FIXED-FILM FERMENTATION OF WASTEWATER AND ITS EFFECT ON

BNR PLANT PERFORMANCE

by

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ABSTRACT

Biological nutrient removal (BNR) at wastewater treatment plants, with strict effluent discharge limits, often require supplementary fermentation by-products to meet permit requirements without chemical addition. However, some wastewaters entering BNR plants, especially those located in warmer climates, have sufficient fermentation by-products, or volatile fatty acids (VFAs) present in the influent for efficient nutrient removal without supplementary VFAs or chemical addition. It is believed that fermentation within the collection systems is responsible for contributing necessary VFA to such wastewaters. This theory, and efforts to simulate and measure the effects of such fermentation in a wastewater treatment plant unit operation, forms the basis for this research.

The main objective of this study was to investigate fixed-film fermentation of wastewater and measure its effects on biological nutrient removal at a pilot-scale wastewater treatment plant. Research to support this objective was conducted over a nine month period, beginning in summer of 1997 and ending in the spring of 1998. Control and Experiment fixed-film fermenters, which were designed and constructed by a previous researcher (Dumitrescu, 1998), were attached to the front end of a 3-Stage Bardenpho process.

It was demonstrated in this study that fixed-film fermentation of primary effluent was a feasible means of producing VFAs at a rate between 2 mg/L/hr and 9 mg/L/hr. Furthermore, when solids, present in the primary effluent, were allowed to settle and accumulate in the fermenters, VFA

production was enhanced considerably as a result of fixed-film and solids fermentation.

The effects of prefermentation on twin 3-Stage Bardenpho processes running in parallel were observed during three experimental runs. Process parameters of interest included ammonia, nitrates, total Kjeldahl nitrogen, phosphates, total phosphorus, carbon, solids, and mixed liquor suspended solids.

During Experimental Run #1, there was no significant difference in process performance between the Control Process, which had a fermenter containing no media, and the Experiment Process which had a fermenter containing Ringlace. Both processes performed exceedingly well, reducing effluent phosphorus to less than 0.3 mg/L and effluent nitrogen to less than 5 mg/L.

During Run #2, it was decided to eliminate fermentation from the Control Process and continue to run the Experimental side as per Run #1. Again, there was no significant difference between Control and Experiment Process performance, even though the fixed-film fermenter was contributing additional VFAs to the Experiment Process. It was concluded that sufficient VFA (and fermentation by-products) were already present in the wastewater for good nutrient removal, nullifying any improvements attributable to the fermenters.

During experimental Run #3, it was decided to add phosphorus to the anaerobic zone to reveal any process performance improvements which might be attributable to VFAs produced in the fixed-film fermenters. Once again, there were no significant differences between Control or

Experiment Processes with both sides performing equally well.

Three possible explanations for the failure to show improved BNR performance with the addition of a fixed-film fermenter are discussed in this report:

- The existence of sufficient fermentation by-products inherent to the raw wastewater masked any process performance improvements that might have otherwise been observed.

- Nitrates present in the anaerobic zone hindered phosphorus removal. Microbes, responsible for denitrification in the anaerobic zone, utilized VFAs from the subject fermenters which would have been available for phosphorus accumulating organisms.

- A combination of the above.

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BNR	Biological Nutrient Removal
EBPR	Enhanced Biological Phosphorus Removal
F^3	Fixed-Film Fermenter
HRT	Hydraulic Retention Time
NH_3, NH_4	Ammonia
NO_x	Nitrate/Nitrite
Ortho-P	Soluble Phosphorus
P	Phosphorus
PO_4	Soluble Phosphorus, Phosphate
PVC	Polyvinyl Chloride
RAS	Return Activated Sludge
SCVFA or VFA	Short Chain Volatile Fatty Acids
SRT	Solids Retention Time
TOC	Total Organic Carbon
TKN	Total Kjeldahl Nitrogen
TN	Total Nitrogen
UBC	University of British Columbia

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CHAPTER 1

1.0 INTRODUCTION

The primary objective in treating wastewater is to reduce the impact of discharge on the environment. Conventional activated sludge wastewater treatment plants are designed for physical treatment (removal of solids) and reduction in oxygen demanding organics (biochemical oxygen demand). Advanced wastewater treatment, involving the removal of all forms of nitrogen and phosphorus, is now becoming necessary as our understanding of the effects of these pollutants develops. Nitrogen, in its various forms, is responsible for a number of problems including methaemoglobinaemia in humans, ammonia toxicity to fish, depletion of dissolved oxygen in receiving waters and links to cancer from nitrosamines (Mirvish, 1977) among others. Complications stemming from eutrophication, especially in land bound bodies of water, have given rise to the need for reduction or elimination of growth stimulating nutrients. Nitrogen and phosphorus have been identified as the nutrients which influence the progression of eutrophication most dramatically. The ability of some algae to fixate nitrogen from the atmosphere (nitrification) has led to the conventional wisdom that phosphorus, not nitrogen, is the limiting nutrient in most water bodies (Horne, 1977).

The negative impact of eutrophication on wildlife diversity, lucrative fisheries, drinking water and recreational areas was the impetus for North America's first biological nutrient removal (BNR) plant in Palmetto, Florida (Burdick *et al.* 1978). The first Canadian and second North American BNR plant was commissioned at Kelowna, BC in 1982 (Barnard *et al.* 1984).

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Biological nutrient removal has since proven to be an effective method for achieving nitrogen and phosphorus removal because it is compatible with existing activated sludge treatment plants, it requires similar equipment and operational techniques, and it is cost effective.

Biological nutrient removal refers to processes that utilize biological mechanisms instead of chemical mechanisms to remove phosphorus and nitrogen from wastewaters (Randall, *et al.* 1992). Biological nutrient removal in this study refers to the removal of all forms of nitrogen and phosphorus from the waste stream by a microbial culture that is established and carefully maintained. These microbes require a simple carbon food source - termed short chained volatile fatty acids (SCVFAs or VFAs) such as acetic acid or propionic acid - so they can efficiently perform their tasks. The vital role of SCVFAs in biological nutrient removal has been well studied and documented by several researchers (Barnard *et al.* 1984; Rabinowitz and Oldham, 1986; Nicholls *et al.* 1985; Wentzel and Ekama, 1997; Christensson *et al.* 1998). SCVFAs are a simple and consumable carbon source necessary for nutrient reducing microbes to thrive and thereby perform their intended function of nitrogen and phosphorus removal.

1.1 Background to This Research

Dr. James Barnard (Reid Crowther & Partners Ltd.) initiated the project and collected evidence to support a successful United States Patent application for the fermentation of primary effluent using a commercially available growth medium. Year 1 of the project began with research being conducted at the University of British Columbia (UBC) Pilot Plant by Dumitrescu (1998), who ascertained that SCVFAs can be produced in fixed-film fermentation reactors with an hydraulic

retention time (HRT) of less than 60 minutes. Dumitrescu investigated the performance of the reactor units using two commercially available media fermenting raw sewage and primary effluent in separate experiments. The two media types tested in Year 1 were Ringlace® media, which is a PVC rope-like material with many attached fibres, and Kaldnes media which is a plastic barrel shaped carrier with many fins for increased surface area. The Ringlace® can best be described as a rope or strand approximately 1 cm in diameter, cut to a desired length; it requires a frame or some kind of mounting apparatus. Kaldnes media are individual cylinders, 9 mm in diameter by 7 mm long, which are designed to be easily mixed or fluidized.

During Year 1, Dumitrescu (1998) found that SCVFAs were produced with both media types while fermenting domestic raw sewage or primary effluent; however, there were advantages and disadvantages in each case. Using raw sewage as the feed, he found VFA production with the Ringlace fermenters to exceed 11 mg/L/hr as acetic acid (HAc); however, the Kaldnes reactors frequently plugged and the media was therefore deemed unsuitable for use in this plug-flow fixed-film system. When primary effluent was used as the feed source, VFA production decreased but was still evident in both systems with 3.7 mg/L/hr and 5.6 mg/L/hr produced with Kaldnes and Ringlace, respectively. Raw sewage produced a greater yield of SCVFA; however, operational issues associated with plugging and solids build-up in the fermenters led to the selection of primary effluent as the feed source and Ringlace ® media as the carrier for the fixed film.

The focus of this research (Year 2), which was carried out at the UBC Pilot Plant, was to

confirm and elaborate on Dumitrescu's findings, as well as evaluate the effects that such SCVFAs have on BNR performance. The same apparatus from Year 1 was employed during Year 2 but instead of wasting the fermentation byproducts, fermenter effluent was directed towards a BNR pilot plant. The UBC Pilot plant was configured for operation as a 3-stage Bardenpho process, so that results could be compared against the rich database of BNR data acquired over 15 years of previous research at the UBC Pilot Plant. A nine month series of experiments was planned for the purposes of measuring and recording parameters necessary to evaluate the fixed-film fermenter (F^3) and BNR process. It is hoped that knowledge gained from this study will enhance the understanding of fixed-film fermentation and possibly lead to full scale applications for new plant construction or retrofits where treatment plant performance requires optimization.

1.2   Objectives

The research objectives were clearly defined at the beginning of the project in a proposal written in July, 1997. Meeting those objectives was the driving force behind some of the decisions made in an effort to maintain accountability to the agency funding the project.

Primary Objective

1.   Investigate Pilot Plant BNR process performance when VFAs produced in the subject fermenters are introduced to the waste stream.

Secondary Objectives

2.   Confirm findings of the earlier study which found that VFAs could be produced in a high-

rate, fixed-film, anaerobic reactor in sufficient quantities to improve the BNR process performance.

3.   To establish preliminary design and operating criteria necessary to incorporate fixed-film fermenters into the Pilot Plant waste stream.

Fulfilment of these objectives would provide useful information and knowledge regarding the operation and performance effects of a patented, novel approach to the pretreatment of domestic wastewater, prior to entry into a biological nutrient removal process. Given the project duration (less than one year), it was important to ensure that research objectives remained in focus to ensure information required to make a useful assessment of the systems could be delivered to the project sponsors.

CHAPTER 2

2.0 LITERATURE REVIEW

The following literature review contains a brief introduction to wastewater treatment, specifically biological nutrient removal (BNR) and how fermentation can augment the performance of such processes. Enhancement of BNR was a primary objective of this research, therefore the review begins with a general introduction to BNR. Next, a "state-of-the-art" summary of models pertaining to biological phosphorus removal is included, since there are many new developments in this area and the subject matter is pertinent to the basis of this thesis.

An introduction to primary sludge prefermenters currently in use, their configurations, operating characteristics and products will be presented to provide baseline information with which the concept of primary effluent fermentation can be compared. It should be noted that the literature sometimes refers to fermentation as "prefermentation" which might imply the existence of two unit operations: namely that of a prefermenter followed by a fermenter. Since this is not actually the case in today's BNR fermentation applications, "prefermentation" has been used interchangeably with "fermentation" in this document to more accurately reflect the single unit operation in this case. The literature review is intended to be a brief introduction to the topic headings. A more detailed review and discussion of some of the topics is included in the results and discussion section under many of the subheadings.

2.1   Enhanced Biological Phosphorus Removal

Enhanced biological phosphorus removal (EBPR) refers to processes operated in such a way as to stimulate the growth of polyphosphate accumulating organisms (PAOs) which have the ability to store large amounts of phosphorus.   From the early stages of EBPR, it was recognized that readily biodegradable substrates were a necessary addition to the anaerobic zone of an activated sludge treatment plant designed for biological P-removal. Barnard (1974) deduced that mixed liquor must pass through an anaerobic stage, in which phosphorus release may occur, followed by an aerobic stage, in which phosphates are taken up by the organisms or precipitated as a result of the change in redox potential. There has been much discussion regarding the exact mechanism by which phosphates are removed from municipal wastewater in biological nutrient removal plants with one school of thought believing some form of chemical precipitation (without the addition of chemicals) was responsible for the net reduction (Arvin, 1983), and others believing that phosphate removal was the result of biological uptake (Barnard, 1976). Most of the debate on this point has been put to rest in recent years with research findings that conclude phosphate precipitation in EBPR processes is not a significant phosphorus removal mechanism (Carlsson *et al.* 1997).

The exact mechanism or model by which EBPR occurs is the subject of continued research. However, one can put things in perspective by considering the conventional activated sludge system in which about 2.0% of the sludge mass is phosphorus (Randall *et al.* 1997, Wentzel and Ekama, 1997). The percentage phosphorus by mass is directly related to the stoichiometric nutrient requirement for activated sludge. Therefore, if a wastewater contained 400 mg/L COD,

with a sludge yield of about 0.25 kg VSS/kg COD, one would expect about 2.0 mg/L removal of phosphorus by microbial assimilation and subsequent wasting of the process sludge. EBPR systems operate successfully by providing an environment favourable to polyphosphate accumulating organisms capable of storing 5% (US EPA, 1987, Jones, *et al.* 1985), or more, of their cell mass as inorganic phosphorus. A treatment plant operating as an EBPR system could then be expected to remove about 4 to 5 mg/l of phosphorus from the waste stream. Key design requirements necessary to provide a favourable environment for Bio-P removal include the presence of readily biodegradable substrates in an initial anaerobic contact zone where minimal amounts of nitrates are present (Rabinowitz, 1985), followed by an aerobic zone. *Acinetobacter* was the first group of bacteria to be isolated and associated with EBPR; however, other microorganisms such as *Lampropedia sp.* (Stante *et al.* 1997), *Pseudomonas sp.* and *Aeromonas sp.* (Randall *et al.* 1997).

2.2   Enhanced Biological Phosphorus Removal Models

There are several EBPR models used to explain the phenomenon associated with phosphorus release and subsequent phosphorus uptake in activated sludge operated in an anaerobic-aerobic sequence. The most representative model is still the subject of much debate and so a general narrative describing biological-P removal, as well as a summary of Bio-P model development, will be presented.

Comeau et al. (1986) produced the first comprehensive model for biological removal of phosphorus by *Acinetobacter*. Figure 2.1 (US EPA, 1987, Barnard and Rabinowitz, 1998) is a
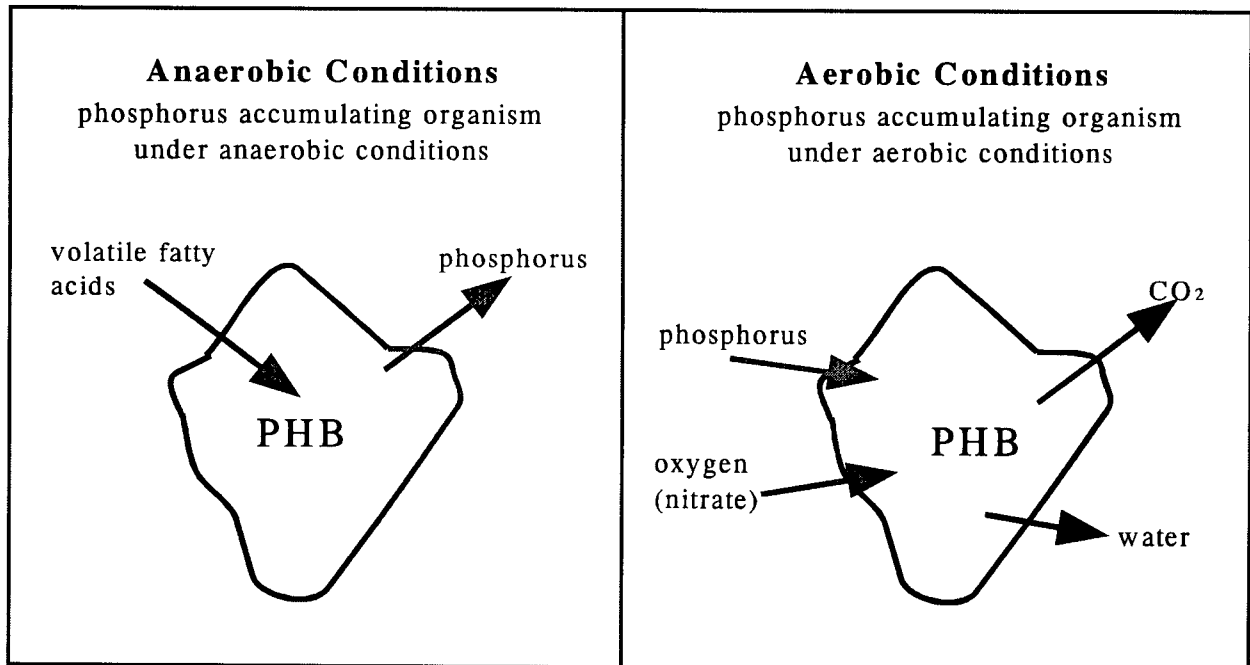
Figure 2.1   **Simplified phosphorus removal mechanism** (US EPA, 1987)

simplified version of the model and can be explained as follows. Polyphosphate accumulating

organisms become stressed in the anaerobic zone and begin to break down (through hydrolysis)

stored polyphosphate reserves into orthophosphate (PO_4) which is expelled from the

microorganisms. This releases energy necessary for the anaerobic uptake of fermentation

products during anaerobic respiration. This biodegradable substrate, SCVFA for example, is

present in the incoming wastewaters is readily assimilated and stored by the PAOs in the

anaerobic condition. The fermentation products are stored as polyhydroxyalkanoates (PHA), of

which polyhydroxybutyrate (PHB) is the best known member. The energy required for anaerobic

uptake of SCVFA and storage as PHB is provided by the aforementioned polyphosphate

conversion to and subsequent release of orthophosphate. Because PAOs are able to assimilate

SCVFA in the anaerobic condition they have a competitive advantage over other microorganisms

present in the activated sludge. As result, the anaerobic zone is sometimes referred to as a population selector because the growth and development of PAOs can occur there.

