51 | 8.53 | 633 | 620 | 32.71 | 18.59 | 18.1 | 2.26% | 0 | 0.016 | | | | | 5.461 | 21 | |
| | 50 | B | Effluent | 3.82 | 8.49 | 72 | 80 | | | 19.38 | | 0 | 0.002 | | | | | 4.786 | | |

| Date | Day | Reactor | Stage | D.O. | pH | TSS | VSS | Total P | Tot Sol P | PO4-P | %P | NO2-N | NO3-N | NH3-N | TKN | Total TKN | %N | Sol TOC | Temp (C) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3/31/93 | 39 | A | Influent | | 7.44 | | | | 17.41 | 26.82 | | 0 | 0.794 | | 7.099 | | | 255.4 | | |
| | 39 | A | Anaerobic | 0.12 | 7.5 | | | | | 24.88 | | 0 | 0.011 | | | | | 61.13 | | |
| | 39 | A | Anoxic | 0.05 | 7.67 | | | | | 27.14 | | 0 | 0.013 | | | | | 63.45 | | |
| | 39 | A | Aerobic | 5.8 | 8.02 | 1147 | 1100 | 30.35 | 24.88 | 25.6 | 0.517% | 0 | 0 | | 0.546 | 67.16 | 6.08% | 31.89 | | * Error |
| | 39 | A | Effluent | 0.5 | 8.15 | 20* | 28* | | | 24.69 | | 0 | 0.12 | | | | | 29.98 | | ** Est. @ 88% TSS |
| | 42 | C | Influent | | 7.5 | | | | 30.75 | 26.96 | | 0 | 0.787 | | 8.502 | | | 311.6 | | |
| | 42 | C | Anaerobic | 0.15 | 7.89 | | | | | 24.67 | | 0 | 0 | | | | | 69.54 | | |
| | 42 | C | Anoxic | 0.05 | 7.9 | | | | | 24.52 | | 0 | 0 | | | | | 65.81 | | |
| | 42 | C | Aerobic | 6.6 | 8.57 | 940 | 807 | 34.17 | 26.81 | 24.18 | 0.912% | 0 | 0.017 | | 0 | 75.89 | 9.40% | 7.394 | | |
| | 42 | C | Effluent | 0.65 | 8.56 | 78* | 94* | | | 23.67 | | 0 | 0.013 | | | | | 10.08 | | |
| | 42 | D | Influent | | 7.44 | | | | 29.74 | 27.38 | | 0 | 0.797 | | 7.099 | | | 265 | | |
| | 42 | D | Anaerobic | 0.12 | 7.39 | | | | | 21.48 | | 0 | 0.018 | | | | | 35.82 | | |
| | 42 | D | Anoxic | 0.05 | 7.55 | | | | | 23.72 | | 0 | 0.011 | | | | | 42.4 | | |
| | 42 | D | Aerobic | 7 | | 1380 | 1280 | 31.13 | 25.78 | 23.91 | 0.418% | 0 | 0.007 | | 1.092 | 75.89 | 5.94% | 6.813 | | |
| | 42 | D | Effluent | 0.1 | 8.32 | 12* | 28* | | | 24.19 | | 0 | 0.02 | | | | | 7.765 | | |
| | 1 | E | Influent | | 7.43 | | | | 24.02 | 29.02 | | 0 | 0.823 | | 43.68 | | | 202.7 | | |
| | 1 | E | Anaerobic | 0.1 | 7.17 | | | | | 67.23 | | 0 | 0.06 | | | | | 28.73 | | |
| | 1 | E | Anoxic | 0.05 | 7.25 | | | | | 73.63 | | 0 | 0.045 | | | | | 26.15 | | |
| | 1 | E | Aerobic | 4.56 | 7.92 | 1467 | 1300** | 165.6 | 19.73 | 15.02 | 11.24% | 0 | 3.61 | | 3.276 | 76.44 | 2.40% | 16.86 | | |
| | 1 | E | Effluent | 0.18 | 8.01 | 0* | 12* | | | 13.16 | | 0 | 4.63 | | | | | 17.7 | | |

Appendix A: Raw data for reactors A-F

| Date | Day | Reactor | Stage | D.O. | pH | TSS | VSS | Total P | Tot Sol P | PO4-P | %P | NO2-N | NO3-N | NH3-N | TKN | Total TKN | %N | Sol TOC | Temp (C) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4/7/93 | 66 | A | Influent | | 7.33 | | | | 26.37 | 27.16 | | 0 | 0.758 | | 10.92 | | | 257.2 | | |
| | 66 | A | Anaerobic | 0.12 | 6.86 | | | | | 23.39 | | 0 | 0.01 | | | | | 30.89 | | |
| | 66 | A | Anoxic | 0.11 | 6.91 | | | | | 23.3 | | 0 | 0.013 | | | | | 35.09 | | |
| | 66 | A | Aerobic | 0.1* | 7.77 | 1173 | 1100 | 40.79 | 22.23 | 23.23 | 1.69% | 0 | 0.016 | | 1.638 | 48.048 | 4.22% | 22.77 | | *D.O.<4.0 |
| | 66 | A | Effluent | 0.07 | 7.57 | 40 | 0 | | | 23.51 | | 0 | 0.015 | | | | | 18.87 | | |
| | 40 | C | Influent | | 7.27 | | | | 23.94 | 26.12 | | 0 | 0.757 | | 6.736 | | | 380.9 | | |
| | 40 | C | Anaerobic | 0.13 | 7.77 | | | | | 21.31 | | 0 | 0.021 | | | | | 44.64 | | |
| | 40 | C | Anoxic | 0.14 | 7.76 | | | | | 20.43 | | 0 | 0.019 | | | | | 40.21 | | |
| | 40 | C | Aerobic | 6.55 | 8.24 | 767 | 707 | 37.46 | 21.52 | 22.4 | 2.25% | 0 | 0.013 | | 0 | 38.22 | 3.41% | 8.084 | | |
| | 40 | C | Effluent | 2.25 | 8.22 | 80 | 56 | | | 21.95 | | 0 | 0.014 | | | | | 7.016 | | |
| | 40 | D | Influent | | 7.18 | | | | 23.8 | 26.07 | | 0 | 0.74 | | 7.644 | | | 308.5 | | |
| | 40 | D | Anaerobic | 0.13 | 7.55 | | | | | 21.25 | | 0 | 0.025 | | | | | 38.9 | | |
| | 40 | D | Anoxic | 0.11 | 7.52 | | | | | 22.02 | | 0 | 0.021 | | | | | 39.25 | | |
| | 40 | D | Aerobic | 6.23 | 8.11 | 1387 | 1280 | 39.86 | 22.2 | 21.79 | 1.38% | 0 | 0.013 | | 0.546 | 66.066 | 5.12% | 5.506 | | |
| | 40 | D | Effluent | 2.2 | 8.22 | 4 | 0 | | | 20.29 | | 0 | 0.021 | | | | | 5.225 | | |
| | 8 | E | Influent | | 7.25 | | | | 26.71 | 28.06 | | 0 | 0.76 | | 48.14 | | | 285.7 | | |
| | 8 | E | Anaerobic | 0.1 | 7.39 | | | | | 46.53 | | 0 | 0.032 | | | | | 12.14 | | |
| | 8 | E | Anoxic | 0.1 | 7.44 | | | | | 51.76 | | 0 | 0.051 | | | | | 7.581 | | |
| | 8 | E | Aerobic | 6.88 | 7.96 | 1407 | 1004 | 74.12 | 17.08 | 8.989 | 5.66% | 0 | 6.122 | | 2.73 | 87.734 | 9.46% | 7.658 | | |
| | 8 | E | Effluent | 0.1 | 7.85 | 0 | | | | 7.763 | | 0 | 6.261 | | | | | 6.429 | | |

| Date | Day | Reactor | Stage | D.O. | pH | TSS | VSS | Total P | Tot Sol P | PO4-P | %P | NO2-N | NO3-N | NH3-N | TKN | Total TKN | %N | Sol TOC | Temp (C) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4/14/93 | 73 | A | Influent | | 7.2 | | | | 25.38 | 26.8 | | 0 | 0.77 | 9.811 | 10.73 | | | 274.5 | | |
| | 73 | A | Anaerobic | 0.12 | 7.28 | | | | | 23.55 | | 0 | 0 | 0 | | | | 16.36 | | |
| | 73 | A | Anoxic | | 7.75 | | | | | 24.36 | | 0 | 0 | 0 | | | | 7.773 | | |
| | 73 | A | Aerobic | 5.1 | 8.1 | 1230 | 1137 | 43.79 | 24.1 | 21.72 | 1.73% | 0 | 0.232 | 1.226 | 3.088 | 67.07 | 7.39% | 6.62 | | *D.O.<4.0 |
| | 73 | A | Effluent | 0.15 | 8.05 | 28 | 24 | | | 21.41 | | 0 | 0.007 | 0 | | | | 7.393 | | **Error |
| | 56 | C | Influent | | 7.2 | | | | 23.29 | 27 | | 0 | 0.761 | 9.811 | 11.04 | | | 302.8 | | |
| | 56 | C | Anaerobic | 0.1 | 7.84 | | | | | 25.79 | | 0 | 0 | 0 | | | | 64.25 | | |
| | 56 | C | Anoxic | | 8.08 | | | | | 23.84 | | 0 | 0 | 0 | | | | 32.36 | | |
| | 56 | C | Aerobic | 5.65 | 8.18 | 893 | 800 | 42.3 | 22.82 | 20.98 | 2.44% | 0 | 0.013 | 0 | 2.453 | 58.87 | 7.09% | 12.03 | | |
| | 56 | C | Effluent | 2.5 | 8.33 | 9** | 12** | | | 22.91 | | 0 | 0.011 | 2.453 | | | | 9.234 | | |
| | 56 | D | Influent | | 7.19 | | | | 25.88 | 26.84 | | 0 | 0.757 | 11.65 | 12.26 | | | 299.3 | | |
| | 56 | D | Anaerobic | 0.12 | 7.42 | | | | | 24.76 | | 0 | 0 | 0 | | | | 58.75 | | |
| | 56 | D | Anoxic | | 7.58 | | | | | 23.38 | | 0 | 0 | 0 | | | | 57.01 | | |
| | 56 | D | Aerobic | 4.5* | 8.05 | 1460 | 1253 | 44.74 | 23.68 | 21.65 | 1.44% | 0 | 0.017 | 0 | 2.453 | 108.15 | 8.52% | 11.74 | | |
| | 56 | D | Effluent | 0.05 | 8.2 | 16 | 16 | | | 22.58 | | 0 | 0.01 | 0 | | | | 7.188 | | |
| | 15 | E | Influent | | 7.12 | | | | 27.74 | 30.61 | | 0 | 1.332 | 12.88 | 84.43 | | | 321 | | |
| | 15 | E | Anaerobic | 0.1 | 7.42 | | | | | 61.89 | | 0 | 0 | 7.032 | | | | 16.36 | | |
| | 15 | E | Anoxic | | 7.44 | | | | | 68.33 | | 0 | 0 | 10.731 | | | | 12.79 | | |
| | 15 | E | Aerobic | 4.8 | 7.65 | 1580 | 1253 | 70.88 | 22.24 | 21.72 | 3.88% | 4.92 | 3.1 | 0 | 6.132 | 45.38 | 3.13% | 8.581 | | |
| | 15 | E | Effluent | 1.4 | 7.76 | 4 | 0 | | | 17.4 | | 5.78 | 4.43 | 0 | | | | 9.467 | | |