During the aerobic phase, the PAO-rich activated sludge metabolizes stored PHBs, cells reproduce and soluble phosphorus is taken up with excess amounts stored as polyphosphates (US EPA, 1987). The phosphorus uptake by PAOs in the mixed liquor, results in a net phosphorus uptake. Phosphorus removal is achieved by wasting phosphorus rich sludge from the process.

The first step in the EBPR process is an anaerobic uptake of SCVFAs by PAOs and its storage as PHB (Felipe *et al.* 1998). This biochemical conversion requires energy which is provided by polyphosphate; however, reducing power is also required. Three models exist to describe the reducing power in the anaerobic phase:

1. The Comeau model (1986) assumes some of the VFA taken up by the cells goes through the tricarboxylic acid cycle (TCA), where nictinamide adenine dinucleotide (NADH) is generated and used to transform the remaining VFA to PHB.

2. The Mino model (1987) assumes reducing power is supplied from stored glycogen which is directed through the Embden-Meyerhof pathway (EMP).

3. The adapted Mino model (Wentzel *et al.,* 1991) is similar to the Mino model except the Embden-Duodoroff pathway is used instead of the EMP pathway.

Research by Smolders *et al.* (1994) and Arun *et al.* (1989) determined that the observed data was closely predicted by both Mino models, but deviated significantly from the Comeau model. This led to a departure from the Comeau model and was a major step in the identification of the

commonly accepted EBPR model.

The development of an EBPR model continued with further research being conducted by Wentzel, Gujer, Mino, and Smolders (Felip, *et al.* 1998). The Activated Sludge Model (ASM) No. 2, introducing PAOs (Gujer, *et al.* 1995), was developed in 1995 by a Specialist Group from the International Association of Water Quality (IAWQ), comprising many of the above mentioned authors. Further to the publication by the IAWQ Specialist Group, a well recognized metabolic model was proposed by Smolders and co-workers (Smolders *et al.*, 1995a, b). Other models, which expand upon or improve upon the above, have recently been reported in the literature by Murnleitner *et al.* (1997) and Felipe *et al.* (1998).

The IAWQ Specialist Group in their publication on ASM No. 2 (Gujer, *et al.* 1995) admitted that their group " did not have an understanding of the processes involved in biological phosphorus removal to a similar degree or reliability as was the case ..... when ASM No. 1 was proposed for nitrogen control" and so work by the group continued. In a recent IAWQ conference held March 16-18, 1998 in Copenhagen, a new proposal for ASM No. 3 was revealed. The new model includes two storage processes and a compound representing PHA. ASM No. 3 includes a more detailed description of internal cell processes and allows for better adjustment of decay processes to real conditions. The importance of hydrolysis has been reduced, since growth is now based on stored compounds and the kinetics of hydrolysis is now independent of the aerobic conditions.
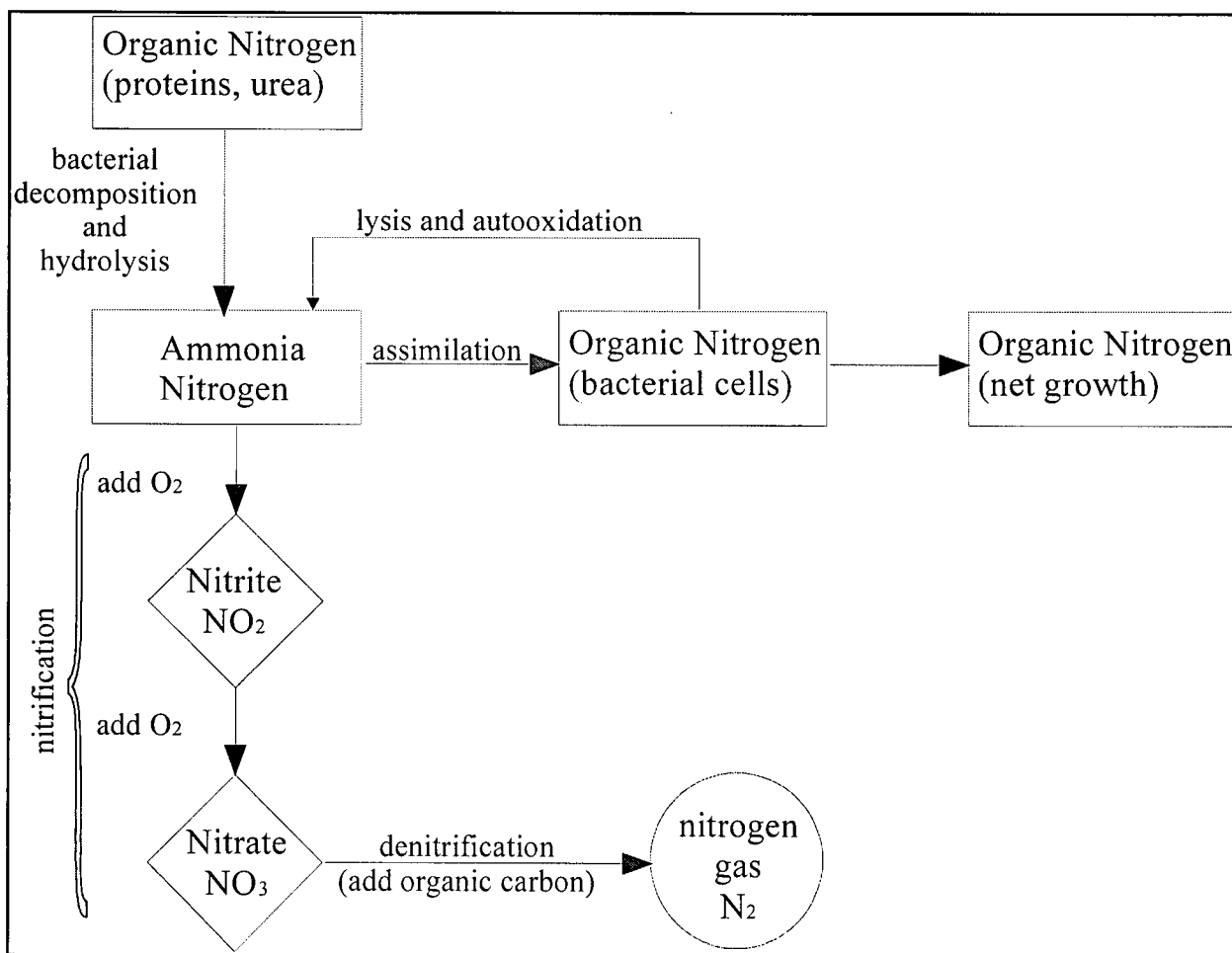
Figure 2.2   **Biological nitrogen transformations** (From Metcalf and Eddy, 1991)

2.3   Nitrogen Removal

Nitrogen, the other nutrient of primary concern, is removed biologically in a multi-step process

through decomposition of organics to ammonia, oxidation of ammonia to nitrite/nitrate, followed

by denitrification to N_2 as an off gas (Figure 2.2). The nitrification process is progressed by two

autotrophic bacteria, *Nitrosomonas* and *Nitrobacter* which consume large amounts of oxygen and

alkalinity (HCO_3^- and H_2CO_3) while converting NH_3 to NO_2^- then NO_3^-, as depicted in Figure

2.2.

The stoichiometry involved requires that for every 1.0 kg of ammonia-nitrogen oxidized approximately:

- 4.3 kg of O_2 is consumed

- 7.1 kg of alkalinity is destroyed

- 0.15 kg of new cells are formed   (source: Argaman, 1991).

There is a list of at least ten known bacteria responsible for reducing nitrate, to nitrogen gas, involving several reactions $(NO_3 \rightarrow NO_2 \rightarrow NO \rightarrow N_2O \rightarrow N_2)$. The denitrification process adds alkalinity back to the process and requires a readily biodegradable carbon source to proceed to completion.   For every 1.0 kg of nitrate-nitrogen removal to be denitrified approximately:

- 6.9 kg of COD is consumed

- 3.6 kg of alkalinity is formed

- 0.45 kg of new cells are formed (source: Argaman, 1991)

Table 2.1 is a summary of the principal organism groups responsible for biological nutrient removal, their function and their zone of activity.

New research conducted in South Africa and Holland has found evidence concluding that the biological nitrogen and phosphorus mechanisms are interconnected (Ostgaard et al. 1997, Kuba et al. 1997). The two cases cited in the literature clearly demonstrated that denitrifying phosphorus removing bacteria (ie. P removal and N removal was carried out by the same organisms) were prevalent in the University of Cape Town (UCT) type wastewater treatment

plants. This being the case, it would follow that feed substrate typically associated with good phosphorus removal would also benefit nitrogen removal. As early as 1985 it was reported by Nicholls, *et al.* (1985) that availability of fermentation byproducts could greatly assist both nitrogen and phosphorus removal.

Table 2.1   Principal organisms responsible for BNR (Wentzel and Ekama, 1997)

Organism	Biological Process	Condition
1. Ordinary heterotrophs (unable to accumulate ortho-P)	COD removal, organic degradation, DO consumed	Aerobic
	ammonification (Organic N $\rightarrow$ NH$_3$)	Aerobic
	denitrification (NO$_3$ $\rightarrow$ NO$_2$ $\rightarrow$ N$_2$)	Anoxic
	Fermentation (complex organics $\rightarrow$ SCVFA)	Anaerobic
2. Ortho-P heterotrophs (accumulate PO$_4$, facultative organisms)	P release (SCVFA uptake, PHA storage)	Anaerobic
	P release (SCVFA uptake, PHA storage	Anoxic
	P uptake (PHA degradation; denitrification)	Anoxic
	P uptake (PHA degradation, DO consumed)	Aerobic
3. Autotrophs (nitrifiers)	Nitrification (NH$_4$ $\rightarrow$ NO$_2$ $\rightarrow$ NO$_3$) DO consumed	Aerobic

2.4   SCVFA Production by Fermentation

Fermentation is the anaerobic, microbial decomposition of complex organic matter to end products of methane and carbon dioxide. It is a multi-step process as depicted in Figure 2.3 (adapted from Randall, *et al.* 1992). The complete fermentation process comprises several steps including hydrolysis, acidogenisis, acetogenisis, and methanogenisis (Gujer, *et al.* 1983), which can be simplified into acidogenisis and methanogenisis.

Traditionally, interest in fermentation as a means of generating energy through methane

production was paramount and so the acidogenisis-methanogenisis pathway was allowed to run

its full course. Once SCVFAs, principally acetic and propionic acids, were sought after for use

as readily biodegradable substrates, it was important to avoid methanogenisis by limiting HRTs

to 12 hours (Elefsiniotis and Oldham, 1994); SCVFAs can be assimilated and/or converted to

end products CH_4 and CO_2 when HRTs exceed 12 hours. Amongst other advantages, the
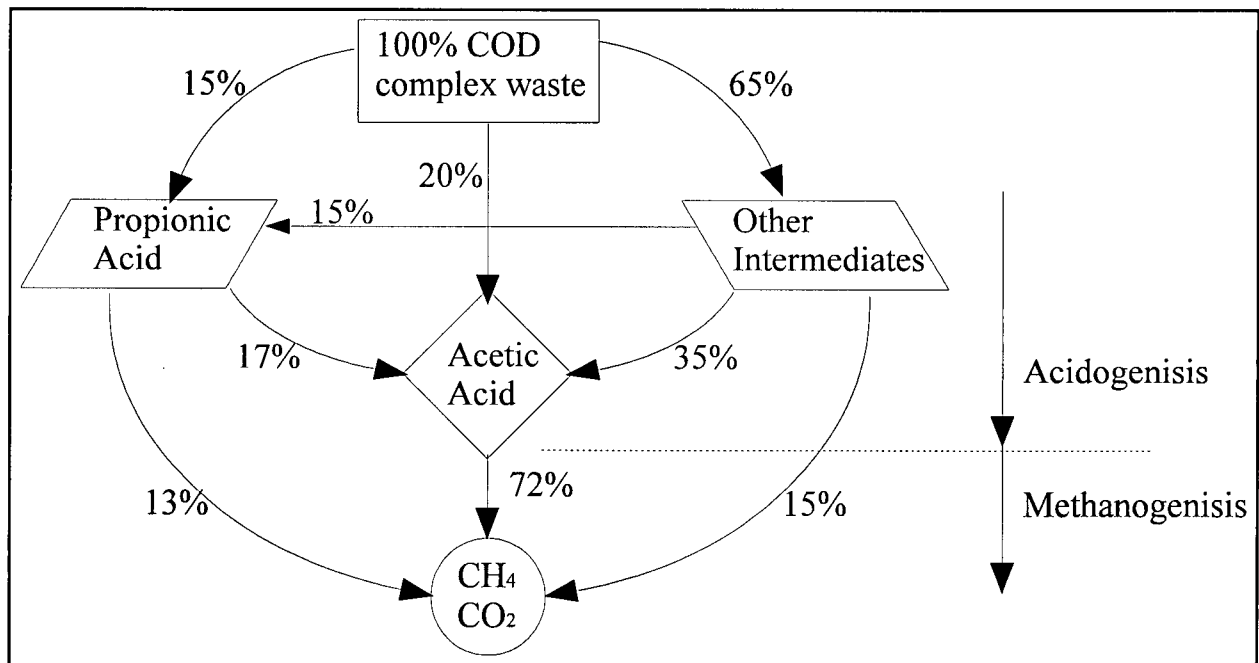
Figure 2.3   Acidogenisis - methanogenisis pathway

development of a high rate fermentation process for the production of SCVFAs would ensure

that methanogenisis would be averted, resulting in efficient production and usage of substrate.

2.4.1   SCVFA Characterization

The acidogenisis percentage breakdown (Figure 2.3) results in a split of about 70% acetic acid

and 15% propionic acid before fermentation is complete. This ratio can vary considerably depending on several variables including pH, temperature and retention time as well as influent composition (Gupta, 1986). Elefsiniotis (1994) found that SCVFA produced from fermentation of primary sludge consisted of acetic and propionic acids of 46% and 32%, respectively, with the remainder being valeric, butyric or other acids. Chu (1995) reported a relatively even distribution of VFA between acetate and propionate under strict anaerobic conditions while acetate accounted for 70 to 80% of the VFA produced (propionate about 10%) under microaerobic conditions in an autothermophilic aerobic digester (ATAD). Elsewhere, laboratory experiments at the University of Cape Town, investigating batch and series fermentation of primary sludge, found that of the total VFA generated, acetic acid was 43%, propionic was 41% and 16% was butyric or valeric (Randall *et al.*, 1992).

Much higher proportions of acetate production have been found with fermentation of raw sewage versus fermentation of sludge. Koch (1994) observed an acetate percentage of between 72% and 85% of total SCVFA produced over a three year period (remainder being propionate) in a study involving fermentation of raw sewage at short SRTs (hours), while Danesh (1995) also reported a high percentage of acetic acid (86 to 97%), while fermenting raw wastewater at solids retention times (SRTs) between four and thirteen days.

2.5 Fermenters and Their Role in BNR

The importance of fermentation by-products has been recognized since Fuhs and Chen (1975) identified *acinetobacter* as an organism reponsible for excess phosphorus uptake. Since

acinetobacter is a facultative organism which feeds preferentially on acetates and ethanols, it was deduced that these microbes thrive in the anaerobic-aerobic sequence necessary for phosphorus removal in the activated sludge (Fuhs and Chen, 1975, Randall *et al.* 1992). Since the ground breaking research by Fuhs and Chen (1975), enhanced biological phosphorus removal (EBPR) has been attributable to other phosphorus accumulating organisms in addition to *acinetobacter*, such as *Lampropedia sp.* (Stante *et al.* 1997), *Pseudomonas sp.* and *Aeromonas sp.* (Randall *et al.* 1997).

Once it was established that SCVFAs are required for efficient BNR, much work was done to optimize anaerobic zone fermentation in cases where sufficient readily biodegradable substrate was not present in the influent raw wastewater. It was believed that larger anaerobic zones would cause enough fermentation to ensure the process worked efficiently, but instead, a phenomenon termed "secondary release" of phosphorus (Barnard, 1984) resulted. It was found to be very difficult to produce sufficient VFA in the anaerobic zone of a BNR plant when influent BOD was below 200 mg/L or temperatures were below 17°C. Enlargement of the anaerobic zone to a residence time greater than one hour, resulted in more P release than SCVFA induced phosphorus uptake (Barnard, 1984). It is believed the additional P release is not associated with SCVFA uptake, but rather cell lysis, resulting in a net increase of effluent total phosphorus (TP) instead of excess P removal. Avoiding secondary release of phosphorus was the impetus for the development of a separate unit process, designed specifically to produce SCVFAs through fermentation of primary sludge. The SCFAs are then added to the anaerobic zone of the BNR process. It is generally accepted that SCVFA production in the anaerobic zone

is not considered significant, necessitating the use of fermenter units when influent raw sewage does not contain sufficient fermentation by-products to enable EBPR to achieve desired results.

2.6   Fermentation Processes

There are four types of primary sludge fermenters in operation, which are briefly described below (From Rabinowitz, 1994). Comparisons between the various fermenters are made in Table 2.2.

The *Activated Primary Tank (APT)* is the simplest type of primary sludge fermenter and was proposed by Barnard (1984). The APT receives the entire wastewater flow, and is essentially a primary clarifier with a higher than normal sludge blanket. Sludge is drawn off the bottom of the sludge layer and recycled to the inlet of the clarifier, resulting in a solids retention time (SRT) greater than the HRT enabling fermentation to occur. The SCVFA produced in the sludge blanket of the primary clarifier is ellutriated by incoming raw wastewater and transported to the BNR process by the primary effluent.