Appendix A: Raw data for reactors A-F

| Date | Day | Reactor | Stage | D.O. | pH | TSS | VSS | Total P | Tot Sol P | PO4-P | %P | NO2-N | NO3-N | NH3-N | TKN | Total TKN | %N | Sol TOC | Temp (C) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 4/21/93 | 80 | A | Influent | | 7 | | | | | 26.59 | | 0 | 0.729 | 10.42 | | | | 319.5 | | |
| | 80 | A | Anaerobic | 0.3 | 8 | | | | | 22.35 | | 0 | 0.019 | | | | | 60.85 | | |
| | 80 | A | Anoxic | 0.15 | 7.81 | | | | | 23.67 | | 0 | 0.019 | 0 | | | | 31.22 | | |
| | 80 | A | Aerobic | 6.4 | 8.12 | 1067 | 1010 | 35.67 | 21.95 | 26.07 | 1.38% | 0 | 0.029 | 0 | 1.23 | 60.94 | 7.89% | 5.256 | | |
| | 80 | A | Effluent | 1.25 | 8.07 | 24 | 20 | | | 22.67 | | 0 | 0.023 | 0 | | | | 6.57 | | |
| | 63 | C | Influent | | 7.2 | | | | | 26.26 | | 0 | 0.721 | 9.26 | | | | 311.4 | | |
| | 63 | C | Anaerobic | 0.15 | 8.14 | | | | | 21.33 | | 0 | 2.99 | | | | | 55.02 | | |
| | 63 | C | Anoxic | 0.12 | 8.36 | | | | | 22.89 | | 0 | 0.143 | 0 | | | | 40.29 | | |
| | 63 | C | Aerobic | 4.36 | 9.6 | 800 | 707 | 34.49 | 22.75 | 19.35 | 1.69% | 0 | 0.566 | 0 | 2.453 | | | 8.601 | | |
| | 63 | C | Effluent | 0.1 | 8.59 | 26 | 20 | | | 22.9 | | 0 | 0.573 | 0 | | | | 9.967 | | |
| | 63 | D | Influent | | 7.2 | | | | 22.89 | 26.74 | | 0 | 0.733 | 9.9 | | | | 307.3 | | |
| | 63 | D | Anaerobic | 0.2 | 8 | | | | | 20.33 | | 0 | 0.081 | | | | | 27.57 | | |
| | 63 | D | Anoxic | 0.1 | 8.36 | | | | | 23.55 | | 0 | 0.017 | 1.53 | | | | 29.97 | | |
| | 63 | D | Aerobic | | 8.32 | 1067 | 1020 | 36.74 | 22.15 | 19.65 | 1.43% | 0 | 0.056 | 0 | 1.84 | | | 5.873 | | |
| | 63 | D | Effluent | | 8.32 | 36 | 28 | | | 22.56 | | 0 | 0.04 | 0 | | | | 6.584 | | |
| | 22 | E | Influent | | 7.08 | | | | 29.94 | 30.55 | | 0 | 0.774 | 11.5 | | | | 309 | | |
| | 22 | E | Anaerobic | 0.16 | 7.89 | | | | | 25.58 | | 0 | 0.08 | | | | | 36.15 | | |
| | 22 | E | Anoxic | 0.13 | 7.79 | | | | | 36.29 | | 0 | 0 | 9.81 | | | | 35.83 | | |
| | 22 | E | Aerobic | 6.9 | 7.85 | 1293 | 1173 | 52.74 | 27.16 | 24.5 | 2.16% | 0 | 3.058 | 7.05 | 9.81 | 96.89 | 7.42% | 8.504 | | |
| | 22 | E | Effluent | 0.6 | 7.93 | 16 | 16 | | | 26.76 | | 0 | 3.883 | 6.13 | | | | 9.27 | | |
| Date | Day | Reactor | Stage | D.O. | pH | TSS | VSS | Total P | Tot Sol P | PO4-P | %P | NO2-N | NO3-N | NH3-N | TKN | Total TKN | %N | Sol TOC | Temp (C) | Comments |
| 4/26/93 | 67 | A | Influent | | 7.21 | | | | 26.38 | 26.86 | | 0 | 0.671 | | 11.65 | | | 260.7 | | |
| | 67 | A | Anaerobic | 0.14 | 7.35 | | | | | 23.82 | | 0 | 0 | 22.69 | | | | 22.77 | | |
| | 67 | A | Anoxic | | 7.95 | | | | | 24 | | 0 | 0 | 0 | | | | 6.32 | | |
| | 67 | A | Aerobic | 6.4 | 8.1 | 1236 | 1156 | 35.02 | 21.3 | 22.57 | 1.19% | 0 | 0.031 | 0 | 0 | 67.5 | 8.43% | 6.262 | | |
| | 67 | A | Effluent | | 8.23 | 28 | 32 | | | 22.75 | | 0 | 0.011 | 0 | | | | 4.935 | | |
| | 70 | D | Influent | | 5.6 | | | | 26.38 | 26.86 | | 0 | 0 | | 34.95 | | | 234.1 | | |
| | 70 | D | Anaerobic | 0.15 | 7.43 | | | | | 22.64 | | 0 | 0 | 0 | | | | 26.37 | | |
| | 70 | D | Anoxic | | 7.73 | | | | | 23.12 | | 0 | 0 | 0 | | | | 15.49 | | |
| | 70 | D | Aerobic | 7.1 | 8.11 | 1176 | 1084 | 38.84 | 22.01 | 21.66 | 1.58% | 0 | 0.025 | 0 | 1.226 | 80.33 | 7.3% | 7.157 | | |
| | 70 | D | Effluent | | 8.15 | 28 | 20 | | | 22.76 | | 0 | 0.017 | 0 | | | | 7.129 | | |
| | 29 | E | Influent | | 7.2 | | | | 25.58 | 26.23 | | 0 | 0 | | 60.71 | | | 283.5 | | |
| | 29 | E | Anaerobic | 0.16 | 7.62 | | | | | 30.13 | | 0 | 0 | 4.908 | | | | 32.38 | | |
| | 29 | E | Anoxic | | 7.74 | | | | | 32.67 | | 0 | 0 | 25.14 | | | | 25.62 | | |
| | 29 | E | Aerobic | 5.7 | 7.98 | 1356 | 1240 | 43.91 | 21.95 | 20.79 | 1.77% | 4.262 | 1.47 | 16.56 | 19.62 | 78.49 | 4.75% | 9.004 | | |
| | 29 | E | Effluent | | 8.03 | 4 | 0 | | | 21.7 | | 4.754 | 1.72 | 16.09 | | | | 7.309 | | |
| | 1 | F | Influent | | 7.14 | | | | 27.68 | 28.61 | | 0 | 0.521 | | 68.3 | | | 276.9 | | |
| | 1 | F | Anaerobic | 0.12 | 7.11 | | | | | 51.36 | | 0 | 0.024 | 0 | | | | 25.07 | | |
| | 1 | F | Anoxic | | 7.16 | | | | | 56.33 | | 0 | 0.086 | 7.972 | | | | 17.8 | | |
| | 1 | F | Aerobic | 5.2 | 7.68 | 2524 | 1592 | 146.1 | 18.75 | 14.74 | 8.00% | 3.884 | 9.711 | 0 | 2.453 | 165.2 | 11.46% | 12.15 | | |
| | 1 | F | Effluent | | 7.74 | 0 | 0 | | | 15.58 | | 3.571 | 10.67 | 0 | | | | 9.61 | | |

Appendix A: Raw data for reactors A-F

| Date | Day | Reactor | Stage | D.O. | pH | TSS | VSS | Total P | Tot Sol P | PO4-P | %P | NO2-N | NO3-N | NH3-N | TKN | Total TKN | %N | Sol TOC | Temp (C) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5/6/93 | 95 | A | Influent | | 7.29 | | | | 28.04 | 27.74 | | 0 | 0.588 | 9.505 | | | | 278.2 | | |
| | 95 | A | Anaerobic | 0.16 | 7.61 | | | | | 24.48 | | 0 | 0 | 0 | | | | 9.34 | | |
| | 95 | A | Anoxic | | 8.14 | | | | | 23.5 | | 0 | 1.229 | 0 | | | | 2.804 | | |
| | 95 | A | Aerobic | 6.45 | 8.29 | 1028 | 956 | 39.13 | 22.27 | 22.36 | 1.76% | 0 | 1.426 | 0 | 3.066 | 84.39 | 6.41% | 1.765 | Const. temp room | |
| | 95 | A | Effluent | | 8.29 | 40 | 24 | | | 24.04 | | 0 | 2.621 | 0 | | | | 2.927 | @ 25-27C | |
| | 78 | D | Influent | | 7.28 | | | | 28.04 | 27.87 | | 0 | 0.582 | 9.505 | | | | 230.3 | | |
| | 78 | D | Anaerobic | 0.12 | 7.67 | | | | | 23.98 | | 0 | 0.011 | 13.49 | | | | 10.61 | | |
| | 78 | D | Anoxic | | 7.96 | | | | | 24.35 | | 0 | 0 | 15.33 | | | | 6.435 | | |
| | 78 | D | Aerobic | 5.25 | 8.24 | 1020 | 936 | 79.7 | 24.75 | 23.16 | 5.87% | 0 | 0.124 | 15.64 | 17.78 | 98.73 | 8.65% | 5.027 | | |
| | 78 | D | Effluent | | 8.23 | 32 | 12 | | | 23.45 | | 0 | 0.032 | 16.56 | | | | 5.742 | | |
| | 37 | E | Influent | | 7.25 | | | | 28.12 | 28.21 | | 0 | 0.607 | 11.038 | | | | 318.9 | | |
| | 37 | E | Anaerobic | 0.14 | 7.54 | | | | | 34.62 | | 0 | 0 | 21.46 | | | | 19.15 | | |
| | 37 | E | Anoxic | | 7.7 | | | | | 35.47 | | 0 | 0.016 | 24.53 | | | | 17.76 | | |
| | 37 | E | Aerobic | 6.31 | 7.98 | 1164 | 1060 | 50.31 | 23.1 | 23.65 | 2.57% | 0 | 0.626 | 19.93 | 22.08 | 88.88 | 4.40% | 6.457 | | |
| | 37 | E | Effluent | | 7.93 | 20 | 4 | | | 23.67 | | 5.082 | 0.946 | 18.92 | | | | 5.318 | | |
| | 9 | F | Influent | | 7.19 | | | | 30.37 | 30.51 | | 0 | 0.585 | 11.32 | | | | 306 | | |
| | 9 | F | Anaerobic | 0.2 | 7.32 | | | | | 46.71 | | 0 | 0.05 | 8.565 | | | | 11.19 | | |
| | 9 | F | Anoxic | | 7.42 | | | | | 56.73 | | 0 | 0.043 | 8.278 | | | | 6.538 | | |
| | 9 | F | Aerobic | 6.21 | 7.73 | 1778 | 1326 | 122.2 | 24.56 | 23.45 | 7.38% | 0 | 13.03 | 0 | 1.84 | 168 | 12.53% | 6.133 | | |
| | 9 | F | Effluent | | 7.72 | 12 | 8 | | | 23.86 | | 0 | 13.39 | 0 | | | | 7.821 | | |
| Date | Day | Reactor | Stage | D.O. | pH | TSS | VSS | Total P | Tot Sol P | PO4-P | %P | NO2-N | NO3-N | NH3-N | TKN | Total TKN | %N | Sol TOC | Temp (C) | Comments |
| 6/12/93 | 101 | A | Influent | | 7.09 | | | | | 25.83 | | 0 | 0.519 | 9.408 | | | | 299.2 | | |
| | 101 | A | Anaerobic | 0.1 | 7.66 | | | | | 22.69 | | 0 | 0.029 | 0 | | | | 18.07 | | |
| | 101 | A | Anoxic | | 8.21 | | | | | 23.04 | | 0 | 4.792 | 0 | | | | 4.143 | | |
| | 101 | A | Aerobic | 6.5 | 8.3 | 994 | 924 | 31.08 | 20.84 | 21 | 1.11% | 0 | 5.6 | 0 | 0 | 76.04 | 8.23% | 2.979 | Const. temp room | |
| | 101 | A | Effluent | | 8.22 | 24 | 20 | | | 22.54 | | 0 | 5.767 | 0 | | | | 2.846 | @ 25-27C | |
| | 84 | D | Influent | | 7.12 | | | | | 27.39 | | 0 | 0.521 | 9.198 | | | | 242.9 | | |
| | 84 | D | Anaerobic | 0.07 | 7.35 | | | | | 24.21 | | 0 | 0.022 | 17.17 | | | | 14.92 | | |
| | 84 | D | Anoxic | | 7.97 | | | | | 23.76 | | 0 | 0.016 | 17.46 | | | | 4.92 | | |
| | 84 | D | Aerobic | 6.7 | 8.16 | 1080 | 996 | 39.52 | 22.12 | 23.37 | 1.75% | 0 | 0.08 | 18.7 | 17.17 | 129.2 | 11.14% | 2.978 | | |
| | 84 | D | Effluent | | 8.13 | 8 | 12 | | | 22.82 | | 0 | 0.083 | 18.4 | | | | 5.082 | | |
| | 43 | E | Influent | | 7.1 | | | | | 29.03 | | 0 | 0.552 | 10.42 | | | | 335.2 | | |
| | 43 | E | Anaerobic | 0.07 | 7.76 | | | | | 34.63 | | 0 | 0.032 | 18.09 | | | | 18.19 | | |
| | 43 | E | Anoxic | | 7.96 | | | | | 35.96 | | 0 | 0.018 | 18.7 | | | | 14.34 | | |
| | 43 | E | Aerobic | 4.11 | 8.09 | 1400 | 1276 | 30.76 | 20.21 | 18.13 | 0.829% | 0.06 | 4.874 | 12.57 | 14.72 | 164.3 | 11.73% | 4.888 | | |
| | 43 | E | Effluent | | 8.04 | 8 | 8 | | | 18.39 | | 5.606 | 0.742 | 11.96 | | | | 5.632 | | |
| | 15 | F | Influent | | 7.13 | | | | | 30.05 | | 0 | 0.539 | 12.07 | | | | 359.2 | | |
| | 15 | F | Anaerobic | 0.08 | 7.46 | | | | | 46.78 | | 0 | 0.037 | 10.12 | | | | 14.85 | | |
| | 15 | F | Anoxic | | 7.52 | | | | | 53.33 | | 0 | 0.036 | 10.12 | | | | 10.19 | | |
| | 15 | F | Aerobic | 5.4 | 7.89 | 1464 | 1148 | 58.73 | 16.39 | 17.33 | 3.66% | 0 | 13.43 | 0 | 1.84 | 136.7 | 11.75% | 7.888 | | |
| | 15 | F | Effluent | | 7.78 | 8 | 8 | | | 17.82 | | 0 | 14.37 | 0 | | | | 8.61 | | |

Appendix A: Raw data for reactors A-F

| Date | Day | Reactor | Stage | D.O. | pH | TSS | VSS | Total P | Tot Sol P | PO4-P | %P | NO2-N | NO3-N | NH3-N | TKN | Total TKN | %N | Sol TOC | Temp (C) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 3/19/93 | 108 | A | Influent | | 7.46 | | | | | 23.09 | | 0 | 0.535 | 9.755 | | | | 280 | | |
| | 108 | A | Anaerobic | 0.08 | 7.46 | | | | | 24.87 | | 0 | 0.02 | 0 | | | | 17.57 | | *Error |
| | 108 | A | Anoxic | | 8.3 | | | | | 23.46 | | 0 | 0.02 | 0 | | | | 10.56 | | |
| | 108 | A | Aerobic | 7.83 | 8.34 | 1352 | 1266 | 47.37 | 24.02 | 23.61 | 1.84% | 0 | 0.013 | 0 | 0 | 0 | 0.00% | 8.835 | Const. temp room | |
| | 108 | A | Effluent | | 7.7 | 40* | 48* | | | 24.26 | | | | 0 | | | | 9.87 | @ 25-27C | |
| | 91 | D | Influent | | 7.73 | | | | | 28.91 | | 0 | 0.566 | 10.42 | | | | 247.8 | | |
| | 91 | D | Anaerobic | 0.07 | 7.76 | | | | | 25.96 | | 0 | 0.019 | 19.62 | | | | 13.31 | | |
| | 91 | D | Anoxic | | 8.33 | | | | | 25.29 | | 0 | 0.042 | 20.54 | | | | 10.57 | | |
| | 91 | D | Aerobic | 6.52 | 8.4 | 1168 | 1108 | 47.08 | 25.41 | 24.62 | 1.96% | 0 | 0.089 | 20.54 | 19.62 | 136.52 | 10.46% | 10.74 | | |
| | 91 | D | Effluent | | 8.17 | 20* | 24* | | | 24.88 | | 0 | 0.086 | 20.54 | | | | 10.86 | | |
| | 50 | E | Influent | | 7.44 | | | | | 29.01 | | 0 | 0.571 | 10.47 | | | | 331.7 | | |
| | 50 | E | Anaerobic | 0.1 | 7.85 | | | | | 43.53 | | 0 | 0.015 | 27.9 | | | | 12.96 | | |
| | 50 | E | Anoxic | | 8.19 | | | | | 42.86 | | 0 | 0.023 | 29.82 | | | | 12.37 | | |
| | 50 | E | Aerobic | 5.78 | 8.25 | 1736 | 1556 | 58.65 | 23.15 | 19.27 | 2.26% | 0.261 | 0.313 | 23.82 | 26.21 | 348.5 | 20.60% | 11.33 | | |
| | 50 | E | Effluent | | 8.15 | 32* | 36* | | | 21.13 | | | | 25.46 | | | | 11.1 | | |
| | 22 | F | Influent | | 7.43 | | | | | 30.63 | | 0 | 0.566 | 10.66 | | | | 325.3 | | |
| | 22 | F | Anaerobic | 0.1 | 7.56 | | | | | 35.01 | | 0 | 0 | 43.54 | | | | 27.47 | | |
| | 22 | F | Anoxic | | 7.92 | | | | | 30.89 | | 0 | 0 | 46.38 | | | | 32.44 | | |
| | 22 | F | Aerobic | 6.41 | 7.67 | 1276 | 1152 | 53.29 | 29.43 | 34.53 | 2.07% | 0 | 0.019 | 46.07 | 56.41 | 94.62 | 2.40% | 17.33 | | |
| | 22 | F | Effluent | | 7.92 | 32* | 40* | | | 34.89 | | 0 | 0.019 | 43.84 | | | | 16.86 | | |

| Date | Day | Reactor | Stage | D.O. | pH | TSS | VSS | Total P | Tot Sol P | PO4-P | %P | NO2-N | NO3-N | NH3-N | TKN | Total TKN | %N | Sol TOC | Temp (C) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5/24/93 | 115 | A | Influent | | 7.4 | | | | | 26.05 | | 0 | 0.058 | | | | | 316.3 | | |
| | 115 | A | Anaerobic | 0.15 | 7.33 | | | | | 23.55 | | 0 | 0.021 | 0 | | | | 17.83 | | |
| | 115 | A | Anoxic | | 7.83 | | | | | 26.45 | | 0.883 | 0.013 | 0 | | | | 88.24 | | |
| | 115 | A | Aerobic | 7.1 | 8.37 | 1324 | 1272 | 40.93 | 19.41 | 21.81 | 1.69% | 0 | 0.023 | 0 | 1.84 | 98.27 | 7.42% | 4.168 | | *Error |
| | 115 | A | Effluent | | | 48 | 44 | | | 22.72 | | 0 | 0.021 | 0 | | | | 5.246 | | |
| | 98 | D | Influent | | 7.36 | | | | | 27.18 | | 0 | 0.522 | | | | | 229.8 | | |
| | 98 | D | Anaerobic | 0.12 | 7.72 | | | | | 23.84 | | 0 | 0.011 | 15.15 | | | | 8.822 | | |
| | 98 | D | Anoxic | | 8.26 | | | | | 23.3 | | 0 | 0.026 | 17.91 | | | | 4.965 | | |
| | 98 | D | Aerobic | 4.96 | 8.42 | 1056 | 988 | 42.37 | 21.24 | 21.57 | 2.14% | 0 | 0.176 | 17.29 | 14.1 | 136.7 | 12.41% | 6.433 | | |
| | 98 | D | Effluent | | | 4 | 4 | | | 23.2 | | 0 | 0.213 | 17.88 | | | | 4.943 | | |
| | 57 | E | Influent | | 7.31 | | | | | 28.35 | | 0 | 0.578 | | | | | 305.7 | | |
| | 57 | E | Anaerobic | 0.12 | 7.68 | | | | | 42.19 | | 0 | 0.017 | 30.17 | | | | 12.9 | | |
| | 57 | E | Anoxic | | 7.84 | | | | | 41.64 | | 0 | 0.012 | 28.33 | | | | 9.086 | | |
| | 57 | E | Aerobic | 3.05 | 8.2 | 1636 | 1482 | 54.19 | 19.58 | 21.87 | 2.32% | 0 | 0.185 | 28.33 | 36.18 | 194.4 | 10.60% | 7.145 | | |
| | 57 | E | Effluent | | | 8.0* | 12* | | | 21.35 | | 0 | 0.198 | 24.98 | | | | 8.484 | | |
| | 29 | F | Influent | | 7.41 | | | | | 29.87 | | 0 | 0.502 | | | | | 312.3 | | |
| | 29 | F | Anaerobic | 0.13 | 7.76 | | | | | 27.42 | | 0 | 0.022 | 57.76 | | | | 39 | | |
| | 29 | F | Anoxic | | 7.94 | | | | | 27.09 | | 0 | 0.011 | 58.6 | | | | 37.06 | | |
| | 29 | F | Aerobic | 6.3 | 8.2 | 908 | 856 | 38.98 | 25.52 | 25.57 | 1.68% | 0 | 0.06 | 58.89 | 68.07 | 98.46 | 2.15% | 15.75 | | |
| | 29 | F | Effluent | | | 4 | 4 | | | 26.71 | | 0 | 0.045 | 48.57 | | | | 14.57 | | |

Appendix A: Raw data for reactors A-F

| Date | Day | Reactor | Stage | D.O. | pH | TSS | VSS | Total P | Tot Sol P | PO4-P | %P | NO2-N | NO3-N | NH3-N | TKN | Total TKN | %N | Sol TOC | Temp (C) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 5/31/93 | 120 | A | Influent | | | | | | | | | | | | | | | | | |
| | 120 | A | Anaerobic | 0.13 | 7.4 | | | | | 22.84 | | 0 | 0 | 0 | | | | 23.96 | | *Error |
| | 120 | A | Anoxic | | 7.79 | | | | | 22.89 | | 0 | 0 | 0 | | | | 10.14 | | |
| | 120 | A | Aerobic | 5.01 | 8.23 | 1264 | 1208 | 28.62 | 23.2 | 22.38 | 0.45% | 0 | 0 | 0 | 0 | 56.42 | 4.58% | 4.533 | Const. temp room | |
| | 120 | A | Effluent | | 8.28 | 44* | 48* | | | 22.81 | | 0 | 0 | 0 | | | | 3.821 | @ approx. 30C | |
| | 103 | D | Influent | | | | | | | | | | | | | | | | | |
| | 103 | D | Anaerobic | 0.13 | 7.66 | | | | | 24.16 | | 0 | 0 | 9.96 | | | | 8.073 | | |
| | 103 | D | Anoxic | | 7.85 | | | | | 24.06 | | 0 | 0 | 10.61 | | | | 10.68 | | |
| | 103 | D | Aerobic | 4.4 | 8.29 | 1116 | 1034 | 37.74 | 23.13 | 22.35 | 1.41% | 0 | 0 | 10.83 | 11.26 | 81.84 | 6.83% | 5.267 | | |
| | 103 | D | Effluent | | 8.3 | 8.0* | 16* | | | 25.13 | | 0 | 0 | 10.83 | | | | 4.706 | | |
| | 62 | E | Influent | | 7.2 | | | | | 29.63 | | 0 | 0.549 | | | | | 304.3 | | |
| | 62 | E | Anaerobic | 0.1 | 8.02 | | | | | 35.55 | | 0 | 0 | 19.46 | | | | 12.32 | | |
| | 62 | E | Anoxic | | 8.04 | | | | | 35.05 | | 0 | 0 | 20.35 | | | | 10.96 | | |
| | 62 | E | Aerobic | 5.5 | 8.5 | 1632 | 1320 | 31.95 | 24.38 | 24.16 | 0.57% | 0.123 | 0.103 | 14.89 | 21.22 | 111.71 | 6.86% | 7.009 | | |
| | 62 | E | Effluent | | 8.46 | 36* | 44* | | | 25.04 | | 0.162 | 0.118 | 19.46 | | | | 7.447 | | |
| | 34 | F | Influent | | 7.17 | | | | | 30.96 | | 0 | 0.564 | | | | | 313.4 | | |
| | 34 | F | Anaerobic | 0.12 | 7.8 | | | | | 26.85 | | 0 | 0 | 36.81 | | | | 19.86 | | |
| | 34 | F | Anoxic | | 7.87 | | | | | 27.99 | | 0 | 0 | 37.89 | | | | 18.6 | | |
| | 34 | F | Aerobic | 4.35 | 8.25 | 880 | 808 | 39.29 | 25.2 | 26.84 | 1.74% | 0 | 0.027 | 37.67 | 42 | 52.39 | 1.29% | 11.8 | | |
| | 34 | F | Effluent | | 8.26 | 24* | 38* | | | 26.92 | | 0 | 0.026 | 32.26 | | | | 11.89 | | |