The *Complete-Mix Prefermenter*, proposed by Rabinowitz (1987), is similar to the APT except that it receives primary sludge in a separate completely mixed tank. Primary sludge undergoes acid fermentation in the fermenter, then returns to the inlet of the primary clarifier where SCVFA mixes with incoming wastewater and flows to the BNR process via the primary effluent.

The *Static Prefermenter,* also called a *Single Stage Prefermenter/Thickener,* is a gravity thickener

which receives primary sludge and has increased side water depth to allow for the storage of a

fermenting sludge mass. Because the unit is not mixed, VFA rich supernatant can be drawn off

the surface and added directly to the anaerobic zone for more efficient usage of fermenter

substrate.

The *Two-stage Complete Mix with Thickener Prefermenter,* also called the *Two-stage*

Prefermenter, comprises a complete mix fermenter and a static fermenter in series, to combine

the advantages of each system.

Table 2.2   Comparison of primary sludge fermenters

Type	Advantage	Disadvantage
Activated Primary Tank	• simple • utilizes existing tankage so $ effective	• less SVFA production • odour control (unless covered)
Complete-mix Prefermenter	• complete mixing increases SCVFA production	• needs separate tankage • mixing energy required • supernatant mixes with PC influent before flows to BNR plant
Static Prefermenter	• supernatant flows directly to BNR plant • increased VFA production • no mixing energy, • thickened sludge for wasting	• needs separate tankage, • methanogenisis can be a problem
2 Stage Prefermenter	• Includes most advantages of complete mix and static prefermenters	• sludge does not thicken well, • more costly to build and operate

To-date, there has been some research into fermentation of raw sewage using sequencing batch

reactors (Danesh *et al.* 1995 and Cuevas-Rodriguez *et al.* 1998) but as of yet, there have been no full scale applications utilizing this technology.

Fixed-film systems, such as trickling filters and biological aerated filters, have been used for many years now and their success has been well documented. The benefits of such systems include increased reaction rates, owing to increased surface area, and a resistance to shock loading conditions. These same characteristics should benefit the anaerobic application of such systems for VFA production, however, to date there has been very little research into VFA production using fixed-film systems.

CHAPTER 3

3.0 EXPERIMENTAL METHODS AND ANALYTICAL PROCEDURES

The experimental equipment and methods used in this research are described in detail in this chapter. Section 3.1 deals with the equipment and operation of the UBC Pilot Plant. Section 3.2 provides further details of fermenter design, operation and the series of runs conducted over the nine month sampling period. Sampling methods and analytical methods, as well as a detailed description for the various trial runs, are described in Sections 3.3 and 3.4. A summary of quality assurance and quality control (QA/QC) measures taken to assure the accuracy and precision of the results is described in the final section. Methodology for QA/QC parameters are presented in detail in Appendix A.

3.1 Plant Description and Operation

The UBC Pilot Plant, located in the southeast corner of the campus, is owned and operated by the Department of Civil Engineering at the University of British Columbia. The Pilot Plant consisted of parallel 3-stage Bardenpho BNR systems treating municipal/residential sewage drawn from a gravity sewer line servicing the residential housing on campus. A process schematic, including tankage is depicted in Figure 3.1. Raw sewage was lifted by a chopper-pump into three 12,000L sewage holding tanks twice daily, (at 1100 hr and 1800 hr) and from there sewage was pumped at a rate of 12 to 16 L/minute to the primary clarifier located inside the pilot plant trailer. Since wastewater in the Vancouver area has low alkalinity (approximately 100 mg/L as $CaCO_3$), buffer in the form of sodium bicarbonate (100 mg/L as $CaCO_3$) was added daily

to the raw sewage holding tanks. The addition of sodium bicarbonate maintained a pH balance in the system of 7.0 (+/- 0.5) at all times; this was necessary for complete nitrification in the process.

As shown in Figure 3.1, there were two parallel, 3-Stage Bardenpho process streams - a Control stream and an Experimental stream - receiving effluent from the fermenter units at a rate of 2.0 L/min. The fermenters were in-line systems receiving full flow, as opposed to side stream fermenters, which receive a fraction of the total flow. Primary effluent was split between control reactors and experiment reactors, with fermented effluent being directed to the anaerobic zones of each waste stream. Primary sludge was either wasted back to the gravity sewer or utilized in other experiments. Liquid from the anaerobic zone flowed into an anoxic zone and then to an aerobic zone before secondary clarification. Each process stream comprised 1350 L of reactor volume, not including clarifiers, with a resulting HRT of 11.25 hrs. The solids retention time (SRT) was governed by nitrifier growth rate in the aerobic zone and was chosen arbitrarily to ensure a sufficient factor of safety against washout. The SRT was maintained at 15 days by wasting mixed liquor from the aerobic zone once daily. The volume of sludge to be wasted was determined by monitoring mixed liquor suspended solids (MLSS) and effluent total suspended solids (TSS) concentration. The observed MLSS and TSS were used to calculate the volume of wastage from sludge wasting charts. The sludge wastage charts were designed based on mean cell-residence time (θc), defined as the mass of organisms in the reactor divided by the mass of organisms removed from the system each day (Metcalf and Eddy, 1991).
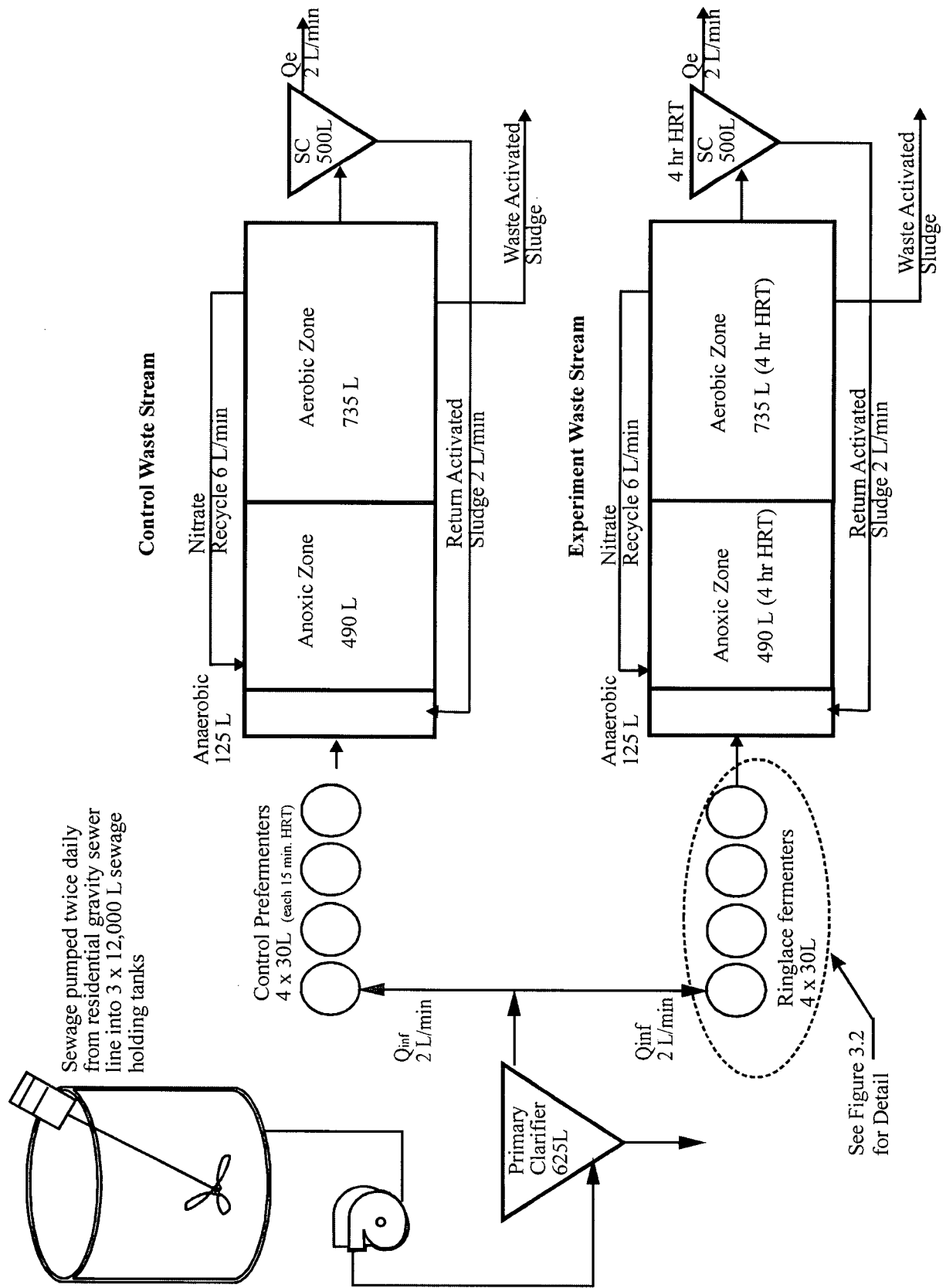
Figure 3.1   UBC Pilot Plant Process Schematic

$$\theta c = \frac{(Vr \times MLSS)}{(Vw \times MLSS) + (Q \times TSS)}$$

where:

Vr = process volume (anaerobic + anoxic + aerobic)

Vw = volume of MLSS wasted daily

Return activated sludge (RAS) was recycled to the anaerobic zone at 1Q (where Q = 2 L/min.); mixed liquor recycle was pumped to the anoxic zone at 3Q. These flows were chosen based on past operating experience (Rabinowitz, 1985, Setter, 1995) and the literature (Randall *et. al.* 1992, Metcalf and Eddy, 1991). Aeration and mixing in the aerobic zone of the process was provided by coarse bubble diffusion and dissolved oxygen levels were manually maintained at 2 mg/L +/- 1 mg/L. Mixing in the anaerobic and anoxic zones was supplied by pneumatic motors with speed controlled DC motors. After passing through the Bardenpho Process, mixed liquor from the aeration tanks passed into secondary clarifiers each equipped with two concentric V-notch weirs and gear driven mechanical rakes. The treated effluent was then sampled and discharged back into the gravity sewer.

3.2　High-Rate Fixed-Film Fermenters

This study was a continuation of the work carried out by Dumitrescu (1998) in Year 1, and as such, the fermenters used in this study are of the same design and similar configuration.

3.2.1 Fermenter Design

Figure 3.2 depicts the configuration of the high-rate fixed-film fermenter (F^3) system in which four identical, 30 L fermenters were connected in series, following the primary clarifier and feed pumps. Since the flow was set at 2 L/min, it was possible to sample in 15 minute intervals after each unit and develop a VFA production rate. The system was operated under pressure for all runs in this experiment to overcome the head pressure differentials and maintain an anaerobic environment necessary for efficient fermentation. Two identical Moyno 500 progressive cavity pumps were used to pump primary effluent through the process. A third pump, shown in Figure 3.2, was used for side stream experiments. Flows were accurately controlled and maintained by means of a variable speed frequency control, which was wired to low liquid level sensors. The purpose of the sensors was to shut the system down in the event of a stoppage in sewage flow from the primary clarifiers. The major components comprising the fermenter system are shown in Figure 3.2 - Detail A.

It is important to note the F^3 system was operated in-line instead of side-stream to the process, resulting in a process flow equal to the fermenter flow. Side stream primary sludge fermenters, which are beginning to gain acceptance, typically receive between 5% and 25% of the process flow (Munch, 1997c) and so fermentation products rerouted back to the process train are diluted by the total flow. Control fermenters utilized during the first part of the project were identical to experimental fermenters, except that they did not contain media. Fermentation byproducts, from control reactors, resulted from sidewall fixed growth and could easily be quantified by subtracting experimental fermenter results from control results.

Detail A - Exploded View of Fermenter
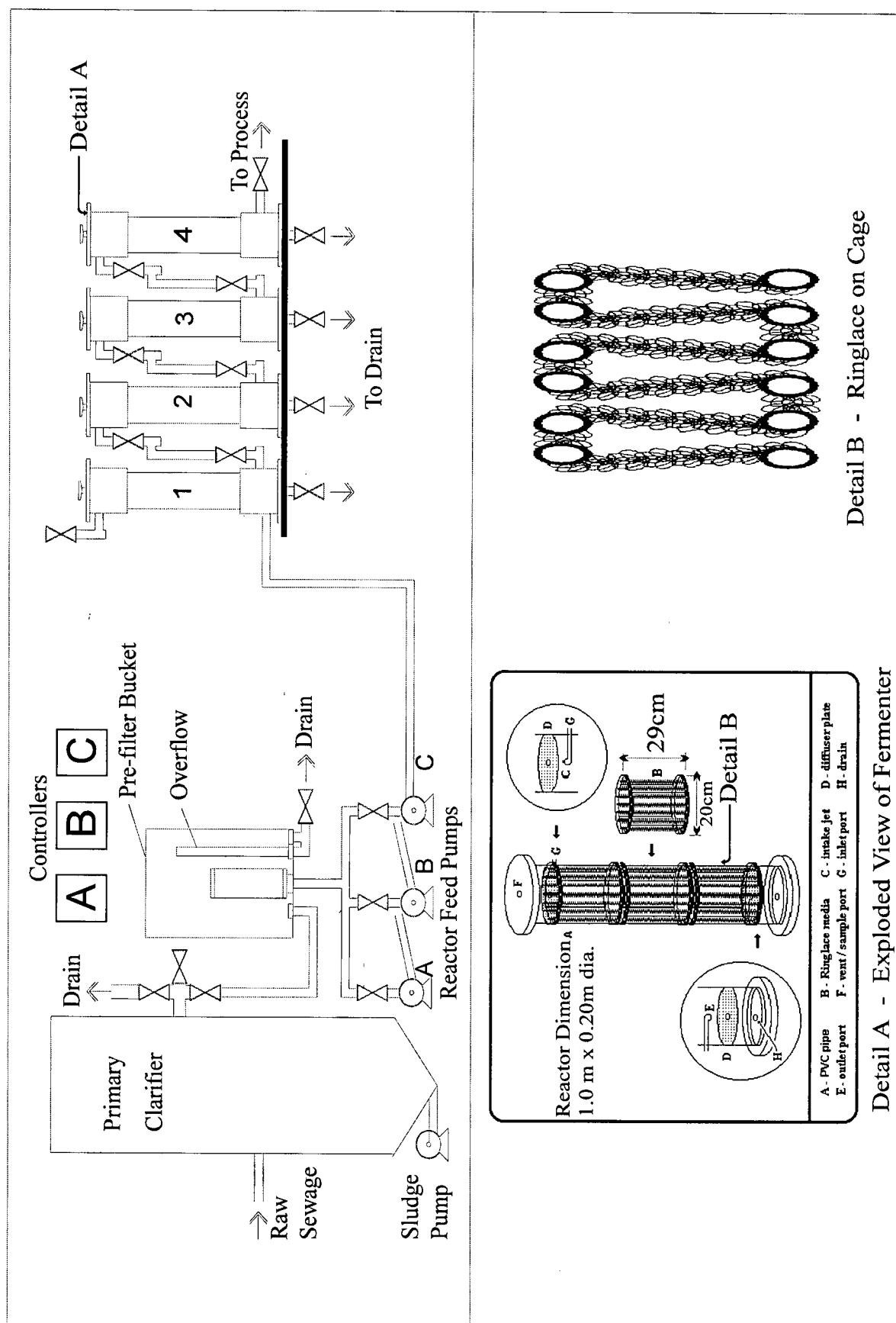
Figure 3.2 Fermenter Configuration and Construction Details

The fermentation units consisted of the following components:

- 1.0 m. high x 0.20 m. diameter PVC pipe served as reactor body (30 L)

- PVC covers c/w drain valve on the bottom and bleed valve on the top

- 12 mm diameter PVC rigid pipe and flexible hose complete with ball valves

- 10 mm diameter nozzle

- 6 mm thick diffuser plate with 6 mm circular holes at 12 mm centres

- Stainless steel cylindrical media support cages inside the reactors

- Ringlace ® strands fixed at 25 mm centres for a total of 38 strands per cage

- 3 Ringlace ® cages per reactor

- Ringlace density in the reactors was fixed at 1,100 m/m^3 for a maximum total surface area of approximately 5.8 m^2/reactor or 197 m^2/m^3. During operation, bio-growth or adhesion of solids would likely reduce the available surface area because individual loops would stick together. The available surface area during operation could be as low as 67 m^2/m^3 (Dumitrescu, 1998).

Primary effluent entered the top of Fermenter #1 through a 10 mm diameter nozzle, which was necessary to stimulate turbulence in the top 75 mm of the unit termed the inlet mixing chamber. Liquid was sprayed tangentially around the inner wall of the pipe into the inlet mixing chamber; a diffuser plate separated the inlet and outlet chambers from the media which supported the attached growth. The provision of an inlet and outlet zone, complete with diffuser plates served several purposes:

- Zone for complete mixing of influent upon entry to the fermenter

- Provision of head space for trapped gases so as not to have deleterious effects on the attached growth. All trapped gases were bled daily from a bleed valve on top of the inlet zone.

- Even distribution of flow through the diffuser plates eliminating the possibility of short circuiting through the reactor. The diffuser plates were periodically checked to ensure that plugging did not occur.

- The diffuser plates also served as a structural barrier between the attached growth zone and the inlet/outlet zone.

- The bottom outlet zone served as a catch basin from which accumulated solids were removed each and every day.