| Date | Day | Reactor | Stage | D.O. | pH | TSS | VSS | Total P | Tot Sol P | PO4-P | %P | NO2-N | NO3-N | NH3-N | TKN | Total TKN | %N | Sol TOC | Temp (C) | Comments |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 6/11/93 | 131 | A | Influent | | 6.75 | | | | | 26.89 | | 0 | 0.318 | | | | | 272.1 | | |
| | 131 | A | Anaerobic | 0.07 | 7.38 | | | | | 25.52 | | 0 | 0.044 | 0 | | | | 57.2 | | |
| | 131 | A | Anoxic | | 7.7 | | | | | 25.41 | | 0 | 0.024 | 0 | | | | 29.85 | | |
| | 131 | A | Aerobic | 4.28 | | 1204 | 1192 | 32.06 | 23.54 | 23.9 | 0.71% | 0 | 0.036 | 0 | 0.43 | 24.68 | 2.03% | 8.132 | Const. temp room | |
| | 131 | A | Effluent | | | 32 | 24 | | | 23.71 | | 0 | 0 | 0 | | | | 6.561 | @ approx. 30C | |
| | 73 | E | Influent | | 7.61 | | | | | 26.55 | | 0 | 0.046 | | | | | 116.7 | | |
| | 73 | E | Anaerobic | 0.08 | 7.96 | | | | | 47.32 | | 0 | 0 | 31.16 | | | | 18.17 | | |
| | 73 | E | Anoxic | | 8.04 | | | | | 50.61 | | 0 | 0 | 24.9 | | | | 8.04 | | |
| | 73 | E | Aerobic | 5.81 | | 1612 | 1428 | 56.58 | 16.98 | 16.46 | 2.63% | 0 | 0.029 | 25.98 | 27.28 | 75.34 | 3.37% | 4.158 | | |
| | 73 | E | Effluent | | | 28 | 20 | | | 16.88 | | 0 | 0.024 | 26.41 | | | | 2.68 | | |
| | 46 | F | Influent | | 7.53 | | | | | 29.12 | | 0 | 0.062 | | | | | 265.9 | | |
| | 46 | F | Anaerobic | 0.06 | 7.91 | | | | | 30.27 | | 0 | 0.027 | 34.21 | | | | 21.85 | | |
| | 46 | F | Anoxic | | 7.94 | | | | | 28.78 | | 0 | 0 | 40.7 | | | | 14.74 | | |
| | 46 | F | Aerobic | 6.27 | | 828 | 796 | 36.38 | 26.15 | 26.81 | 1.38% | 0 | 0.041 | 38.4 | 41.57 | 63.22 | 3.34% | 6.053 | | |
| | 46 | F | Effluent | | | 0 | 0 | | | 27.29 | | 0 | 0.031 | 36.16 | | | | 3.774 | | |
| | 114 | D | Influent | | 6.84 | | | | | 26.85 | | 0 | 0 | | | | | 200.8 | | |
| | 114 | D | Anaerobic | 0.07 | 7.68 | | | | | 26.7 | | 0 | 0.046 | 12.77 | | | | 84.97 | | |
| | 114 | D | Anoxic | | 8 | | | | | 24.88 | | 0 | 0 | 13.42 | | | | 40.14 | | |
| | 114 | D | Aerobic | 4.43 | | 1306 | 1256 | 44.1 | 23.16 | 22.83 | 1.67% | 0 | 0.04 | 13.64 | 12.12 | 48.5 | 2.80% | 11.78 | | |
| | 114 | D | Effluent | | | 0 | 0 | | | 24.2 | | 0 | 0.05 | 13.42 | | | | 8.103 | | |

# Appendix B:

# Summary of Raw Data

# from Microscopic Analyses

| Date | Reactor | Stage | # Poly-P (*10^6) | Std. Dev. | % Error | # G-beat (10^6) | Std. Dev. | % Error |
|---|---|---|---|---|---|---|---|---|
| 2/8/93 | A | Influent | 0 | 0 | ERR | 0 | 0 | ERR |
| 2/8/93 | A | Anaerobic | 1622 | 484 | 29.86 | 792 | 176 | 22.17 |
| 2/8/93 | A | Anoxic | 1070 | 218 | 20.41 | 448 | 79 | 17.56 |
| 2/8/93 | A | Aerobic | 1366 | 303 | 22.19 | 830 | 95 | 11.46 |
| 2/8/93 | A | Effluent | 0 | 0 | ERR | 0 | 0 | ERR |
| 2/8/93 | B | Influent | 0 | 0 | ERR | 0 | 0 | ERR |
| 2/8/93 | B | Anaerobic | 1122 | 252 | 22.44 | 756 | 166 | 22.00 |
| 2/8/93 | B | Anoxic | 377 | 90 | 23.86 | 279 | 89 | 31.97 |
| 2/8/93 | B | Aerobic | 239 | 75 | 31.47 | 231 | 73 | 31.49 |
| 2/8/93 | B | Effluent | 35 | 10 | 27.67 | 29 | 8 | 27.71 |
| 2/17/93 | A | Influent | 0 | 0 | ERR | 0 | 0 | ERR |
| 2/17/93 | A | 8:30am | 1126 | 282 | 25.04 | 452 | 105 | 23.21 |
| 2/17/93 | A | Anaerobic | 509 | 174 | 34.20 | 473 | 159 | 33.66 |
| 2/17/93 | A | Anoxic | 492 | 170 | 34.66 | 594 | 119 | 20.10 |
| 2/17/93 | A | Aerobic | 1610 | 348 | 21.59 | 751 | 208 | 27.65 |
| 2/17/93 | A | Effluent | 19 | 5 | 26.20 | 15 | 5 | 36.42 |
| 2/17/93 | B | Influent | 0 | 0 | ERR | 0 | 0 | ERR |
| 2/17/93 | B | 8:30am | 342 | 35 | 10.26 | 377 | 85 | 22.59 |
| 2/17/93 | B | Anaerobic | 470 | 139 | 29.66 | 640 | 185 | 28.92 |
| 2/17/93 | B | Anoxic | 166 | 50 | 30.00 | 215 | 33 | 15.31 |
| 2/17/93 | B | Aerobic | 554 | 151 | 27.19 | 403 | 109 | 27.13 |
| 2/17/93 | B | Effluent | 54 | 14 | 25.68 | 34 | 11 | 33.31 |
| 2/18/93 | C | Influent | 0 | 0 | ERR | 0 | 0 | ERR |
| 2/18/93 | C | Anaerobic | 926 | 353 | 38.15 | 443 | 130 | 29.27 |
| 2/18/93 | C | Anoxic | 1773 | 561 | 31.62 | 296 | 95 | 31.95 |
| 2/18/93 | C | Aerobic | 1533 | 479 | 31.24 | 405 | 124 | 30.54 |
| 2/18/93 | C | Effluent | 15 | 4 | 27.36 | 14 | 4 | 30.63 |
| 2/18/93 | D | Influent | 0 | 0 | ERR | 0 | 0 | ERR |
| 2/18/93 | D | Anaerobic | 2060 | 440 | 21.34 | 387 | 107 | 27.65 |
| 2/18/93 | D | Anoxic | 1260 | 384 | 30.46 | 377 | 78 | 20.65 |
| 2/18/93 | D | Aerobic | 1113 | 371 | 33.31 | 258 | 103 | 39.80 |
| 2/18/93 | D | Effluent | 33 | 10 | 29.42 | 24 | 8 | 34.71 |
| 2/22/93 | A | Influent | 0 | 0 | ERR | 0 | 0 | ERR |
| 2/22/93 | A | Anaerobic | 1069 | 333 | 31.13 | 609 | 137 | 22.50 |
| 2/22/93 | A | Anoxic | 1494 | 426 | 28.49 | 672 | 119 | 17.65 |
| 2/22/93 | A | Aerobic | 911 | 276 | 30.31 | 364 | 101 | 28.30 |
| 2/22/93 | A | Effluent | 21 | 4 | 20.61 | 29 | 10 | 33.61 |
| 2/22/93 | B* | Influent | 8 | 4 | 48.62 | 3 | 3 | 97.24 |
| 2/22/93 | B | Anaerobic | 419 | 122 | 29.19 | 495 | 159 | 32.19 |
| 2/22/93 | B | Anoxic | 434 | 104 | 23.86 | 289 | 90 | 31.30 |
| 2/22/93 | B | Aerobic | 379 | 95 | 25.16 | 655 | 187 | 28.61 |
| 2/22/93 | B | Effluent | 11 | 4 | 35.84 | 12 | 4 | 35.54 |

| Date | Reactor | Stage | # Poly-P (*10^6) | Std. Dev. | % Error | # G-beat (10^6) | Std. Dev. | % Error |
|---|---|---|---|---|---|---|---|---|
| 2/26/93 | C | Influent | 12 | 4 | 29.32 | 18 | 4 | 23.90 |
| 2/26/93 | C | Anaerobic | 686 | 210 | 30.59 | 442 | 102 | 23.15 |
| 2/26/93 | C | Anoxic | 1083 | 264 | 24.42 | 675 | 64 | 9.42 |
| 2/26/93 | C | Aerobic | 1752 | 542 | 30.91 | 789 | 82 | 10.36 |
| 2/26/93 | C | Effluent | 21 | 7 | 31.67 | 67 | 18 | 20.96 |
| 2/26/93 | D | Influent | 12 | 4 | 30.79 | 38 | 11 | 28.38 |
| 2/26/93 | D | Anaerobic | 1147 | 262 | 22.86 | 596 | 105 | 17.59 |
| 2/26/93 | D | Anoxic | 572 | 148 | 25.86 | 796 | 194 | 24.27 |
| 2/26/93 | D | Aerobic | 857 | 246 | 28.75 | 754 | 127 | 16.80 |
| 2/26/93 | D | Effluent | 18 | 6 | 31.56 | 59 | 23 | 39.39 |
| 3/1/93 | A | Influent | 0 | 0 | ERR | 0 | 0 | ERR |
| 3/1/93 | A | Anaerobic | 1347 | 282 | 20.93 | 1026 | 298 | 29.02 |
| 3/1/93 | A | Anoxic | 212 | 26 | 12.20 | 694 | 104 | 15.06 |
| 3/1/93 | A | Aerobic | 817 | 176 | 21.56 | 607 | 139 | 22.96 |
| 3/1/93 | A | Effluent | 10 | 3 | 31.46 | 30 | 8 | 26.17 |
| 3/1/93 | B | Influent | 5 | 1 | 28.27 | 10 | 4 | 39.92 |
| 3/1/93 | B | Anaerobic | 150 | 34 | 22.41 | 620 | 150 | 24.22 |
| 3/1/93 | B | Anoxic | 126 | 32 | 25.32 | 413 | 96 | 23.13 |
| 3/1/93 | B | Aerobic | 180 | 39 | 21.53 | 706 | 171 | 24.20 |
| 3/1/93 | B | Effluent | 16 | 5 | 29.21 | 77 | 22 | 28.21 |
| 3/5/93 | C | Influent | 9 | 3 | 29.17 | 14 | 5 | 39.96 |
| 3/5/93 | C | Anaerobic | 266 | 48 | 18.12 | 718 | 145 | 20.15 |
| 3/5/93 | C | Anoxic | 403 | 81 | 20.21 | 757 | 231 | 30.50 |
| 3/5/93 | C | Aerobic | 617 | 181 | 29.30 | 716 | 143 | 19.97 |
| 3/5/93 | C | Effluent | 26 | 5 | 21.04 | 30 | 8 | 27.04 |
| 3/5/93 | D | Influent | 13 | 3 | 23.37 | 107 | 15 | 13.56 |
| 3/5/93 | D | Anaerobic | 783 | 230 | 29.39 | 814 | 149 | 18.34 |
| 3/5/93 | D | Anoxic | 361 | 44 | 12.31 | 660 | 128 | 19.43 |
| 3/5/93 | D | Aerobic | 673 | 161 | 23.90 | 426 | 82 | 19.14 |
| 3/5/93 | D | Effluent | 26 | 5 | 16.87 | 27 | 4 | 16.21 |
| 3/8/93 | A | Influent | 16 | 5 | 32.33 | 27 | 7 | 24.58 |
| 3/8/93 | A | Anaerobic | 403 | 94 | 23.28 | 840 | 95 | 11.35 |
| 3/8/93 | A | Anoxic | 444 | 112 | 25.19 | 615 | 68 | 11.10 |
| 3/8/93 | A | Aerobic | 462 | 117 | 25.41 | 537 | 112 | 20.91 |
| 3/8/93 | A | Effluent | 20 | 4 | 20.61 | 67 | 17 | 24.85 |
| 3/8/93 | B | Influent | 36 | 9 | 25.13 | 95 | 13 | 14.08 |
| 3/8/93 | B | Anaerobic | 214 | 50 | 23.39 | 365 | 62 | 16.91 |
| 3/8/93 | B | Anoxic | 126 | 40 | 31.80 | 466 | 136 | 29.61 |
| 3/8/93 | B | Aerobic | 133 | 35 | 26.29 | 325 | 77 | 23.66 |
| 3/8/93 | B | Effluent | 20 | 5 | 24.19 | 33 | 10 | 29.61 |