The fermenter design and operation was such that fermentation attributable solely to fixed-film growth could be determined without any confounding effects from entrapped air or solids deposition. This was crucial in quantifying fermentation byproducts from attached growth, one of the objectives of this research.

Based on results obtained from Year 1, Ringlace® media was chosen for this study for its high surface area (0.179 m^2/lineal metre), flexible configuration, aversion to plugging and low maintenance requirements. The Ringlace® itself has no structural stability so cylindrical cages were designed to support the media and allow the media density to be fixed at 1,100 lineal metres per cubic metre inside the reactors. The media itself, is made of PVC consisting of a 6 mm wide band with bundles of ten loops woven into the band. There are 20,000 loops per lineal metre of

band; the loops resemble hair and are 0.1 mm ϕ each. An in-depth description of Ringlace® can be found in Dumitrescu (1998) and at http:/www.Ringlace.com.

3.2.2 Fermenter Operation

Four downflow fermenters (15 minute HRT) in series were fed primary effluent at 2 L/min to maintain a combined maximum HRT of 60 minutes. Daily flushing was a routine part of the operation with approximately 10 L being flushed from each reactor while the feed pumps were still running. Flushing was carried out in an attempt to rid the reactor of solids build up, which would mask VFA production attributable to fixed-film fermentation. The flushed liquid, containing large amounts of solids, was wasted. As a result, air entered the reactors which were under negative pressure from the reduced liquid volume. To eliminate entrapped air, drain valves were closed and air was released through the top bleed valve as continuously pumped influent displaced the entrapped air. Sampling was carried out via sample ports installed near the base of each reactor. All flushing exercises were conducted after sampling had taken place. Valves between fermenters were manipulated during flushing and sampling to ensure that cross mixing was minimized.

3.3 Experimental Program

There were several runs during the project designed to evaluate fixed-film fermentation efficiency and consequent effects on the BNR process performance. A solitary modification was made in each run so a direct cause could be attributed to a change in results. Table 3.1 provides a summary of the different runs and the rationale behind the changes.

Table 3.1   Summary of experimental runs

Run #	Days	Description	Rationale
1	60	Fixed-Film & control fermenters connected to Bardenpho process.	Evaluate Ringlace F^3 vs control and consequent effects on nutrient removal.
2	34	By-pass control fermenters. Operate Ringlace fermenters only.	Evaluate Ringlace F^3 vs unfermented primary effluent on nutrient removal.
3A	39	Phosphorus addition to anaerobic zones. Supplementary fermenter study independent of process.	Ensure excess phosphorus in effluent to evaluate fermenter effect on P loaded system. Determine P:VFA ratios, N:VFA ratios.
3B	37	Continued phosphorus addition; return of drain liquid to process. Continue supplementary study.	Continuation of Run 3a with return of COD normally lost in drain liquid

3.3.1   Experimental Run #1

Run #1 began on July 22, 1997 after a four week break-in period in which the fermenters were conditioned and both the control and experimental processes were stabilized. It was originally intended to last for thirteen weeks, but a serious process upset after Week 5 caused the run to be discontinued between September 1 and October 13.

Fermenter performance and consequent effects on nutrient removal were of prime importance with potential differences between Control side (no fermenter media) and Experiment side (Ringlace® media) being observed. Run #1 was the only experiment incorporating the use of control fermenters.

3.3.2   Experimental Run #2

Run #2 was a continuation of Run #1 except that the Control fermenters were decommissioned and primary effluent was added directly to the anaerobic zone on the control side. The rationale for doing this was to amplify any differences in Control and Experiment process performance by eliminating any contributions in readily biodegradable substrates to the control process introduced by the control fermenters. To ensure both systems had identical biomass at the start of the experimental run, mixed liquor between Experiment and Control processes were cross-mixed for several days prior to the onset of sampling. Run #2 sampling started November 15 and was completed by December 17, 1997.

3.3.3   Experimental Run #3A and #3B

Measurement and comparison of process performance parameters was also of prime importance in these runs, as with previous runs; however, there was added focus on phosphorus removal. During Runs #1 and #2, all soluble phosphorus was removed from both waste streams by the Control and Experimental BNR processes; this meant that the full capacity of the two process to assimilate ortho-P was not known. In Runs #3a and #3b, it was decided to double the ortho-P entering the process by adding 3.0 mg/L soluble phosphorus as mono-sodium phosphate ($NaH_2PO_4 \cdot H_2O$) to the anaerobic zones of the Control and Experimental processes. The rationale for doing this, was to gain insight into the full capacity of the process for phosphorus removal by ensuring that ortho-P (PO_4) was evident in the process effluent.

Run #3b differed from Run #3a in that flushed liquid from the experimental fermenters was not

wasted but was returned to the anoxic zone of the process manually. The flushed liquid was returned to the experimental process to equalize the COD load to both the Experiment and Control sides. As the Control process did not have fermenters, flushing was not required and there was no subsequent loss of COD entering the process. Initially, during Run #2 and #3a, COD lost in the flush water was ignored but unexpected findings from the Experiment process led to the conclusion that COD lost during flushing was significant to process performance. In hindsight, between 15 L and 50 L of flush water was drained from the Experiment side fermenters each day which actually accounted for, as much as 1.5% of the daily COD load to the Pilot Plant.

Sampling for Runs #3a and #3b commenced on January 19, 1998 and ended approximately three months later on April 5.

3.3.4   Auxiliary Study

A side stream investigation, carried out independent of the process, was conducted concurrent with Run #2 and Run #3 experiments. Control fermenters, decommissioned at the start of Run #2, and available Ringlace were used for the auxiliary study. This study focused on VFA production in two fermenters connected in series, in which solids were allowed to accumulate and augment fixed-film fermentation. This system required no flushing and was also fed primary effluent, as the primary clarifier provided excess flow which would have otherwise been wasted. The auxiliary study was designed to be an independent study and therefore had no impact on process performance.   More details are provided in Chapter 4, Results and Discussion.

3.4   Sampling Design

A sampling program was established which focused on assessment of fermenter performance and pilot plant performance by selecting the appropriate sampling points and parameters. Sampling was conducted five days per week, with two of the five days termed "scan days" in which all parameters were sampled at all locations; sampling on the remaining days was limited in scope to influent and effluent locations as depicted in Figure 3.3.

It was clear from previous work (Dumitrescu, 1998, Setter 1995, Rabinowitz, 1985) that sampling should be conducted at the same time each day to avoid upsets caused by diurnal flow patterns and timed pumping to the 12, 000 L sewage holding tanks. A 24-hour sampling test for carbon analysis was carried out to determine (and confirm) acceptable "windows" during the day for sampling to occur. Total organic carbon (TOC) and VFA grab samples were collected every hour for 24 hours. From the 24-hour test, shown in Figure 3.4, it was evident that upsets and instabilities were occurring when the main chopper pump started at 1100hr and 1800 hr and during the afternoon period. The most stable time frame, in terms of influent carbon, was in the morning prior to 1100 hr and so all sampling was done prior to 1100 hr for the duration of the project. These results were consistent with previous experimental findings at the Pilot Plant.

3.4.1   Analyte Selection

Figure 3.3 is a schematic representation of the sampling program and schedule for Run #1. The parameters, listed on the left of Figure 3.3: carbon, nitrogen, phosphorus, suspended solids, as well as pH, temperature, and sludge volume index (SVI) were chosen to aid in fermenter and

Raw → PC → fixed film fermentors* → anaerobic* | anoxic* | aerobic* → SC → effluent*

anoxic recycle 3Q

return sludge 1Q

waste sludge

#4 20um

analyte	Raw	PC	fixed film fermentors			anaerobic	anoxic	aerobic	effluent
TCOD									
TKN (X)									
T-P									
#4 NO3									
PO4									
NH3									
SCVFA									
1.5 um TOC									
0.45 um SCOD									
#4 MLSS/TSS									
SVI									
Temp									
pH									
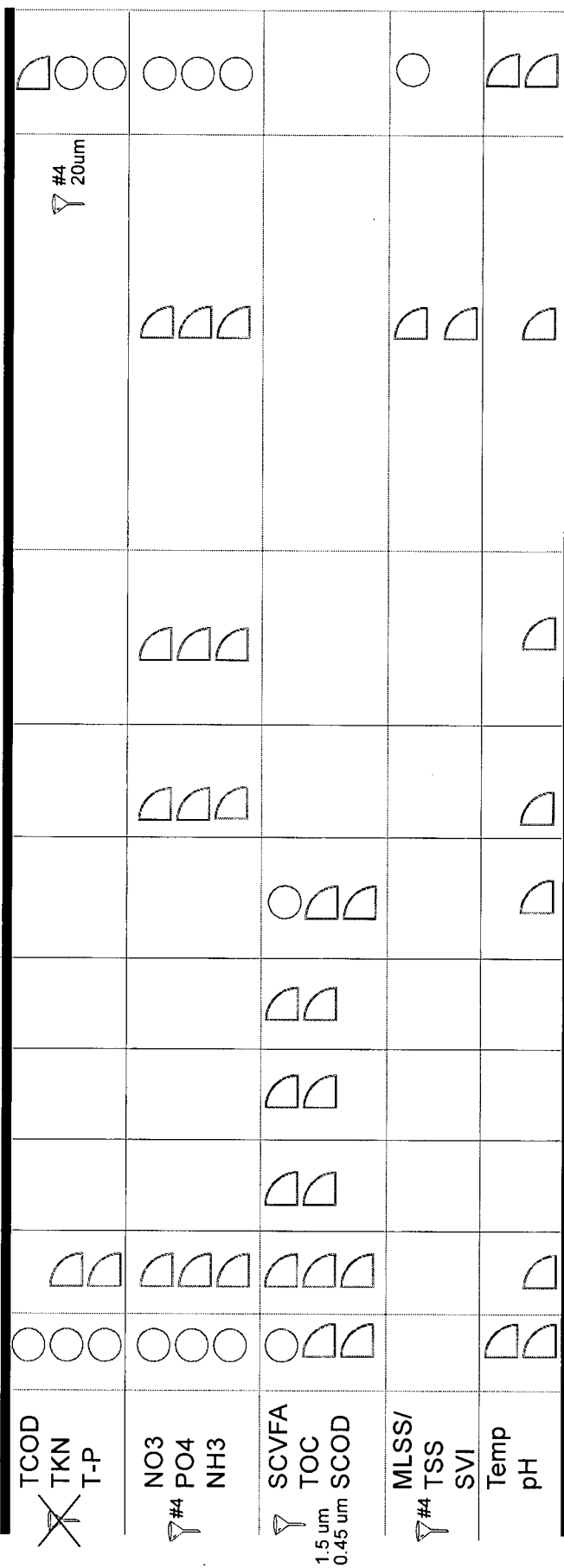
Notes:
- Sampled only Monday and Thursday - "Scan Days"
- Sampled every weekday
- Sample point
- * Both control and experiment waste streams to be sampled

FIGURE 3.3   Pilot Plant sampling program - Run #1
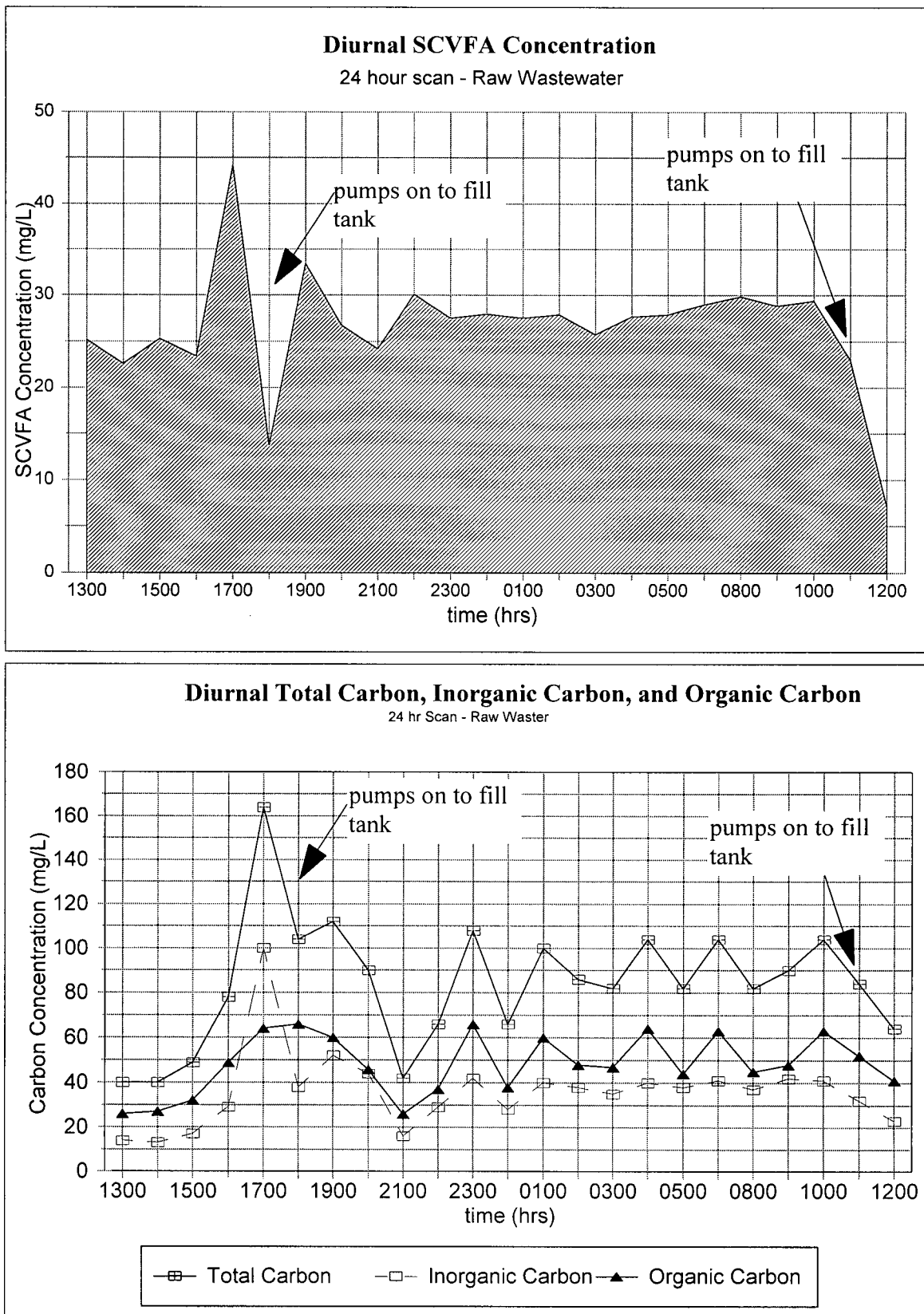
Figure 3.4   Raw wastewater 24 hour results

process evaluation. This selection of parameters was in agreement with those selected for process evaluations described in the literature (Rabinowitz *et al.* 1995, Dawson *et al.* 1995, Randall, 1992). The annotated sketch for Run #1 also denotes the sample locations using the beaker symbol: raw sewage, primary effluent, each fermenter in series (beginning with downstream one), the three BNR process zones and secondary effluent. The symbols (quarter circle and full circle) indicate which analytes were sampled and when. Filter types employed are designated by the funnel with description as follows:

- #4, 20 um = Whatman No. 4 filter paper

- 1.5 um = Whatman 934-AH glass fibre (or equivalent)

- 0.45 um = Whatman 0.45 um membrane filters (or equivalent)

- The funnel with the cross through it indicates that filtering was not required.

The same sampling regime was used for both Control and Experimental waste streams for a total of 3,780 different samples and 6,328 different analyses. Sampling for Runs #2 and #3 varied slightly in that control fermenters were not used and total organic carbon was substituted for chemical oxygen demand.

3.5   Analytical Methods

Sampling was carried out as per the American Public Health Association's Standard Methods (1995) and previous work except where necessary deviations could be justified. Early on in the project, filtration was carefully considered as cost and practicality issues brought about questions regarding the continued use of membrane filters (0.45 um). These filters were very costly, they were difficult to use properly and there was some question with regards to the fractionation of

analytes with membrane versus glass fibre filters (1.5 um).

In previous work at the UBC Pilot Plant, membrane filters were rarely used. It was decided that a filter test be conducted to determine the fractionation of analytes according to filter size. The procedures and results from the filter test can be found in Appendix B. The results clearly justified the substitution of membrane filters with Whatman Glass Fiber 934-AH filters in the analysis of carbon samples (SCVFA and TOC) and Whatman #4 filters in the analysis of ions (NH_3, NO_3 and PO_4). A summary of the sampling protocol is provided in Table 3.2.

3.5.1   Carbon Analysis

Carbon measurements consisted of SCVFA, soluble and total chemical oxygen demand (COD), and total organic carbon (TOC). SM 5560 A/B (Standard Methods, 1995) was followed for analysis of volatile fatty acids; analysis was done with a Hewlett Packard 5880A Gas Chromatograph equipped with a flame ionization detector and automatic sampler. Samples were acidified with phosphoric acid to about pH 2 at the time of sampling and racks of SCVFA were processed by laboratory technicians once weekly. COD measurements were done following SM 5220D "The Closed Reflux Colorimetric Method" (Standard Methods, 1995) on a Hach DR2000 Spectrophotometer. COD measurements were found to be highly variable (+/- 15%), and demanding of materials and labour. In Runs #2 and #3, COD measurements were discontinued in favour of TOC analysis. Total organic carbon analysis was carried as per SM 5310B (Standard Methods, 1995) on a TOC 500, Shimadzu Total Organic Carbon Analyser with automatic sample injector. TOC samples were preserved at the time of sampling by acidification

as per Standard Methods. Organic carbon was found to be consistently accurate and precise with less than 6% error, 95% of the time.

3.5.2 Nitrogen and Phosphorus Analysis

For the purposes of this study, nitrogen and phosphorus were characterized by analysis of ammonia (NH_3), nitrate/nitrite (NO_3), orthophosphorus (PO_4), Total Kjeldahl Nitrogen (TKN) and Total Phosphorus (TP). All analyses were done on a Lachat QuikChem Automated Ion Analyser following QuikChem methods 10-107-06-1-Z for NH_3, 10-107-04-1-Z, for NO_3, 10-115-01-1-7 for PO_4, 10-107-06-2-E for TKN and 10-115-01-1-I for T-P. (QuikChem, 1990). QuikChem methods have been adapted from the 4500 series Standard Methods for their respective analyses. Samples were preserved as per Standard Methods at the time of sampling with sulfuric acid down to pH 2 or with phenyl mercuric acetate in the case of NO_3 & PO_4.

3.5.2 Solids

Solids analysis included mixed liquor suspended solids (MLSS) and total suspended solids (TSS) and was carried as per SM 2540 D "Total Suspended Solids Dried at 103-105 °C" (Standard Methods, 1995). To monitor settling characteristics of the activated sludge in the BNR process, the sludge volume index (SVI) was calculated daily by collecting a 1.0 L sample of mixed liquor from the aerobic zone and allowing it to settle in a 1.0 L graduated cylinder for 30 min. The SVI was calculated as follows:

$$SVI = \frac{30 \text{ min. settled sludge volume (mL/L) x 1000.}}{\text{mixed liquor suspended solids (mg/L)}} \quad \text{(Standard Methods, 1995)}$$

Table 3.2 summarizes the parameters measured, as well as the filtration, preparation and storage methods employed.

Table 3.2   Sampling Protocol

	Analyte	Sample Points	Filtration	Preparation/ Preservation	Storage
Total Samples	TCOD	influent & process	none / Wh#4 (20 um)	prepared COD tubes add 2ml sample	4°C in steel racks
	TKN & T-P	influent & process	none / Wh#4 (20 um)	60 ml sample add H_2SO_4 to pH 2	4°C in fridge; labelled in box
Anions	NOx/ PO_4	influent & effluent	Wh#4 (20 um)	2 X 8 mL; 2 drops phenyl mercuric Ac	4°C in fridge; plastic racks
	NH_3	influent & effluent	Wh#4 (20 um)	2 X 8 mL; 2 drop H_2SO_4 to pH 2	4°C in fridge; plastic racks
Carbon	SCVFA	influent & fermenters	934-AH (1.5 um)	1 mL in GC vial 0.1 mL HPO_4	4°C in fridge; VFA rack
	TOC	influent & fermenters	934-AH (1.5 um)	1 X 8 mL; 2 drop H_2SO_4 to pH 2	4°C in fridge; labelled in box
	SCOD	influent & fermenters	934-AH (1.5 um)	prepared COD tubes add 2ml sample	4°C in steel racks
Solids	MLSS/ TSS	process effluent	934-AH (1.5 um)	filter 50 mL; dry at 105°C	na
	%P %N	aerobic zone	na	divide T-P, T-N by MLSS	na

Note: na - Not Applicable

3.6   Data Quality

Quality Assurance/Quality Control (QA/QC) parameters are summarized in this section; details and calculations are presented in Appendix A. For the purposes of this thesis, QA/QC encompassed the protocols for ensuring representative data were reported, and the correct sampling procedures in accordance with the established methods. There are many possible

sources of error in reporting environmental data including sampling error, error associated with processing a sample (i.e. filtering, preservation, storage), handling error, and analytical error. Since differences between data sets were often small or indeterminate in this project, there was additional emphasis placed on assuring the precision and accuracy of the reported data. The comparative nature of this research required that data be subject to statistical analysis prior to the formulation of any conclusions. A 95% confidence interval or α value equal to 0.05 was used, unless otherwise noted.

3.6.1 Determination of Outliers

One or more measurements often vary substantially from other values and are subsequently suspected of being outliers or anomalous to the data set. A simple method for detecting outliers presented in Standard Methods (Standard Methods, 1995), involves calculating a T-statistic for each measured parameter based on the mean and standard deviation of the data set. Each T-statistic was compared against the critical T value for a 5% test of discordancy for a single outlier in a normal sample. T values for each observation were calculated as follows (Barnett *et al.*, 1978).

$$T = |(x - \bar{x})| / s \qquad \text{where: } x = \text{the observation}$$

$$\bar{x} = \text{data set (run) mean}$$

$$s = \text{data set standard deviation}$$

If the absolute value calculated for T exceeded the critical T value, an outlier was identified. A decision was then made to either drop or include the data point based on any possible explanations for the outlier. In theory, no result should be rejected, because it might indicate the

presence of a true variant or a faulty technique that casts doubt on all results (Standard Methods, 1995). Therefore, the decision to include or reject an outlier was dependant on there being a plausible explanation for the deviance. In the absence of a reasonable explanation, the outlier was included. If, however there was some plausible explanation - failed pumps for example - that data point was rejected from the calculations.

3.6.2   Precision and Accuracy

Precision and accuracy testing for all analytical methods was routinely carried out as per Standard Methods (1995) through recovery of known additions (accuracy), measurement of known standards (accuracy) and through analysis of duplicate samples (precision). Example calculations are shown in Appendix A.

Once the accuracy of a method was ascertained through recovery or measurement of a known standard, precision for each method was necessary to determine confidence intervals for the analyte of interest. Precision was a factor of sampling error, error associated with preservation and handling, and/or equipment error. Method confidence intervals are presented in Table 3.3

3.6.3   Method Detection Limit

The U.S. EPA defines the Method Detection Limit (MDL) as "the minimum concentration of a substance that can be measured and reported with 99% confidence that the analyte concentration is greater than zero....." It is essential that all sample processing steps be included in the determination of the method of detection limit (Berthouex, et al., 1997). The method detection

limit is a statistical concept estimated from data at low concentrations for the analyte in question. The MDL varies for each parameter of interest and each piece of analytical equipment utilized. A total variance model elaborated on by Berthouex *et al.* (1997) was applied to parameters where concentrations were frequently found at or near zero concentration. The methodology used in determining the MDL for PO_4, TP, NO_3, TKN and NH_3 is elaborated on in Appendix A and the values are presented in Table 3.3.

Table 3.3   Method Confidence Intervals and Detection Limits

parameter	Standard Deviation (mg/L)	Confidence Interval +/- (mg/L)	Method Detection Limit (mg/L)
PO_4	0.30	0.59	0.003
TP	0.86	1.7	0.003
NO_x	0.24	0.46	0.003
TKN	1.17	2.3	0.084
NH_3	1.43	2.8	0.164
SCVFA	0.30	0.60	na
MLSS	96	190	na
TSS	9	17	na

Note: na - Not Applicable

CHAPTER 4

4.0 RESULTS AND DISCUSSION

All experimental work was carried out at the UBC Pilot Plant between July of 1997 and April of 1998. The experiments were carried out according to the details provided in Chapter 3, Experimental Methods and Analytical Procedures. Section 4.1 is a summary of influent characteristics, both physical (temperature, pH and solids) and chemical (nitrogen, phosphorus, and carbon). Fermenter performance for Runs #1 through #3B is presented in Section 4.2. Process performance, and the influence of fermentation by-products, are discussed in Sections 4.3 and 4.4. In addition to the above, results from a process independent side-stream study are presented in the last section.

4.1 Influent Wastewater Characteristics

The influent wastewater originated from a domestic/residential source on the campus at the University of British Columbia. The wastewater could be characterized as weak to medium strength, although there was an unusually high concentration of SCVFA in the raw wastewater. The distance from source to treatment was quite short, which may have limited temperature variations to between 24°C in the summer to 12°C in winter (Figure 4.1) Also, the collection system was relatively flat prior to reaching the pilot plant; this condition coupled with the storage of sewage in the 12,000 L tanks prior to treatment meant that no measurable dissolved oxygen was present in the process influent. There were no lift stations between the residences and the pilot plant (Marty Cole, 1997).

The combination of a flat collection system and warm temperatures could account for some of the SCVFA present in the raw sewage (Randall, 1994); however, fermentation of raw sewage, stored in batch at the plant (in 12,000 L tanks), probably accounted for most of the SCVFA in the process influent. Figures 4.1 and 4.2 are temperature profiles and nutrient profiles, respectively, for the primary effluent just prior to entry into the fermenters. A daily pilot plant log, maintained on site, was useful in explaining anomalous data points or divergent trends. Figures 4.1 and 4.2 have been annotated to help explain such deviations.

Variations in temperature were seasonal, with low temperature spikes coinciding with heavy rainfall or snowfall events, suggesting the existence of inflow and infiltration in the UBC collection system. Influent pH was maintained at about 7 (+/- 0.5) as about 100 mg/L (as $CaCO_3$) of alkalinity in the form of sodium bicarbonate was added to the process daily. Unusually high and variable concentrations of influent volatile fatty acids were observed during the study period; 84% of the time, observations ranged between 20 mg/L and 35 mg/L expressed as acetic acid (HAc). Influent VFA concentrations recorded in previous studies conducted at the UBC Pilot Plant rarely exceeded 20 mg/L. The highly variable observations comprising the remaining 16% can be explained after a review of the plant log, for example:

1. The period of low influent SCVFAs near the beginning of August was a result of a cleaning exercise (cleaning in Figure 4.2) in which bio-film from the storage walls and a large amount of solids (200 kg) were physically removed from the 12,000 L storage tanks.

2. A downward spike in mid-October coincided with sampling conducted during the evening instead of the usual sampling time between 0800 and 1030 hr.
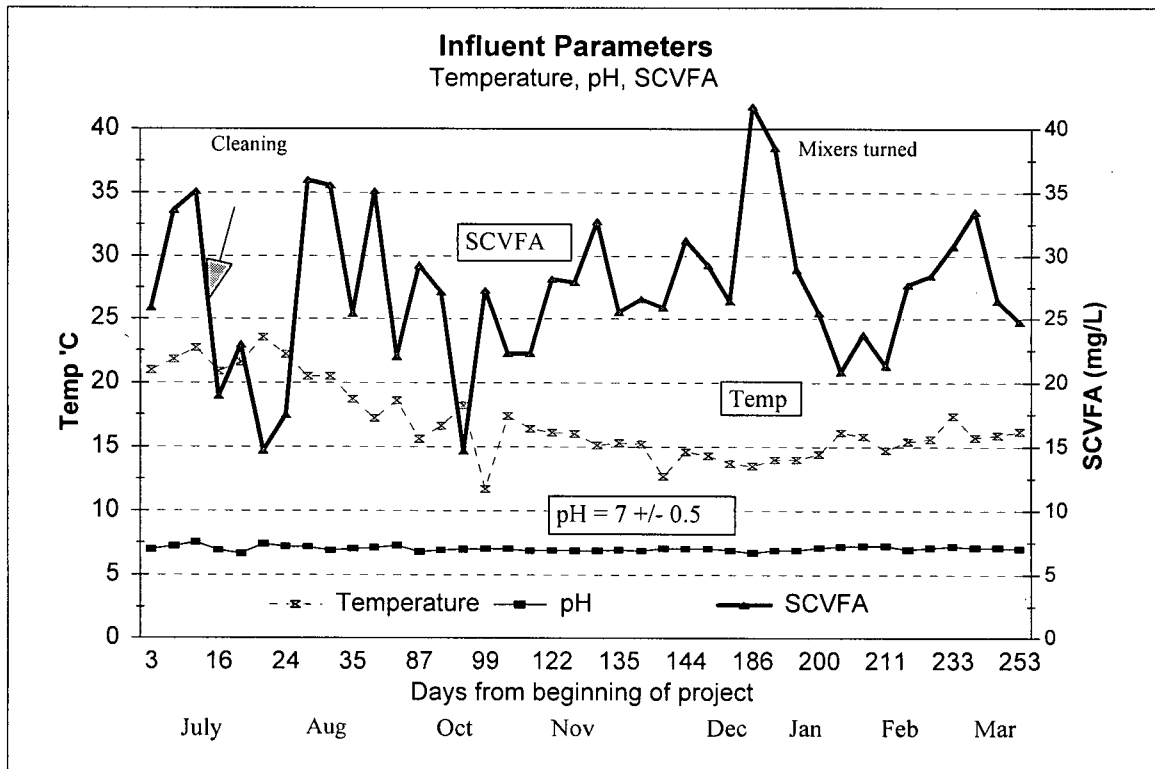
Figure 4.1   Influent temperature and SCVFA variation
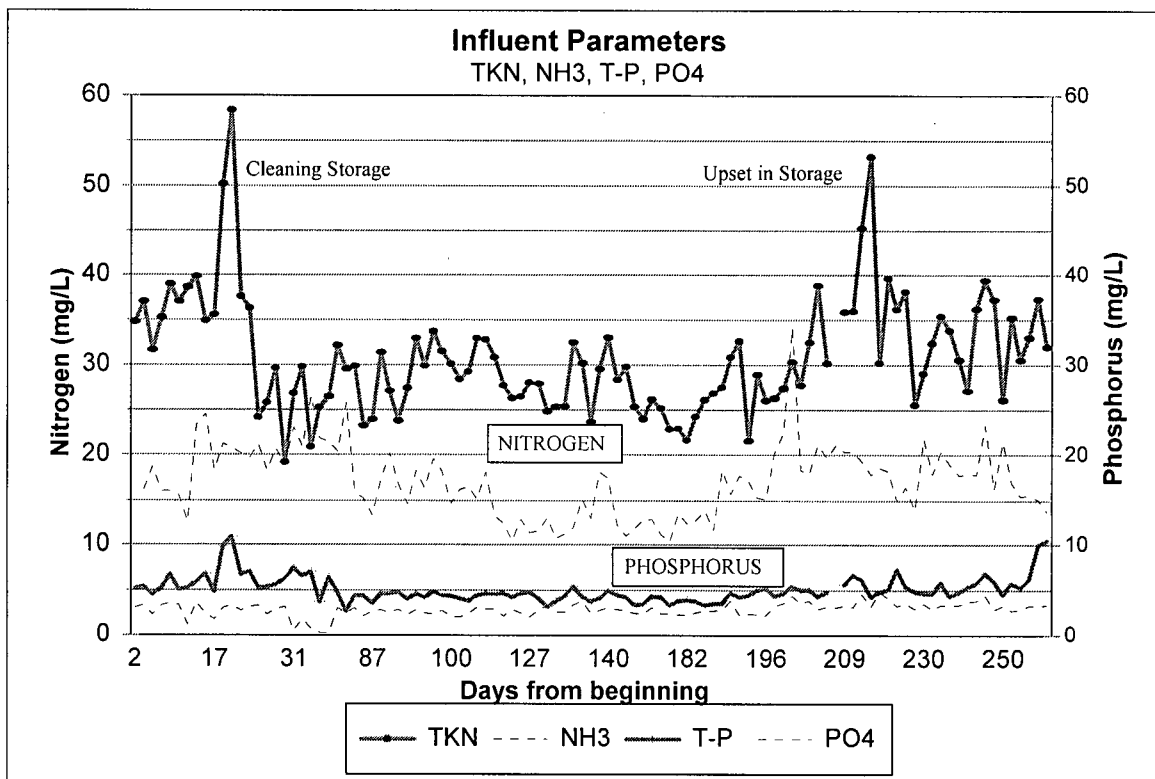
Figure 4.2   Influent Nutrient Variation

3.	The upward spike near the end of January, labelled "Upset in Storage Tank", coincided

with the re-activation of a failed mixer in one of the 12,000 L storage tanks. The mixer

had been out of service for an extended period of time, resulting in the formation of a

floating sludge blanket in the tank. When the mixer was turned on, a surge of SCVFA,

exceeding 35 mg/L, and lasting for 7 days was elutriated from the blanket.

There is no evidence from Figure 4.1 that the influent SCVFA concentration was influenced by

temperature of the raw wastewater. The variation of influent volatile fatty acids does not

correspond to seasonal temperature variations but does appear sensitive to storage upsets,

changes in routine, or precipitation events. Therefore, it is likely that fluctuations in influent

SCVFA concentration is a direct result of conditions at the pilot plant (sewage storage, handling)

more so than conditions in the collection system.

An examination of spikes in influent nitrogen and phosphorus (Figure 4.2) indicates there was no

discernable trend related to temperature. Deviations were, for the most part, coincident with

upsets which influenced SCVFA concentrations as described above. There were two periods of

high influent concentrations for which there was no obvious explanation; one in TKN near mid-

February, the other in T-P at the end of the study. The most probable explanation is an

operational problem associated with raw sewage lift pump failure and irregular operation which

occurred at the time. A lift pump failure often resulted in a high influx of solids after re-start,

which may have contributed to high polyphosphate and organic nitrogen concentrations in the

influent.

Table 4.1 is a summary of the pertinent influent (primary effluent) wastewater parameters arrived

at by calculating the arithmetic means from data collected throughout the project. A few

important points worth noting:

1.   The TCOD:TP ratio was 73 which exceeded the recommended minimum ratio for good

      phosphorus removal reported in the literature by a factor of approximately two. (Barnard

      et al., 1998, Randall *et al.*, 1992, US EPA 1987). The high ratio of carbon to phosphorus

      would indicate that the influent was amenable to good phosphorus removal without the

      need for pre-fermentation.

2.   The TCOD:TKN ratio was about 12 which is just slightly higher than the ratio typical of

      most wastewaters (Randall *et al.*, 1992).