| Date | Reactor | Stage | # Poly-P (*10^6) | Std. Dev. | % Error | # G-bact (10^6) | Std. Dev. | % Error |
|---|---|---|---|---|---|---|---|---|
| 3/12/93 | C | Influent | 24 | 7 | 31.09 | 223 | 37 | 16.75 |
| 3/12/93 | C | Anaerobic | 205 | 64 | 30.94 | 706 | 122 | 17.22 |
| 3/12/93 | C | Anoxic | 219 | 47 | 21.44 | 821 | 160 | 19.53 |
| 3/12/93 | C | Aerobic | 680 | 186 | 27.67 | 1479 | 362 | 24.50 |
| 3/12/93 | C | Effluent | 72 | 17 | 23.66 | 127 | 22 | 17.59 |
| 3/12/93 | D | Influent | 22 | 4 | 16.76 | 86 | 22 | 25.13 |
| 3/12/93 | D | Anaerobic | 289 | 29 | 10.13 | 786 | 101 | 12.86 |
| 3/12/93 | D | Anoxic | 315 | 42 | 13.47 | 654 | 105 | 16.02 |
| 3/12/93 | D | Aerobic | 461 | 79 | 16.35 | 1232 | 299 | 24.23 |
| 3/12/93 | D | Effluent | 131 | 40 | 30.64 | 195 | 12 | 6.01 |
| 3/16/93 | A | Influent | 50 | 9 | 18.11 | 106 | 26 | 24.90 |
| 3/16/93 | A | Anaerobic | 271 | 29 | 10.80 | 551 | 172 | 31.26 |
| 3/16/93 | A | Anoxic | 589 | 76 | 12.97 | 846 | 106 | 12.50 |
| 3/16/93 | A | Aerobic | 416 | 50 | 12.12 | 519 | 24 | 4.59 |
| 3/16/93 | A | Effluent | 30 | 5 | 17.37 | 34 | 4 | 10.57 |
| 3/16/93 | B | Influent | 36 | 9 | 23.97 | 67 | 22 | 24.94 |
| 3/16/93 | B | Anaerobic | 129 | 21 | 16.27 | 360 | 84 | 23.36 |
| 3/16/93 | B | Anoxic | 378 | 101 | 26.83 | 610 | 141 | 23.06 |
| 3/16/93 | B | Aerobic | 267 | 42 | 14.62 | 494 | 49 | 9.97 |
| 3/16/93 | B | Effluent | 35 | 6 | 18.15 | 66 | 17 | 26.94 |
| 3/19/93 | C | Influent | 61 | 18 | 29.94 | 95 | 16 | 17.15 |
| 3/19/93 | C | Anaerobic | 1416 | 441 | 31.12 | 1694 | 214 | 12.60 |
| 3/19/93 | C | Anoxic | 489 | 76 | 15.58 | 807 | 85 | 10.56 |
| 3/19/93 | C | Aerobic | 446 | 36 | 8.56 | 557 | 81 | 14.52 |
| 3/19/93 | C | Effluent | 31 | 4 | 12.64 | 49 | 6 | 13.29 |
| 3/19/93 | D | Influent | 36 | 9 | 25.79 | 42 | 7 | 17.02 |
| 3/19/93 | D | Anaerobic | 348 | 85 | 24.49 | 369 | 103 | 28.57 |
| 3/19/93 | D | Anoxic | 279 | 35 | 12.46 | 375 | 47 | 12.43 |
| 3/19/93 | D | Aerobic | 344 | 20 | 5.78 | 854 | 161 | 18.89 |
| 3/19/93 | D | Effluent | 20 | 5 | 26.50 | 26 | 8 | 31.71 |
| 3/22/93 | A | Influent | 30 | 5 | 16.59 | 62 | 12 | 22.62 |
| 3/22/93 | A | Anaerobic | 247 | 30 | 12.34 | 509 | 90 | 17.61 |
| 3/22/93 | A | Anoxic | 484 | 101 | 20.93 | 789 | 221 | 28.03 |
| 3/22/93 | A | Aerobic | 406 | 50 | 12.22 | 781 | 146 | 18.72 |
| 3/22/93 | A | Effluent | 41 | 6 | 13.46 | 74 | 4 | 6.03 |
| 3/22/93 | B | Influent | 23 | 4 | 15.95 | 36 | 7 | 19.02 |
| 3/22/93 | B | Anaerobic | 154 | 22 | 14.43 | 812 | 126 | 15.47 |
| 3/22/93 | B | Anoxic | 236 | 44 | 18.66 | 677 | 205 | 30.36 |
| 3/22/93 | B | Aerobic | 190 | 47 | 24.69 | 476 | 123 | 25.79 |
| 3/22/93 | B | Effluent | 73 | 18 | 25.00 | 144 | 31 | 21.29 |

| Date | Reactor | Stage | # Poly-P (*10^6) | Std. Dev. | % Error | # G-bact (10^6) | Std. Dev. | % Error |
|---|---|---|---|---|---|---|---|---|
| 3/31/93 | A | Influent | 41 | 7 | 17.86 | 104 | 20 | 19.30 |
| 3/31/93 | A | Anaerobic | 856 | 260 | 30.42 | 1680 | 349 | 20.79 |
| 3/31/93 | A | Anoxic | 393 | 43 | 10.95 | 595 | 118 | 19.92 |
| 3/31/93 | A | Aerobic | 596 | 139 | 23.33 | 928 | 169 | 18.18 |
| 3/31/93 | A | Effluent | 33 | 4 | 11.33 | 79 | 7 | 8.75 |
| 3/31/93 | C | Influent | 19 | 3 | 15.42 | 41 | 9 | 21.67 |
| 3/31/93 | C | Anaerobic | 240 | 44 | 18.18 | 554 | 84 | 15.22 |
| 3/31/93 | C | Anoxic | 326 | 40 | 12.13 | 472 | 140 | 29.66 |
| 3/31/93 | C | Aerobic | 362 | 73 | 20.27 | 769 | 93 | 12.12 |
| 3/31/93 | C | Effluent | 37 | 4 | 11.00 | 105 | 25 | 24.18 |
| 3/31/93 | D | Influent | 26 | 3 | 11.11 | 56 | 12 | 21.47 |
| 3/31/93 | D | Anaerobic | 221 | 35 | 16.04 | 394 | 114 | 29.02 |
| 3/31/93 | D | Anoxic | 412 | 60 | 14.50 | 1012 | 161 | 15.86 |
| 3/31/93 | D | Aerobic | 792 | 225 | 28.37 | 936 | 80 | 8.51 |
| 3/31/93 | D | Effluent | 40 | 6 | 14.16 | 90 | 26 | 29.40 |
| 3/31/93 | E | Influent | 36 | 6 | 16.13 | 89 | 10 | 11.48 |
| 3/31/93 | E | Anaerobic | 1116 | 296 | 26.62 | 504 | 64 | 12.77 |
| 3/31/93 | E | Anoxic | 731 | 181 | 24.81 | 387 | 57 | 14.63 |
| 3/31/93 | E | Aerobic | 963 | 303 | 31.43 | 548 | 76 | 13.93 |
| 3/31/93 | E | Effluent | 35 | 7 | 19.34 | 92 | 17 | 18.45 |
| 4/7/93 | A | Influent | 52 | 17 | 33.49 | 107 | 13 | 12.25 |
| 4/7/93 | A | Anaerobic | 354 | 78 | 21.91 | 549 | 116 | 21.18 |
| 4/7/93 | A | Anoxic | 421 | 113 | 26.92 | 710 | 113 | 15.99 |
| 4/7/93 | A | Aerobic | 556 | 124 | 22.39 | 918 | 153 | 16.64 |
| 4/7/93 | A | Effluent | 61 | 4 | 6.04 | 119 | 23 | 19.33 |
| 4/7/93 | C | Influent | 31 | 6 | 18.04 | 55 | 10 | 18.10 |
| 4/7/93 | C | Anaerobic | 190 | 23 | 12.18 | 549 | 86 | 15.61 |
| 4/7/93 | C | Anoxic | 175 | 45 | 25.51 | 487 | 73 | 14.95 |
| 4/7/93 | C | Aerobic | 230 | 43 | 18.59 | 640 | 55 | 8.55 |
| 4/7/93 | C | Effluent | 21 | 6 | 29.55 | 58 | 12 | 20.00 |
| 4/7/93 | D | Influent | 40 | 8 | 21.18 | 78 | 17 | 21.46 |
| 4/7/93 | D | Anaerobic | 251 | 48 | 19.25 | 649 | 74 | 11.40 |
| 4/7/93 | D | Anoxic | 336 | 46 | 13.74 | 739 | 88 | 11.93 |
| 4/7/93 | D | Aerobic | 474 | 117 | 24.66 | 487 | 148 | 30.37 |
| 4/7/93 | D | Effluent | 32 | 3 | 10.57 | 69 | 7 | 9.61 |
| 4/7/93 | E | Influent | 40 | 11 | 26.25 | 96 | 14 | 14.06 |
| 4/7/93 | E | Anaerobic | 936 | 209 | 22.28 | 444 | 69 | 15.65 |
| 4/7/93 | E | Anoxic | 510 | 106 | 21.19 | 620 | 117 | 18.79 |
| 4/7/93 | E | Aerobic | 1244 | 378 | 30.36 | 676 | 50 | 7.45 |
| 4/7/93 | E | Effluent | 24 | 7 | 28.96 | 31 | 9 | 28.79 |

| Date | Reactor | Stage | # Poly-P (*10^6) | Std. Dev. | % Error | # G-beat (10^6) | Std. Dev. | % Error |
|---|---|---|---|---|---|---|---|---|
| 4/14/93 | A | Influent | 44 | 11 | 24.95 | 45 | 10 | 21.65 |
| 4/14/93 | A | Anaerobic | 247 | 50 | 20.11 | 315 | 68 | 21.40 |
| 4/14/93 | A | Anoxic | 518 | 143 | 27.68 | 459 | 107 | 23.23 |
| 4/14/93 | A | Aerobic | 635 | 117 | 18.45 | 777 | 103 | 13.33 |
| 4/14/93 | A | Effluent | 6 | 2 | 27.50 | 3 | 2 | 54.59 |
| | | | | | | | | |
| 4/14/93 | C | Influent | 23 | 7 | 30.61 | 29 | 10 | 34.60 |
| 4/14/93 | C | Anaerobic | 226 | 64 | 28.45 | 253 | 67 | 26.38 |
| 4/14/93 | C | Anoxic | 334 | 88 | 26.32 | 493 | 109 | 22.17 |
| 4/14/93 | C | Aerobic | 346 | 97 | 28.01 | 394 | 90 | 22.92 |
| 4/14/93 | C | Effluent | 10 | 2 | 19.89 | 1 | 1 | 70.00 |
| | | | 0 | 0 | ERR | 0 | 0 | ERR |
| 4/14/93 | D | Influent | 14 | 3 | 24.47 | 17 | 4 | 24.06 |
| 4/14/93 | D | Anaerobic | 249 | 42 | 16.87 | 355 | 58 | 16.45 |
| 4/14/93 | D | Anoxic | 549 | 167 | 30.48 | 460 | 80 | 17.42 |
| 4/14/93 | D | Aerobic | 511 | 146 | 28.51 | 496 | 73 | 14.81 |
| 4/14/93 | D | Effluent | 7 | 3 | 40.38 | 4 | 3 | 70.31 |
| | | | 0 | 0 | ERR | 0 | 0 | ERR |
| 4/14/93 | E | Influent | 20 | 4 | 21.54 | 24 | 7 | 29.94 |
| 4/14/93 | E | Anaerobic | 282 | 58 | 20.68 | 321 | 31 | 9.60 |
| 4/14/93 | E | Anoxic | 266 | 39 | 14.69 | 523 | 46 | 8.83 |
| 4/14/93 | E | Aerobic | 855 | 248 | 29.04 | 503 | 73 | 14.51 |
| 4/14/93 | E | Effluent | 0 | 0 | ERR | 0 | 0 | ERR |
| | | | 0 | 0 | ERR | 0 | 0 | ERR |
| 4/21/93 | A | Influent | 0 | 0 | ERR | 0 | 0 | ERR |
| 4/21/93 | A | Anaerobic | 699 | 135 | 19.35 | 822 | 184 | 22.34 |
| 4/21/93 | A | Anoxic | 472 | 66 | 14.06 | 684 | 116 | 16.96 |
| 4/21/93 | A | Aerobic | 666 | 155 | 22.63 | 1228 | 110 | 8.95 |
| 4/21/93 | A | Effluent | 61 | 15 | 24.54 | 92 | 17 | 18.15 |
| | | | | | | | | |
| 4/21/93 | C | Influent | 0 | 0 | ERR | 0 | 0 | ERR |
| 4/21/93 | C | Anaerobic | 423 | 80 | 18.93 | 1054 | 103 | 9.75 |
| 4/21/93 | C | Anoxic | 423 | 64 | 15.13 | 640 | 97 | 15.24 |
| 4/21/93 | C | Aerobic | 384 | 64 | 16.55 | 440 | 132 | 30.03 |
| 4/21/93 | C | Effluent | 34 | 4 | 11.56 | 75 | 13 | 17.45 |
| | | | 0 | 0 | ERR | 0 | 0 | ERR |
| 4/21/93 | D | Influent | 0 | 0 | ERR | 0 | 0 | ERR |
| 4/21/93 | D | Anaerobic | 625 | 109 | 17.43 | 848 | 186 | 21.92 |
| 4/21/93 | D | Anoxic | 611 | 186 | 30.43 | 637 | 58 | 9.16 |
| 4/21/93 | D | Aerobic | 536 | 152 | 28.40 | 576 | 71 | 12.26 |
| 4/21/93 | D | Effluent | 35 | 10 | 26.94 | 56 | 12 | 22.21 |
| | | | 0 | 0 | ERR | 0 | 0 | ERR |
| 4/21/93 | E | Influent | 0 | 0 | ERR | 0 | 0 | ERR |
| 4/21/93 | E | Anaerobic | 728 | 202 | 27.72 | 804 | 92 | 11.49 |
| 4/21/93 | E | Anoxic | 465 | 113 | 24.20 | 725 | 100 | 13.76 |
| 4/21/93 | E | Aerobic | 706 | 113 | 15.89 | 691 | 60 | 8.73 |
| 4/21/93 | E | Effluent | 43 | 4 | 9.49 | 78 | 11 | 14.73 |

| Date | Reactor | Stage | # Poly-P (*10^6) | Std. Dev. | % Error | # G-beat (10^6) | Std. Dev. | % Error |
|---|---|---|---|---|---|---|---|---|
| 4/28/93 | A | Influent | 96 | 22 | 23.00 | 142 | 32 | 22.24 |
| 4/28/93 | A | Anaerobic | 571 | 90 | 15.82 | 1344 | 330 | 24.52 |
| 4/28/93 | A | Anoxic | 570 | 143 | 25.15 | 781 | 124 | 15.85 |
| 4/28/93 | A | Aerobic | 605 | 96 | 15.94 | 1526 | 406 | 26.63 |
| 4/28/93 | A | Effluent | 18 | 6 | 31.70 | 29 | 8 | 29.48 |
| | | | | | | | | |
| 4/28/93 | D | Influent | 137 | 25 | 18.04 | 239 | 45 | 18.82 |
| 4/28/93 | D | Anaerobic | 561 | 164 | 29.15 | 972 | 205 | 21.07 |
| 4/28/93 | D | Anoxic | 480 | 107 | 22.38 | 819 | 224 | 27.29 |
| 4/28/93 | D | Aerobic | 514 | 72 | 13.96 | 677 | 95 | 14.09 |
| 4/28/93 | D | Effluent | 14 | 2 | 14.36 | 5 | 1 | 15.22 |
| | | | | | | | | |
| 4/28/93 | E | Influent | 91 | 23 | 25.62 | 169 | 36 | 21.52 |
| 4/28/93 | E | Anaerobic | 522 | 149 | 28.57 | 1068 | 306 | 28.66 |
| 4/28/93 | E | Anoxic | 625 | 185 | 29.61 | 845 | 230 | 27.23 |
| 4/28/93 | E | Aerobic | 489 | 86 | 17.59 | 622 | 171 | 27.43 |
| 4/28/93 | E | Effluent | 7 | 2 | 34.55 | 3 | 1 | 35.35 |
| | | | | | | | | |
| 4/28/93 | F | Influent | 95 | 21 | 22.55 | 198 | 54 | 27.29 |
| 4/28/93 | F | Anaerobic | 670 | 91 | 13.60 | 1042 | 159 | 15.24 |
| 4/28/93 | F | Anoxic | 610 | 91 | 14.86 | 1121 | 178 | 15.90 |
| 4/28/93 | F | Aerobic | 601 | 114 | 19.00 | 1122 | 190 | 16.89 |
| 4/28/93 | F | Effluent | 12 | 1 | 12.13 | 6 | 2 | 28.20 |
| | | | | | | | | |
| 5/6/93 | A | Influent | 0 | 0 | ERR | 0 | 0 | ERR |
| 5/6/93 | A | Anaerobic | 1122 | 195 | 17.36 | 1220 | 369 | 30.23 |
| 5/6/93 | A | Anoxic | 846 | 170 | 20.17 | 772 | 174 | 22.61 |
| 5/6/93 | A | Aerobic | 840 | 91 | 10.86 | 849 | 171 | 20.14 |
| 5/6/93 | A | Effluent | 97 | 6 | 5.77 | 151 | 26 | 17.08 |
| | | | | | | | | |
| 5/6/93 | D | Influent | 33 | 8 | 23.58 | 95 | 26 | 27.21 |
| 5/6/93 | D | Anaerobic | 458 | 64 | 13.99 | 646 | 98 | 15.21 |
| 5/6/93 | D | Anoxic | 820 | 211 | 25.70 | 852 | 122 | 14.30 |
| 5/6/93 | D | Aerobic | 757 | 25 | 3.33 | 1127 | 320 | 28.43 |
| 5/6/93 | D | Effluent | 96 | 22 | 23.00 | 90 | 26 | 29.24 |
| | | | | | | | | |
| 5/6/93 | E | Influent | 0 | 0 | ERR | 0 | 0 | ERR |
| 5/6/93 | E | Anaerobic | 804 | 141 | 17.58 | 717 | 174 | 24.32 |
| 5/6/93 | E | Anoxic | 679 | 128 | 18.81 | 746 | 133 | 17.84 |
| 5/6/93 | E | Aerobic | 649 | 109 | 16.82 | 858 | 48 | 5.63 |
| 5/6/93 | E | Effluent | 79 | 24 | 30.17 | 110 | 10 | 9.06 |
| | | | | | | | | |
| 5/6/93 | F | Influent | 59 | 8 | 14.06 | 59 | 16 | 27.80 |
| 5/6/93 | F | Anaerobic | 658 | 166 | 25.22 | 876 | 128 | 14.65 |
| 5/6/93 | F | Anoxic | 631 | 161 | 25.59 | 660 | 119 | 18.08 |
| 5/6/93 | F | Aerobic | 704 | 115 | 16.35 | 1166 | 171 | 14.65 |
| 5/6/93 | F | Effluent | 119 | 23 | 19.16 | 118 | 11 | 9.20 |

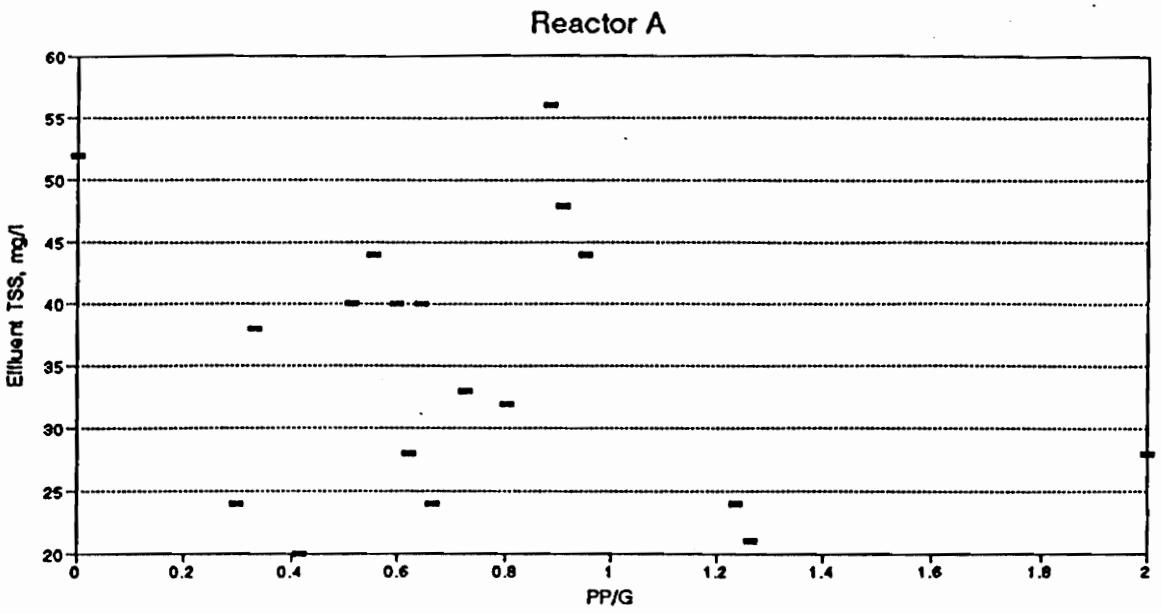
| Date | Reactor | Stage | # Poly-P (*10^6) | Std. Dev. | % Error | # -bact (10^6) | Std. Dev. | % Error |
|---|---|---|---|---|---|---|---|---|
| 5/12/93 | A | Influent | 0 | 0 | ERR | 0 | 0 | ERR |
| 5/12/93 | A | Anaerobic | 652 | 100 | 15.40 | 1116 | 251 | 22.51 |
| 5/12/93 | A | Anoxic | 809 | 186 | 23.00 | 1114 | 324 | 29.09 |
| 5/12/93 | A | Aerobic | 875 | 232 | 26.57 | 966 | 117 | 12.09 |
| 5/12/93 | A | Effluent | 84 | 19 | 22.35 | 66 | 8 | 12.40 |
| 5/12/93 | D | Influent | 0 | 0 | ERR | 0 | 0 | ERR |
| 5/12/93 | D | Anaerobic | 555 | 94 | 16.91 | 747 | 107 | 14.29 |
| 5/12/93 | D | Anoxic | 567 | 119 | 21.06 | 670 | 114 | 16.99 |
| 5/12/93 | D | Aerobic | 541 | 94 | 17.35 | 466 | 130 | 27.89 |
| 5/12/93 | D | Effluent | 39 | 9 | 22.82 | 48 | 11 | 22.33 |
| 5/12/93 | E | Influent | 21 | 7 | 33.08 | 51 | 4 | 8.84 |
| 5/12/93 | E | Anaerobic | 979 | 194 | 19.76 | 1330 | 203 | 15.25 |
| 5/12/93 | E | Anoxic | 683 | 107 | 15.66 | 684 | 150 | 21.99 |
| 5/12/93 | E | Aerobic | 596 | 43 | 7.26 | 491 | 80 | 16.27 |
| 5/12/93 | E | Effluent | 70 | 15 | 21.17 | 103 | 15 | 14.76 |
| 5/12/93 | F | Influent | 0 | 0 | ERR | 0 | 0 | ERR |
| 5/12/93 | F | Anaerobic | 692 | 104 | 15.04 | 919 | 101 | 11.04 |
| 5/12/93 | F | Anoxic | 1004 | 125 | 12.46 | 590 | 85 | 14.40 |
| 5/12/93 | F | Aerobic | 747 | 76 | 10.12 | 769 | 134 | 17.47 |
| 5/12/93 | F | Effluent | 67 | 16 | 24.35 | 83 | 14 | 17.09 |
| 5/19/93 | A | Influent | 76 | 12 | 16.11 | 97 | 20 | 21.04 |
| 5/19/93 | A | Anaerobic | 644 | 89 | 13.80 | 899 | 25 | 2.75 |
| 5/19/93 | A | Anoxic | 1227 | 250 | 20.42 | 2052 | 622 | 30.30 |
| 5/19/93 | A | Aerobic | 881 | 176 | 19.94 | 1242 | 317 | 25.53 |
| 5/19/93 | A | Effluent | 94 | 15 | 15.84 | 158 | 31 | 19.72 |
| 5/19/93 | D | Influent | 68 | 14 | 20.74 | 139 | 26 | 18.47 |
| 5/19/93 | D | Anaerobic | 628 | 176 | 27.99 | 1041 | 151 | 14.50 |
| 5/19/93 | D | Anoxic | 476 | 100 | 20.94 | 570 | 158 | 27.75 |
| 5/19/93 | D | Aerobic | 483 | 135 | 27.88 | 691 | 127 | 18.33 |
| 5/19/93 | D | Effluent | 73 | 19 | 25.67 | 88 | 15 | 16.71 |
| 5/19/93 | E | Influent | 133 | 33 | 25.13 | 153 | 18 | 11.92 |
| 5/19/93 | E | Anaerobic | 451 | 96 | 21.34 | 815 | 154 | 18.83 |
| 5/19/93 | E | Anoxic | 821 | 164 | 19.97 | 1064 | 212 | 19.54 |
| 5/19/93 | E | Aerobic | 906 | 81 | 8.92 | 1533 | 463 | 30.23 |
| 5/19/93 | E | Effluent | 44 | 7 | 15.41 | 68 | 11 | 16.90 |
| 5/19/93 | F | Influent | 74 | 20 | 27.36 | 95 | 16 | 16.36 |
| 5/19/93 | F | Anaerobic | 712 | 187 | 26.21 | 806 | 132 | 16.39 |
| 5/19/93 | F | Anoxic | 683 | 141 | 20.71 | 780 | 89 | 11.40 |
| 5/19/93 | F | Aerobic | 624 | 156 | 24.93 | 793 | 100 | 12.55 |
| 5/19/93 | F | Effluent | 95 | 26 | 27.39 | 88 | 11 | 12.89 |