3.   The high concentration of influent VFA (versus historical Pilot Plant data), already

      discussed.

Table 4.1   Influent wastewater parameters

Flow L/m	Temp °C	pH	SCVFA mg/L	T-P mg/L	PO$_4$ mg/L	TKN mg/L	NH$_3$ mg/L	TCOD mg/L	SCOD mg/L	TOC mg/L	STOC mg/L
2 .0	16.9	7.0	26	6.5	2.9	30.3	16.7	359	219	63	56
Note: 1. Observed primary effluent TSS = 97 mg/L ; VSS/TSS Ratio = 0.85											
2. The primary clarifier removed 44% of the influent TSS											

The average values shown, have been corrected according to Standard Method 1010 (Standard

Methods, 1995), which provides a procedure for identifying outliers in a normally distributed

data set. Observations were identified as outliers using a 5% critical value test for discordancy.

Only outliers in which a known error or process upset had occurred were rejected from the data

set. The procedure is explained further in Appendix A - Statistical Analysis.

4.2 Fermenter Performance

Fermenter performance in all experimental runs was gauged by measuring VFA yields and production rates, as well as the COD and TOC concentrations in the fermenter effluent. It was found that SCVFA production in the fermenters was closely related to unit HRT and temperature of the influent, as previously reported in the literature (Elefsiniotis *et al.* 1995, Canziani *et al.* 1996, Christensson *et al.* 1998).

Fermenter daily operation and maintenance was an important factor in VFA production during this study. It was discovered by Dumitrescu (1998), that solids accumulation in these units could easily be controlled by increasing or decreasing the volume of liquid flushed daily from each fermenter. It was then established, and confirmed in this study, that an increase in solids accumulation in the fermenters led to an increased VFA production. Since the purpose of this research was to assess the ability of a fixed-film to produce fermentation by-products, solids were rigorously flushed until the drain liquid resembled primary effluent in clarity and colour.

4.2.1 Experimental Run #1 SCVFA Production Rates

Run #1 was a direct comparison between fixed-film fermenters (F^3) with Ringlace media and control fermenters with no media as described in Section 3.2.2. This section is a summary of fermentation by-products from each fermenter train during the period from late July, 1997 to late October, 1997. All raw data can be found in the Appendix C - Experimental Data.

The VFA production rate, illustrated in Figure 4.3 and Figure 4.4, was arrived at by subtracting

SCVFA concentration leaving the fermenters from the concentration entering and dividing by

HRT, which is 1 hour in this case.

$$VFA_{rate} = \frac{SCVFA_{out} - SCVFA_{in}}{Time\ (HRT)}$$

The observed concentrations in Figures 4.3 and 4.4 comprise acetic acid (HAc), as well as

propionic acid (HPr); both are presented as HAc. (The conversion factor for HPr to HAc is 0.81

based on the molecular weight of each compound). The bottom area in both graphs consisted of

HAc, which accounted for about 75% of the total SCVFA, while the top area was propionic. For

fermentation of raw sewage, this ratio of HAc to HPr is consistent with previous research (Koch,

1994, Danesh, 1995) and fermentation of primary sludge under micro-aerobic conditions

(Sharma, 1998, Chu, 1995).

The Run #1 VFA production rates were highly variable in both Control and Experimental units

even though temperature of the influent remained fairly constant at 20 °C, +/- 2.3 °C. Possible

causes for the variability in SCVFA production included, inconsistencies in fermenter flushing

and draining, failure to bleed entrapped air from inside the fermenter units, variations in influent

VFA entering the plant, and sampling error. In several instances, the production rate peaks and

valleys for Control and Experiment mirrored each other, indicating that fermenter influent was

responsible for the variations. This point is investigated further in following sections.

SCVFA Production Rate
Run #1 - Control Fermenters

mean = 4.4 mg/L
std. dev. = 4.5 mg/L
% HAc = 75%

Rate mg/L/hr

Days from beginning of project

Acetic   propionic
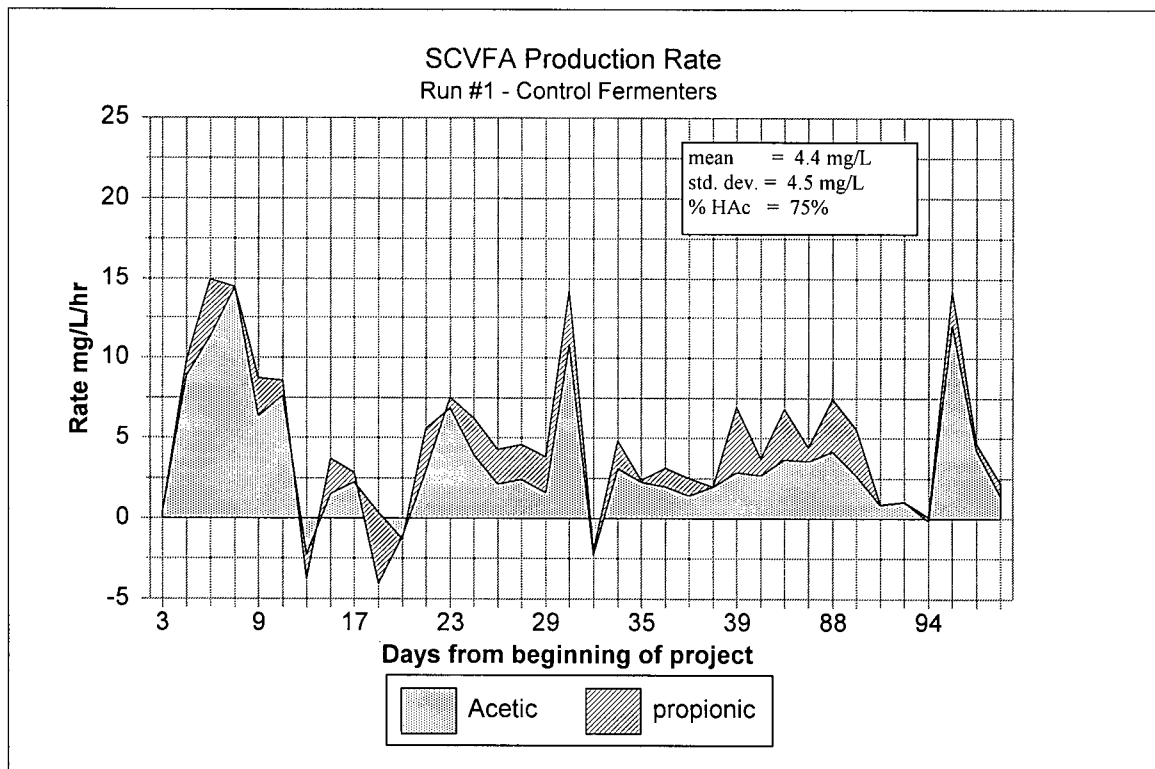
Figure 4.3   Run #1 SCVFA production rate in control fermenters

SCVFA Production Rate
Run #1 - Fixed Film Fermenters

mean = 9.1 mg/L
std. dev. = 4.9 mg/L
% HAc = 73%

Rate mg/L/hr

Days from beginning of project

Acetic   propionic
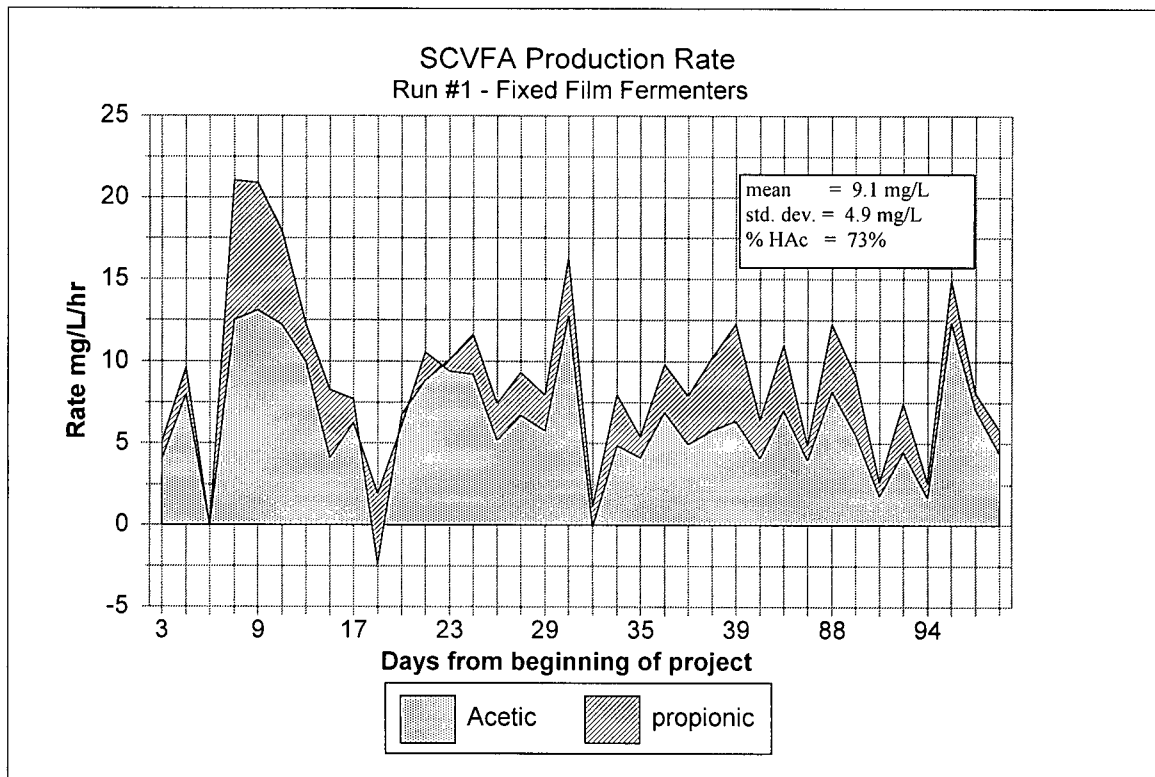
Figure 4.4   Run #1 SCVFA production rate in fixed-film fermenters

4.2.2 Experimental Run #1 TOC and COD

Only brief mention of COD and TOC fermenter "production" results is warranted here since the results were deemed either insignificant or inconclusive. Table 4.2 is a statistical summary of the various forms of carbon measured in the Control and Experiment fermenters. All recorded results were calculated by subtracting fermenter influent concentrations from the concentration leaving the reactors.

Table 4.2 Run #1 Carbon Summary (C_{out} - C_{in})

		Experiment Fermenters (mg/L)			Control Fermenters (mg/L)		
Form	n	mean	median	std dev (σ)	mean	median	std dev (σ)
COD	16	17	14	72	-7	8.5	54
TOC	16	8.2	0.9	21.1	-6.9	1.0	25.5
SCVFA	35	9.1	8.3	4.9	4.4	3.9	4.5

The high degree of TOC and COD variability (as indicated by their standard deviations) suggested these two parameters were not suitable indicators of daily fermenter performance. SCVFA was determined to be a superior means of measuring daily fermenter performance and the data supported this conclusion. The high degree of variability in the COD and TOC measurements can be explained by the solids present in the filtrate. Both methods of measurement (TOC and COD) convert all forms of carbon passing the filter, both dissolved and solid, into an equivalent carbon concentration. Solids present in the filtrate were highly variable and dependant on fermenter flushing, filter type, volume of filtrate and human error among other factors. The method for detecting SCVFA is analyte specific and the statistical data

demonstrates this method is less sensitive to filtrate solids. Furthermore, there was no

discernable trends or correlations between either TOC or COD leaving the fermenters and

SCVFA leaving the fermenters; Stevens (1994) also reported the same finding in a two year

study at the Kelowna Pollution Control Centre. Normally, TOC and COD leaving the fermenters

are correlated to SCVFA leaving, but sampling and analytical techniques frequently mask such

relationships, as was the case in this study. For these reasons, SCVFA measurements on the gas

chromatograph were chosen as the means of assessing fermenter performance.

4.2.3   Experimental Run #2 & #3 SCVFA Production Rates

Run #2 and #3 focussed primarily on how prefermentation affects the BNR process. Operation

of the Control fermenters ceased with Control side primary effluent being routed directly to the

anaerobic zone. The SCVFA production rates, shown in Figure 4.5, are presented as an area plot

comprising acetic acid on the bottom with propionic acid on top. This section covers all

corrected observations starting from run #2 in November, 1997 and ending with Run #3B ending

in April, 1998.

SCVFA Production dropped about 50% during this time period from an average of about 4.9

mg/L in Run #1, to an average of 2.3 mg/L in Runs #2 and #3. The cause for this decrease in

VFA production was colder influent wastewater temperatures, resulting in a slower rate of

hydrolysis (Llabres-Luengo *et al.* 1988).   During the first run, wastewater temperatures were

fairly consistent at about 20 °C. During the period from November to April the average

temperature of the influent dropped to about 15°C +/- 1.3 °C, which is a significant drop in

temperature in an anaerobic system (Gupta, 1985, Lilley, *et al.* 1990).
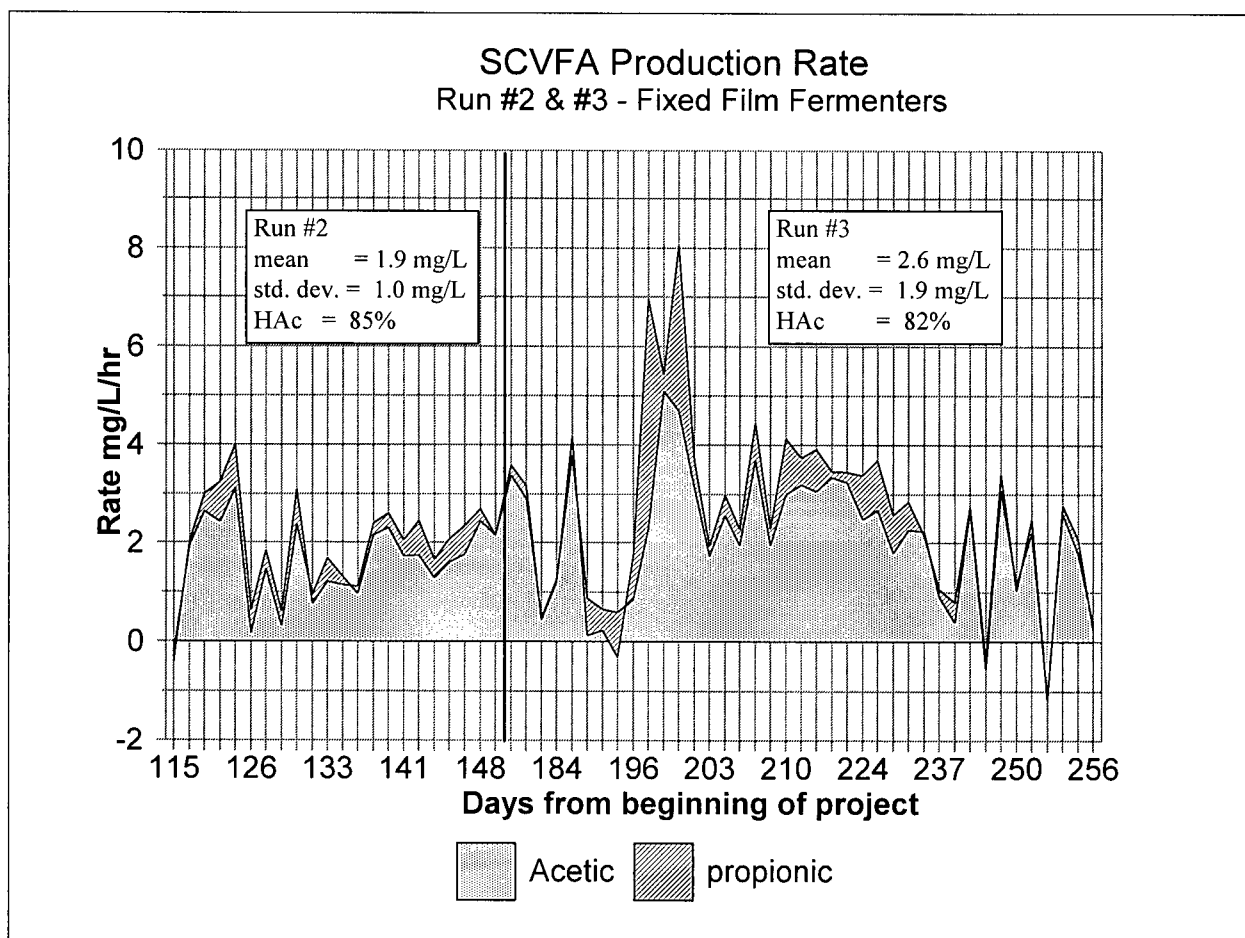
Figure 4.5   SCVFA production rate in runs #2 and #3

4.2.4   Factors Affecting Fermenter Performance

This section further discusses several factors that affected the observed SCVFA yields and

production rates from the high-rate, fixed-film fermenters used in this study.

4.2.4.1   Temperature Effects

A frequently quoted approximation known as the van't Hoff rule states that the reaction rate

doubles for every 10°C temperature rise (Benefield *et al.* 1982). The Arrhenius equation is

another often quoted model relating temperature, activation energy and the ideal gas constant to

reaction rate. Researchers Llabres-Luengo and Mata-Alvarez (1988) found that the rate of

hydrolysis, during acidogenisis, followed the Arrhenius equation between 20 °C and 44 °C.