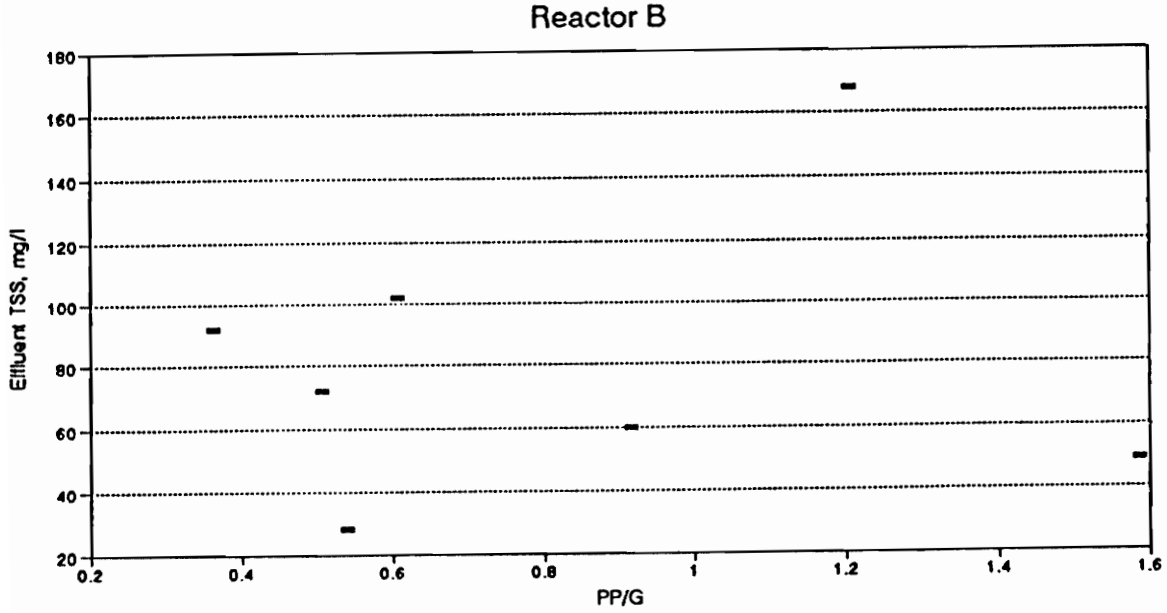
| Date | Reactor | Stage | # Poly-P (*10^6) | Std. Dev. | % Error | # -bact (10^6) | Std. Dev. | % Error |
|---|---|---|---|---|---|---|---|---|
| 5/26/93 | A | Influent | 95 | 23 | 24.57 | 131 | 25 | 18.84 |
| 5/26/93 | A | Anaerobic | 848 | 200 | 23.62 | 1217 | 189 | 15.55 |
| 5/26/93 | A | Anoxic | 724 | 174 | 23.98 | 667 | 89 | 13.41 |
| 5/26/93 | A | Aerobic | 1267 | 174 | 13.52 | 1227 | 353 | 28.79 |
| 5/26/93 | A | Effluent | 88 | 19 | 21.54 | 97 | 27 | 27.86 |
| 5/26/93 | D | Influent | 119 | 25 | 21.00 | 121 | 16 | 13.24 |
| 5/26/93 | D | Anaerobic | 989 | 135 | 13.60 | 1210 | 249 | 20.57 |
| 5/26/93 | D | Anoxic | 642 | 150 | 23.31 | 747 | 138 | 18.45 |
| 5/26/93 | D | Aerobic | 651 | 81 | 12.40 | 1063 | 163 | 15.36 |
| 5/26/93 | D | Effluent | 91 | 15 | 16.41 | 87 | 19 | 22.27 |
| 5/26/93 | E | Influent | 78 | 23 | 30.16 | 154 | 21 | 13.58 |
| 5/26/93 | E | Anaerobic | 653 | 108 | 16.46 | 1072 | 270 | 25.17 |
| 5/26/93 | E | Anoxic | 759 | 183 | 24.08 | 1119 | 150 | 13.43 |
| 5/26/93 | E | Aerobic | 725 | 175 | 24.21 | 1173 | 121 | 10.29 |
| 5/26/93 | E | Effluent | 74 | 4 | 5.58 | 99 | 9 | 9.16 |
| 5/26/93 | F | Influent | 109 | 16 | 14.94 | 97 | 28 | 28.57 |
| 5/26/93 | F | Anaerobic | 1223 | 244 | 19.96 | 1669 | 412 | 24.72 |
| 5/26/93 | F | Anoxic | 851 | 253 | 29.78 | 1303 | 91 | 6.97 |
| 5/26/93 | F | Aerobic | 699 | 129 | 18.46 | 1303 | 174 | 13.34 |
| 5/26/93 | F | Effluent | 138 | 34 | 24.44 | 94 | 23 | 23.95 |
| 5/31/93 | A | Influent | 0 | 0 | ERR | 0 | 0 | ERR |
| 5/31/93 | A | Anaerobic | 1603 | 202 | 12.58 | 1537 | 137 | 8.90 |
| 5/31/93 | A | Anoxic | 1330 | 164 | 12.32 | 1100 | 154 | 13.96 |
| 5/31/93 | A | Aerobic | 1025 | 238 | 23.18 | 856 | 154 | 18.02 |
| 5/31/93 | A | Effluent | 37 | 7 | 19.31 | 39 | 4 | 8.98 |
| 5/31/93 | D | Influent | 0 | 0 | ERR | 0 | 0 | ERR |
| 5/31/93 | D | Anaerobic | 783 | 174 | 22.28 | 730 | 103 | 14.11 |
| 5/31/93 | D | Anoxic | 546 | 144 | 26.41 | 369 | 105 | 28.55 |
| 5/31/93 | D | Aerobic | 396 | 85 | 21.57 | 336 | 85 | 25.19 |
| 5/31/93 | D | Effluent | 23 | 4 | 18.56 | 25 | 6 | 23.96 |
| 5/31/93 | E | Influent | 78 | 12 | 14.80 | 66 | 12 | 18.59 |
| 5/31/93 | E | Anaerobic | 1315 | 239 | 18.20 | 992 | 147 | 14.77 |
| 5/31/93 | E | Anoxic | 722 | 146 | 20.17 | 553 | 106 | 19.58 |
| 5/31/93 | E | Aerobic | 1065 | 112 | 10.52 | 434 | 77 | 17.84 |
| 5/31/93 | E | Effluent | 41 | 8 | 19.33 | 41 | 6 | 14.87 |
| 5/31/93 | F | Influent | 0 | 0 | 19.14 | 0 | 0 | 14.42 |
| 5/31/93 | F | Anaerobic | 805 | 196 | 24.30 | 803 | 221 | 27.46 |
| 5/31/93 | F | Anoxic | 834 | 244 | 29.29 | 709 | 89 | 12.55 |
| 5/31/93 | F | Aerobic | 956 | 266 | 27.81 | 772 | 112 | 14.47 |
| 5/31/93 | F | Effluent | 76 | 16 | 21.30 | 38 | 10 | 25.47 |

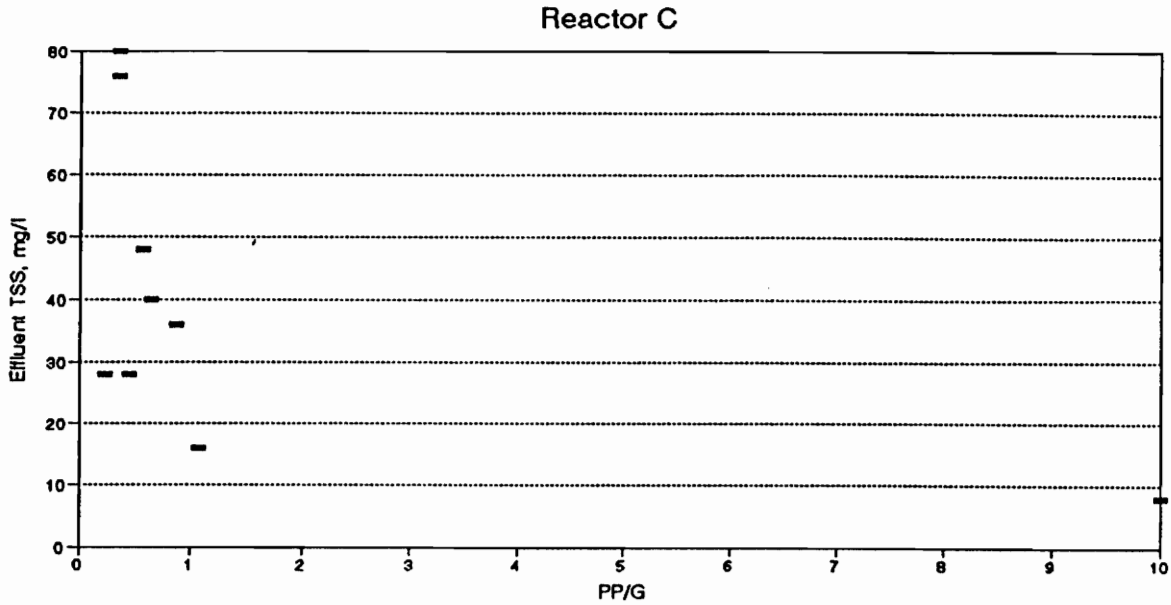
| Date | Reactor | Stage | # Poly-P (*10^6) | Std. Dev. | % Error | # G-bact (10^6) | Std. Dev. | % Error |
|---|---|---|---|---|---|---|---|---|
| 6/11/93 | A | Influent | 64 | 19 | 29.34 | 60 | 14 | 23.47 |
| 6/11/93 | A | Anaerobic | 906 | 265 | 29.15 | 974 | 186 | 19.06 |
| 6/11/93 | A | Anoxic | 829 | 178 | 21.41 | 650 | 202 | 31.11 |
| 6/11/93 | A | Aerobic | 988 | 231 | 23.38 | 794 | 118 | 14.84 |
| 6/11/93 | A | Effluent | 41 | 6 | 13.60 | 51 | 11 | 22.09 |
| 6/11/93 | D | Influent | 92 | 25 | 27.19 | 81 | 9 | 11.30 |
| 6/11/93 | D | Anaerobic | 1207 | 138 | 11.47 | 983 | 165 | 16.81 |
| 6/11/93 | D | Anoxic | 736 | 190 | 25.78 | 557 | 157 | 28.28 |
| 6/11/93 | D | Aerobic | 402 | 77 | 19.20 | 366 | 85 | 23.28 |
| 6/11/93 | D | Effluent | 37 | 10 | 26.91 | 35 | 9 | 24.56 |
| 6/11/93 | E | Influent | 102 | 33 | 31.85 | 107 | 18 | 16.59 |
| 6/11/93 | E | Anaerobic | 1385 | 180 | 13.02 | 905 | 208 | 22.93 |
| 6/11/93 | E | Anoxic | 1161 | 269 | 23.15 | 544 | 116 | 21.36 |
| 6/11/93 | E | Aerobic | 561 | 98 | 17.52 | 432 | 111 | 25.58 |
| 6/11/93 | E | Effluent | 68 | 14 | 20.89 | 69 | 8 | 10.97 |
| 6/11/93 | F | Influent | 112 | 21 | 18.38 | 88 | 21 | 24.31 |
| 6/11/93 | F | Anaerobic | 1084 | 122 | 11.29 | 1136 | 80 | 7.06 |
| 6/11/93 | F | Anoxic | 570 | 88 | 15.48 | 561 | 134 | 23.84 |
| 6/11/93 | F | Aerobic | 434 | 71 | 16.44 | 354 | 58 | 16.44 |
| 6/11/93 | F | Effluent | 28 | 8 | 29.49 | 28 | 4 | 13.86 |

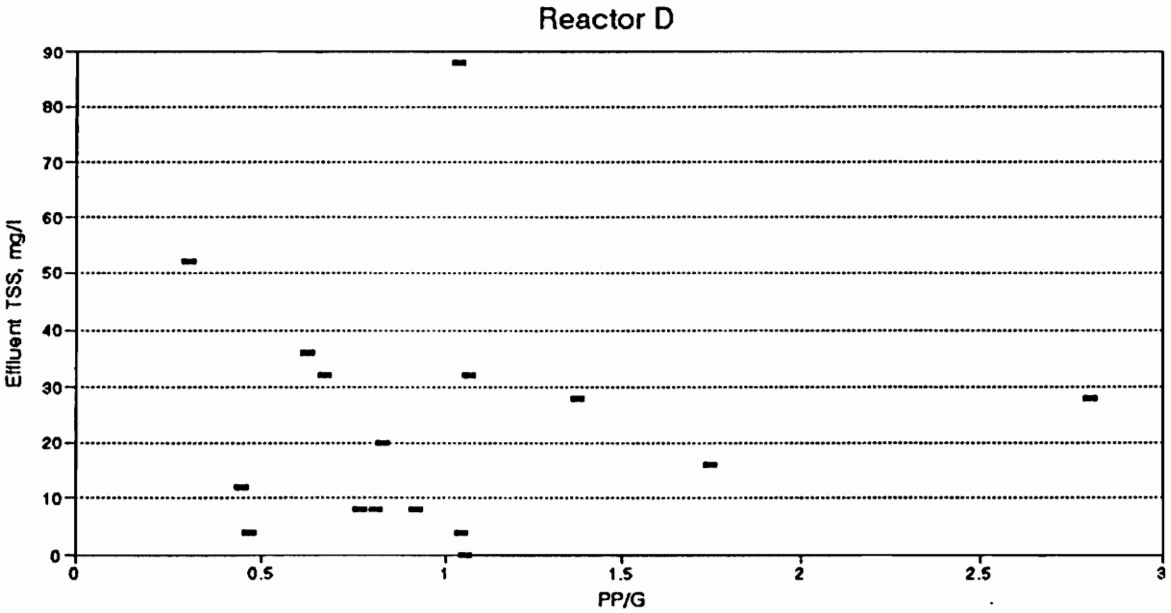
# Appendix C:

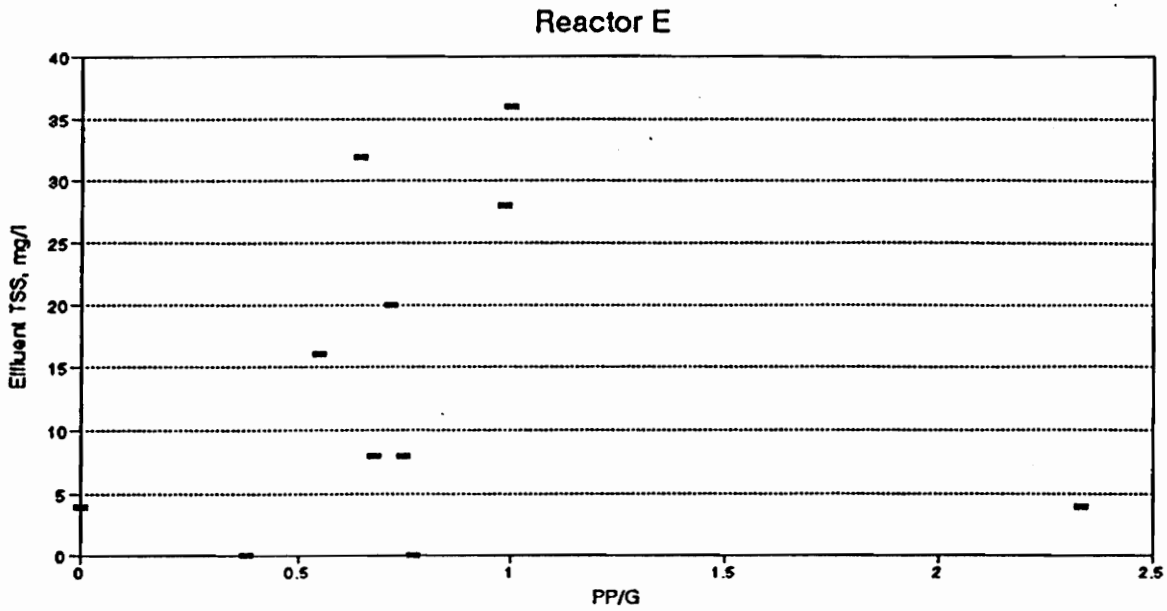
# Effluent Total Suspended Solids As a Function of PP and G Bacteria Populations

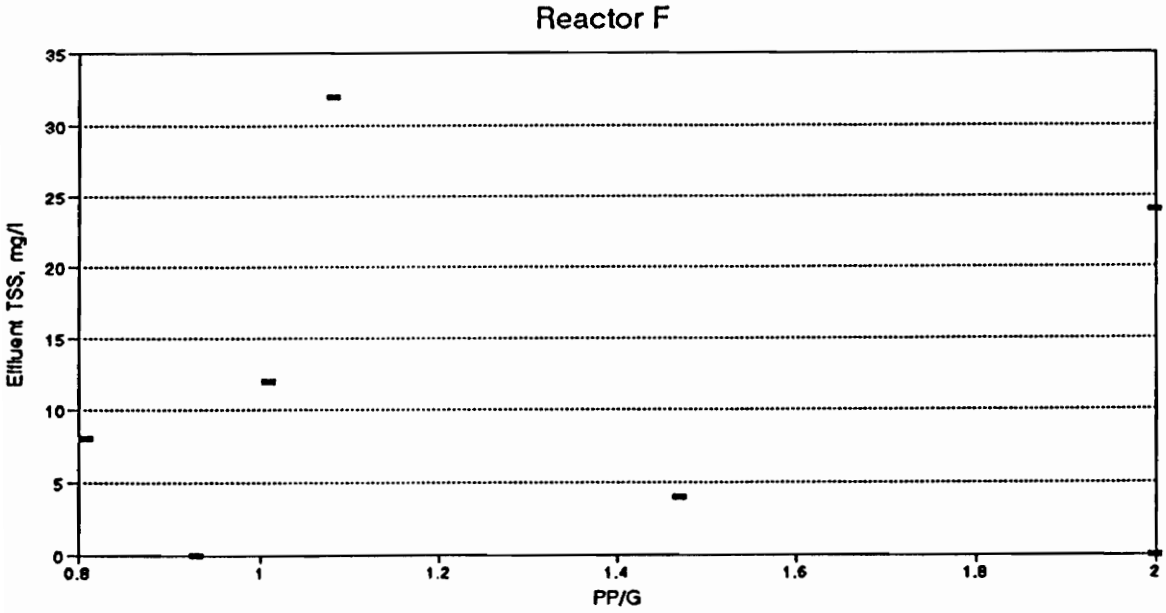

Reactor A
Effluent TSS, mg/l
60
55
50
45
40
35
30
25
20
0
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
1.8
2
PP/G


Reactor B
Effluent TSS, mg/l
180
160
140
120
100
80
60
40
20
0.2
0.4
0.6
0.8
1
1.2
1.4
1.6
PP/G


Reactor C
Effluent TSS, mg/l
0
10
20
30
40
50
60
70
80
0
1
2
3
4
5
6
7
8
9
10
PP/G


Reactor D
Effluent TSS, mg/l
0
10
20
30
40
50
60
70
80
90
0
0.5
1
1.5
2
2.5
3
PP/G


Reactor E
Effluent TSS, mg/l
40
35
30
25
20
15
10
5
0
0
0.5
1
1.5
2
2.5
PP/G


Reactor F
Effluent TSS, mg/l
35
30
25
20
15
10
5
0
0.8
1
1.2
1.4
1.6
1.8
2
PP/G

## Appendix D: Estimation of influent TOC and $PO_4$.

Estimations of influent TOC and $PO_4$ were required to determine the amount of $PO_4$ release:TOC uptake. The following assumptions were made:

$PO_4$ release = Anoxic $PO_4$ - Influent $PO_4$

TOC uptake = Influent TOC - Anoxic TOC

It was also assumed that the best approximation for background concentrations of TOC and $PO_4$ would be the amount of effluent TOC and $PO_4$ measured for that day in the reactor.

Influent TOC Approximation:

Ave. influent TOC = 296.7 ± 26.3 mg/l

Influent flow = 200 ml

In a 1 liter reactor:

Inf. TOC (mg) = Eff. TOC (mg) + 200 ml * 296.7 mg/l

Influent $PO_4$ Approximation:

Ave. influent $PO_4$ = 28.41 ± 2.36 mg/l

Influent flow = 200 ml

In a 1 liter reactor:

Inf. $PO_4$ (mg) = Eff. $PO_4$ (mg) + 200 ml * 28.41 mg/l

# Vita

Pamela Braunwell Morgan was born on May 29, 1969, in Dover, New Jersey. She attended the E. T. Briggs School in Lake Hopatcong, New Jersey until fourth grade. She then moved to Sussex, New Jersey, where she attended Wantage School, Sussex-Wantage Middle School, and High Point Regional High School. She graduated Valedictorian from high school in 1987. She continued her education earning a Bachelor of Arts in Environmental Science from Lafayette College, Easton, Pennsylvania, in 1991, and a Masters of Science in Environmental Engineering from Virginia Tech (VPI & SU), Blacksburg, Virginia, in 1993. She is currently employed with Malcolm Pirnie in Jackson, Mississippi.

11/29/93