Jorgensen (1990) investigated COD yield of primary sludge versus temperature and found that

yields dropped 30 to 40% when temperatures went from 20°C to 15°C. At 10°C, Jorgensen

states that "the hydrolysis rate was very slow and comparable to the rate in sludge stored at 1-

2°C". Fothergill (1996) and Gupta (1986) also recorded a marked drop in VFA production from

primary sludge when temperatures dropped below 20°C. A correlation between temperature and

SCVFA produced in this study is presented by Figure 4.6.
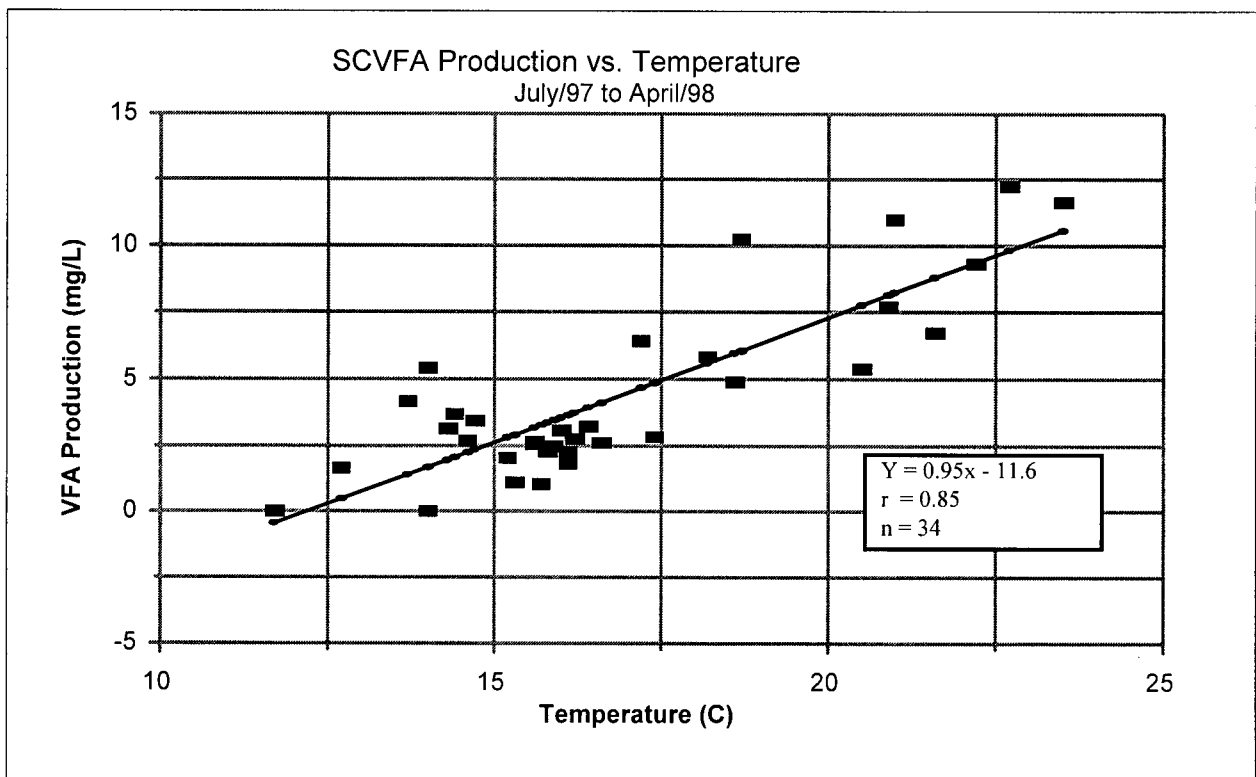
Figure 4.6   Temperature effect on VFA production

There appears to be a positive linear correlation between VFA production and temperature evident in the graph and regression coefficient of correlation. This would indicate that fermentation of primary effluent is a first order reaction, similar to fermentation of primary sludge, in which the reaction constant is temperature dependant (Lilley, *et al.* 1990). A test for significance ($\alpha = 0.05$) revealed that r-critical for the given sample size is 0.287 (Sincich, 1987). Since the calculated regression coefficient (r = 0.85) exceeded the critical coefficient, there was sufficient evidence to conclude that temperature and VFA production were positively correlated. Caution should be exercised in using the linear relationship in Figure 4.6, as it was not the intent to accurately define a relationship, but only to investigate the possibility of its existence. The relationship appears linear in the temperature and production ranges shown for high-rate fermentation of primary effluent. A similar relationship would not necessarily exist at higher temperatures, longer HRTs or with different substrate.

4.2.4.2 Effect of HRT

Dumitrescu (1998) determined an optimal HRT for high-rate VFA production in a fixed-film fermenter to be somewhere between 40 and 60 minutes. In this study, samples for SCVFA analysis were collected after 15, 30, 45 and 60 minutes HRT throughout the duration of the project, to confirm Dumitrescu's findings. Figure 4.7 summarizes VFA yields corresponding to the individual HRTs, by means of a box and whisker plot for each of the three runs.

The box and whisker plot is a useful tool for characterizing many aspects of each HRT data set. The whiskers define the maximum and minimum value for each data set and thus represent the

range. The box represents the inner quartile range (25th to the 75th percentile), and provides a quick method of assessing precision. The two line graphs join the average and median values for each data set and closely resemble each other. When the median is less than the average, a skewed left data set would be indicated; when the median is greater than the average, a skewed right data set would be indicated. The relative closeness of the median and average values observed in Figures 4.7 and 4.8 would indicate that the data sets for the individual HRTS resembled a normal distribution.

In addition to providing statistical information regarding each data set, the average and median values shown in Figures 4.7 and 4.8 provide trends for VFA production yields which are calculated as follows:

$$VFA_{yield} = SCVFA_{out} - SCVFA_{in}$$

From the slope of the graphs, rates can be qualitatively observed after each reactor representing a 15 minute HRT. From the box and whisker plots, there is no evidence to suggest that VFA production would not continue to increase with increased HRT past 1 hour. Fermenter HRT was limited to 60 minutes for practical reasons and also because this experiment was intended to be a high-rate investigation. There appears to be a decrease in the rate (as indicated by the slope) after 45 minutes of hydraulic retention time. This trend was consistent throughout the sampling period and can only be explained by some repeated operational error, or fault in the construction of the third fermenter unit.
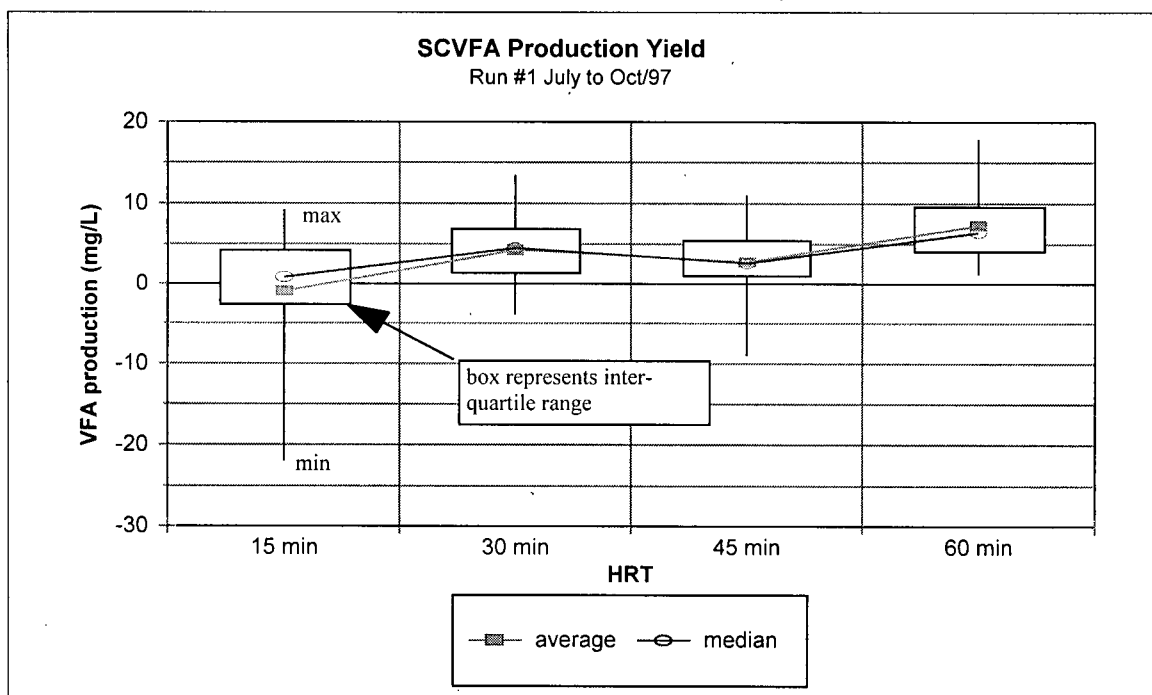
Figure 4.7   **Run #1 effect of HRT on VFA production yield in fixed-film fermenters**
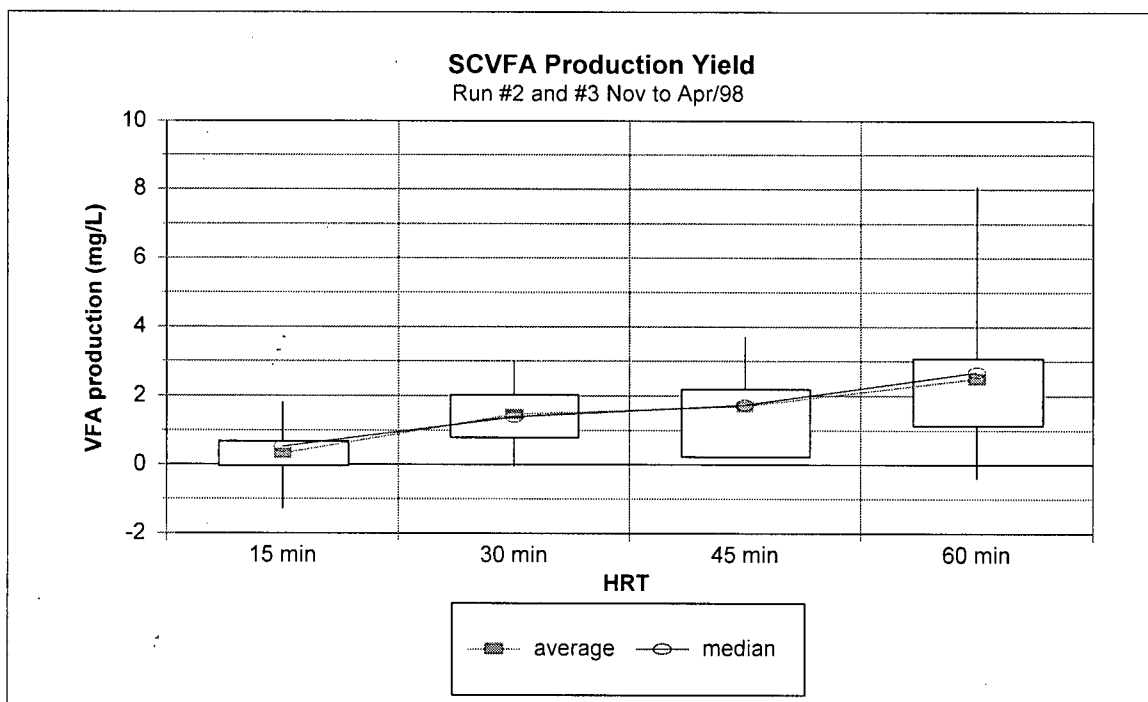
Figure 4.8   **Run #2 & #3 effect of HRT on VFA production yield in fixed-film fermenters**

4.2.4.3 Effect of Influent VFA

When influent VFAs exceeded a certain value, VFA production from the high-rate F^3 units decreased. Figure 4.9 is a scatter plot, VFA produced versus VFA entering the fermenters, from which a discernable downward trend is evident. It appears that production is negatively affected by high influent VFA to the fermenters. In Figure 4.9, when influent VFA is less than 20 mg/L, production exceeds 5 mg/L in all significant observations, except one. When influent VFA is greater than 20 mg/L, production is less than 5 mg/L in most cases as shown in Figure 4.9.

A simple test for significance, similar to that Section 4.2.4.1, reveals that the calculated coefficient of correlation, $r = 0.58$ is greater than the critical value, which was $r = 0.183$. This fact indicates that a negative correlation between the two parameters exists. The reason is not clear but one possible explanation is that fermentation of readily biodegradable substrates, normally occurring in the fixed-film fermenters, has already taken place in the sewage collection system or pilot plant holding tanks.

To explore the possibility of a correlation between influent concentration and VFA production further, recorded observations from Dumitrescu's research (1998) were similarly plotted and are shown in Figure 4.10. The plot of VFA produced versus influent VFA appears scattered with slight negative correlation especially when influent concentration exceeds 20 mg/L of SCVFA. Below an influent VFA concentration of 20 mg/L, there appears to be little evidence suggesting production is related to influent concentration. The results obtained by Dumitrescu corroborate the finding that VFA production in high rate fixed-film fermentation of primary effluent drops
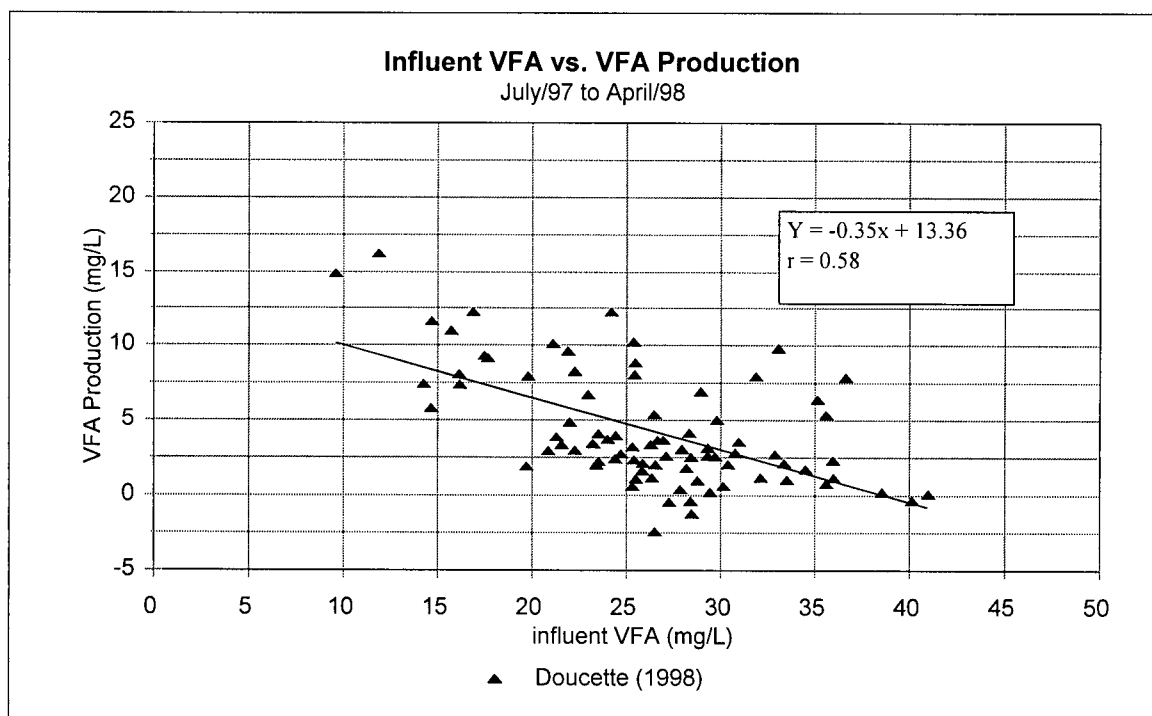
Figure 4.9   **Effect of influent VFA on VFA production rate in fixed-film fermenters - Year 2**
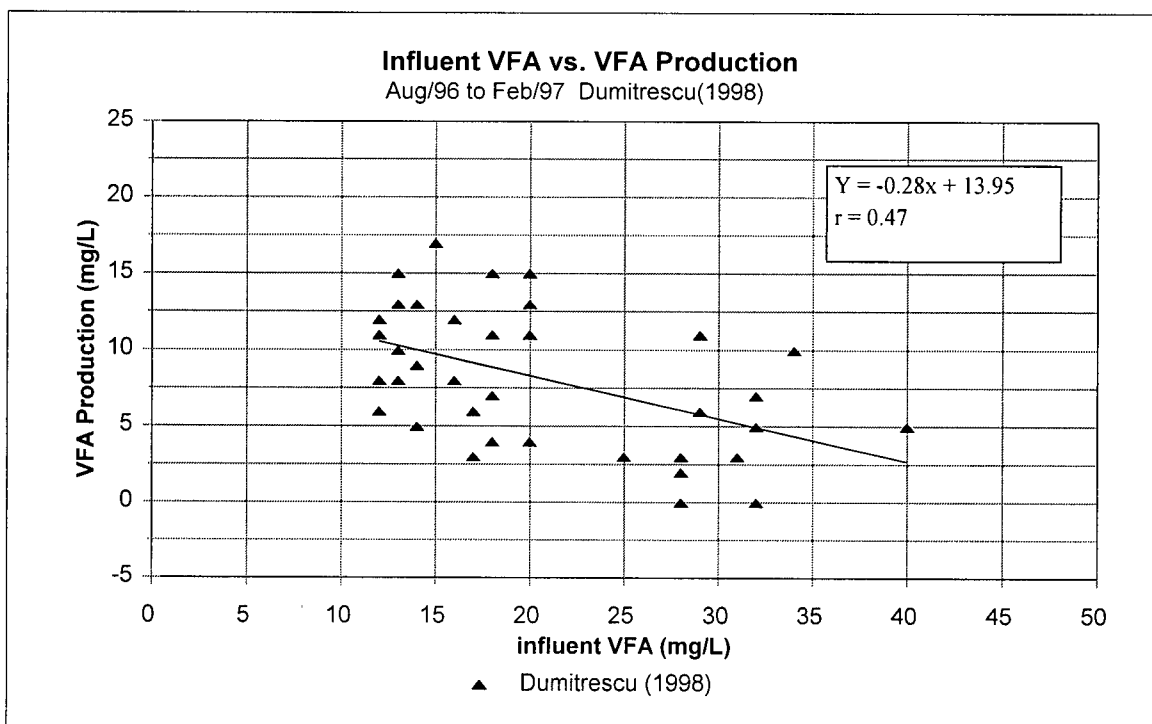
Figure 4.10   **Effect of influent VFA on VFA production rate in fixed-film fermenters - Year 1 (Dumitrescu, 1998)**

when incoming VFAs exceed a certain value. For this particular wastewater, the readily fermentable component could be could be approximated as 20 mg/L, expressed in terms of VFA, after acidogenisis.

These findings were significant to this research, because the implications were that high-rate fermentation might be more applicable to wastewaters which have not undergone fermentation during transmission between source and treatment. In wastewaters subject to anaerobic conditions during transmission/handling, the readily fermentable component has been converted to VFA by acid-producing microorganisms, and is therefore, not available for fermentation in the high-rate type fermenters.

4.2.4.4   Fixed-Film Mass Estimates

At the conclusion of testing, an assay of the Ringlace from inside each of the four reactors was conducted. Segments of 13 to 17 cm in length were removed for the purpose of estimating fixed-film solids attached to the Ringlace media. The results are presented in Table 4.3.

It is evident from these results that the two upstream fermenters in the series (Reactors 1 and 2) carried a higher load than Fermenters 3 and 4, probably because the first two units utilized available RBCOD and colloidal material resulting in less available RBCOD and colloidals for the downstream units. The biological nature of the anaerobic fixed-film was not determined, so it was unclear what percentage of the fixed-film was actually biomass and what was simply adhered.

Table 4.3   Fixed-Film mass estimates (average values)

	length	TSS/length	*VSS/length
Fermenter	cm	g/m	g/m
1	13.2	8.582	6.771
	14.0	8.739	6.894
2	14.0	8.744	6.899
	16.4	6.454	5.092
	12.8	8.271	6.526
3	13.5	5.021	3.962
3	13.0	7.264	5.731
4	17.3	6.324	4.989
4	14.8	4.436	3.500
	avg	7.093	5.596
	st dev	1.543	1.217

* based on 79% volatile fraction solids.

The volatile fraction of the film was calculated to be approximately 79%. The overall average of 7.1 g/m compares well with the findings of Setter (1995) who found 9.5 g/m mass content on Ringlace® in an aerobic environment. The higher solids mass in Setter's work is likely owing to the aerobic environment being able to support a greater variety of life forms than the anaerobic environment in this study. Setter (1995) confirmed that worms, stalked protozoa and bacteria commonly found in sewage was also found growing on the media in an aerobic environment.

4.2.5   Fermenter Performance Summary

A performance summary of the high-rate, fixed-film fermenter and a comparison against production results from previous work is presented in this section. Data presented in Tables 4.4 and 4.5 refers to SCVFA production rates in mg/L/hr for the findings of this research (Year #2), as well as the findings of Dumitrescu (1998). Runs #1 from Year 1 and Year 2 are comparable

with primary effluent serving as the feed in both cases and SCVFA production of 9 mg/L/hr and 6, mg/L/hr respectively.

• Some of the Year 1 data (Run #2) cannot be compared with Year 2 data because the primary clarifier was by-passed and raw sewage was used as influent to the fermenter units. Primary effluent was used exclusively during Year 2 to avoid system upsets caused by plugging in the fermenters; this was prevalent during Year 1 (Dumitrescu, 1998). Primary effluent was desirable, not only for operational reasons, but also because the primary clarifier was assumed to have little impact on the substrate available for high-rate, fixed-film fermentation.

Table 4.4   Fermenter production summary - Year 2

Year 2 - Run #	SCVFA Influent mg/L	SCVFA effluent mg/L	SCVFA Prod'n mg/L/hr	Average Temp °C
#1 July to Oct/97	24.2	33.3	9.1	20.0
#2 Oct to Dec/97	27.6	29.5	1.9	15.1
#3 Jan to Apr/98	28.1	31.2	3.2	15.1
average	**26.6**	**31.3**	**4.7**	**16.7**

Table 4.5   Fermenter production summary - Year 1 (Dumitrescu, 1998)

Year 1 - Run #	SCVFA Influent mg/L	SCVFA effluent mg/L	SCVFA Prod'n mg/L/hr
#1 Aug to Oct/96	24	30	6
#2 Jan to Feb/97	17*	27*	10*
average	**21**	**29**	**8***

*   Influent from Run #2 in Year 1 was raw sewage (versus primary effluent).

A further examination of VFA data from Year 2 - Run #1 revealed that the primary clarifier did have a measurable impact though. During Run #1, the average VFA concentration in the primary effluent was 2.5 mg/L higher than that observed in the raw sewage. The readily fermentable substrate converted to VFA in the primary clarifier (45 minute HRT) was not available for conversion in the fixed-film fermenters. Despite this, it was decided to run primary effluent through the fermenters to simplify and improve the consistency of fermenter operation.

4.3   Process Performance

The primary objective of this research, "to investigate pilot plant BNR process performance when VFAs produced in the subject fermenters are introduced to the waste stream" is addressed in this section. Comparison in process performance between two parallel liquid streams, Control and Experiment streams (Figure 3.1), was made by measuring nutrient removal (carbon, nitrogen and phosphorus), and recording process stability and sludge settling characteristics. Each of these traits will be explored in the following sections where data for the entire project,

comprising Experimental Runs #1 to #3B, is presented.

The three experimental runs that formed the basis of this research were as follows:

i.   Run #1 - Fixed-film fermenters and Control fermenters on the front end of the process.

ii.   Run #2 - Primary effluent bypasses Control fermenters directly to the anaerobic zone. Continue operation of F^3 units.

iii.   Runs #3A and #3B - Addition of excess (3.0 mg/L) orthophosphate to the anaerobic zone. Continued to bypass control fermenters. In #3B return fermenter flush water to the head of the process.

4.3.1   Phosphorus Removal

Phosphorus (P) removal was calculated as TP_{in} -TP_{out} (mg/L) for both Control and Experiment streams and is shown in Figure 4.11. The solid line and dashed line represent the five-day moving average for Experimental and Control streams, respectively. In Figure 4.12, the more conventional % phosphorus removal is plotted with effluent soluble phosphate (PO_4) plotted on the second ordinate. Relevant data, plotted in both figures, is provided in Appendix C - Experimental Data, including statistics describing the data set.

Often removal is expressed in terms of mass per unit time (i.e. kg/day). In this study, it was decided to present removal in units of mass per unit flow (mg/L_{in} - mg/L_{out}) to be consistent with other research (Wentzel et al., 1997, A. Randall et al., 1997, C. Randall et al., 1997), and because both methods of expression are equivalent, as explained below.

To determine removal as kg/d, the total daily flow (L/d) is multiplied by the influent

concentration less the effluent concentration, i.e.

$$kg/d = \frac{L/d \times (mg/L_{in} - mg/L_{out})}{1,000,000 \ mg/kg}$$

To determine removal as mass per unit flow (mg/L), the mass removal per day is divided by the
total flow i.e.

$$mg/L = \frac{kg/d \times 1,000,000 \ mg/kg}{L/d}$$

Which is equivalent to influent concentration less effluent concentration ($mg/L_{in} - mg/L_{out}$).

The quantity of phosphorus removed (in terms of percent and mg/L) for all three runs was similar

with little or no PO_4 in the effluent for either Run #1 or Run #2. A sample test for the difference

between two paired data sets was conducted for each run (Sincich, 1987) using an $\alpha = 0.05$.

There was no significant difference between experimental and control P removals in all runs

except Run #3A, where the control process P removal actually exceeded the experimental P-

removal. A test of hypothesis revealed a calculated t = 2.20 versus a critical t = 2.08. This

finding was deemed inconclusive given the precision for total phosphorus removal (Appendix A)

and the fact that carbon was being wasted from the Experimental process during flushing and not

from the Control process.

There was no significant difference between the Experimental and Control process P removal,

however, there were distinct differences between experimental runs. In the first two runs, total

phosphorus removal consistently exceeded 90% with effluent PO_4 less than 0.3 mg/L (Table 4.6).

TP and PO4 Removal
5 day moving average
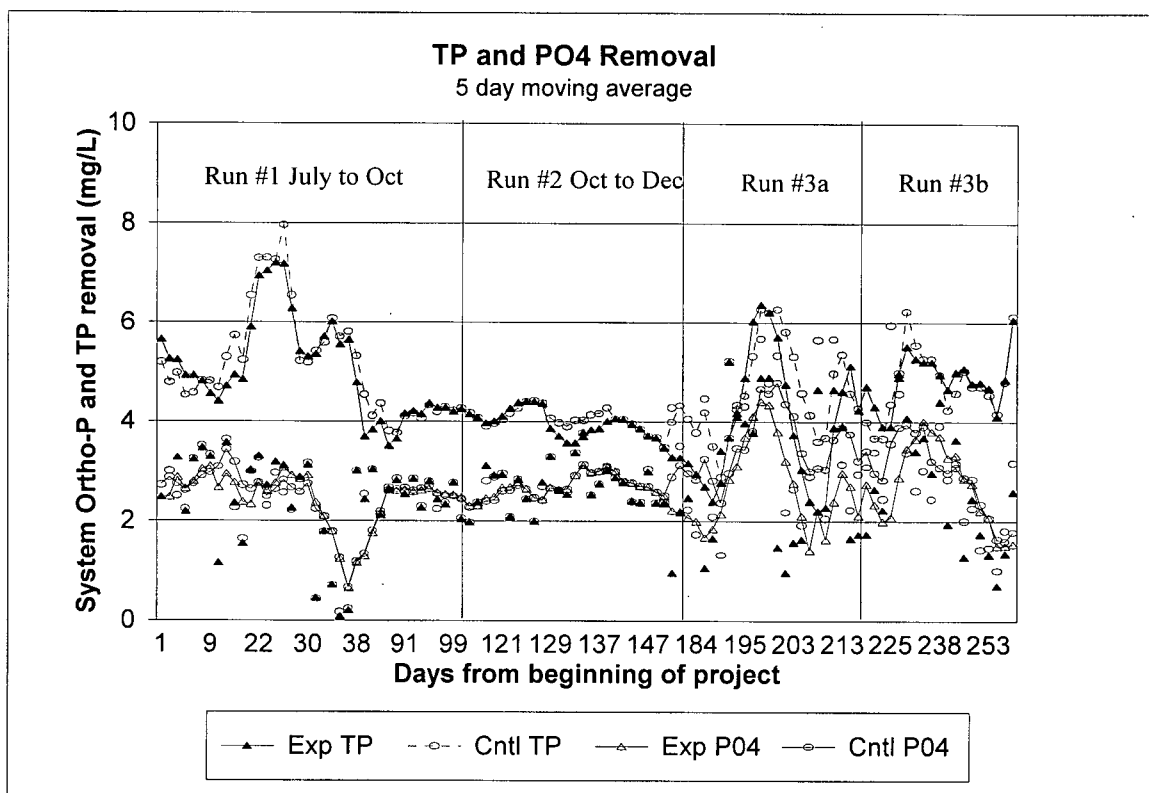
Figure 4.11   Soluble and total phosphorus removal

% Phosphorous Removal
July 1997 to April 1998
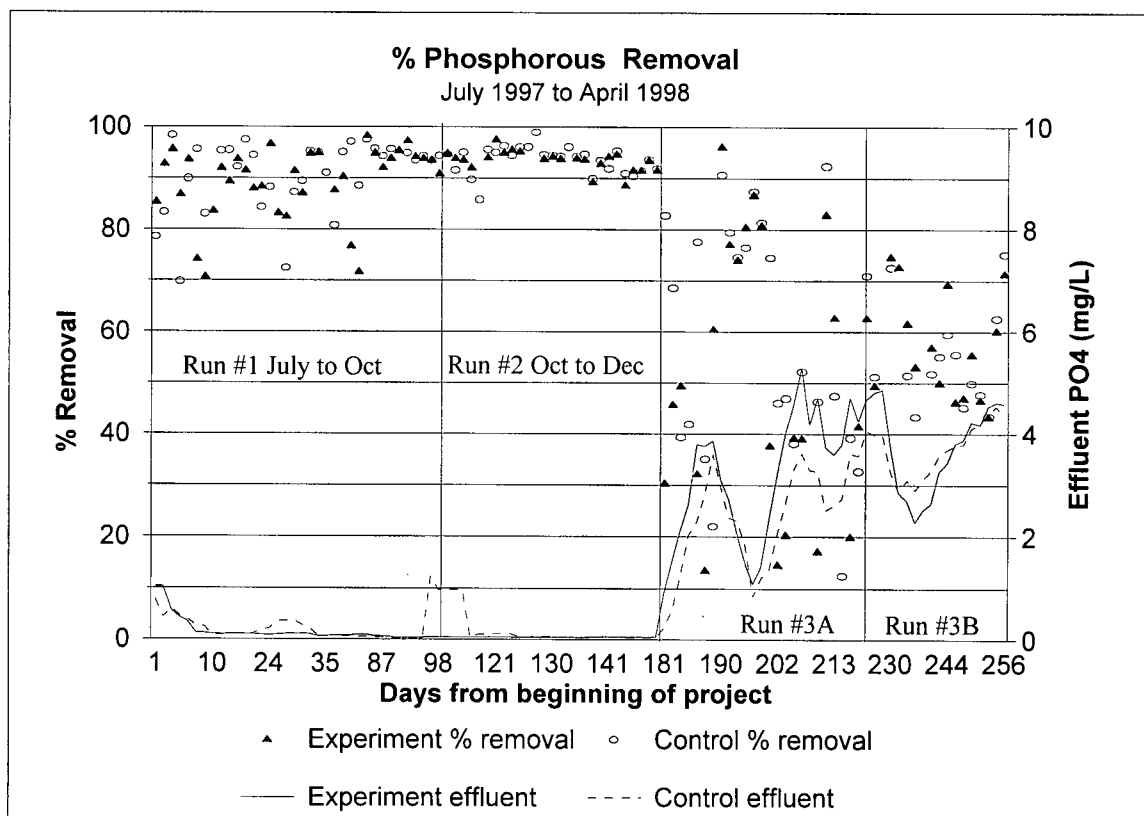
Figure 4.12   Process phosphorus removal efficiency and effluent ortho-P

Table 4.6   PO$_4$ removal and effluent PO$_4$

	PO$_4$ removal	(mg/L)	Effluent PO$_4$	(mg/L)			
Run	Experiment	Control	Experiment	Control	n	σ_{exp}	σ_{ctl}
#1	2.43	2.44	0.25	0.28	35	0.89	0.85
#2	2.71	2.70	0.05	0.06	25	0.43	0.42
#3A	2.55	3.50	3.67	2.70	25	1.73	1.36
#3B	2.67	2.83	3.85	3.67	18	1.17	1.16

Phosphorus removal during Run #3 became very unstable, with an apparent failure in the EBPR mechanism as evidenced by unsteady performance in P-removal (Figure 4.11 & 4.12). Removal is closely related to influent during the first two runs, with peaks and valleys correlating well; the high percentage removals indicated that the system was phosphorus limited, during these two runs. During Runs #3A and #3B, when 3.0 mg/L phosphorus was added, process P removal was very inconsistent and decreased, several times, for both waste streams. The system was probably carbon limited in Run #3 (low F/M ratio), similar to an endogenous activated sludge. Such an environment might be very aggressive and troublesome to phosphorus accumulating organisms which probably were unable to compete with the other microorganisms in the activated sludge.

Another possible explanation, non biological in nature, could be inconsistent P addition to the anaerobic zone. Throughout Run #3A and #3B, it was assumed that 3 mg/L of P was added to the process. A stock solution of high concentration was prepared at the UBC Civil Environmental Lab and diluted to 600 mg/L phosphorus at the Pilot Plant. Phosphorus addition was then metered to the process at 10.0 mL/min from the concentrated stock of 600.0 mg/L.

Process flow and phosphorus addition were measured daily and the stock concentration was verified, but there was still potential for error.

4.3.1.1 Activated Sludge Phosphorus Content

Since phosphorus is ultimately removed during sludge wasting, an elevated percent phosphorus concentration in the sludge is important for efficient system P removal. Mixed liquor (MLSS) in conventional activated sludge systems, not operating as EBPR systems, typically contain about 2.3% TP on a dry weight basis (Randall *et al.* 1997). By definition, EBPR processes have higher MLSS phosphorus contents necessary for enhanced phosphorus removals.

Process mixed liquor was measured twice weekly along with TP, so that percent phosphorus in the activated sludge could be calculated as follows:

$$\%P = \frac{TP}{MLSS} \quad \text{(see Figure 4.13)}$$

Percent phosphorus in the MLSS varied between 4.2%, when phosphorus was limiting in Runs #1 & 2, and about 5.6% when phosphorus was in excess during Runs #3A and #3B. The overall average Experimental and Control percent P content were found to be 5.0% and 4.7%, respectively. These results suggest that Experimental mixed liquor contained more phosphorus than Control mixed liquor; however, the lack of precision in the MLSS and TP tests would not definitively support such a conclusion as explained below.

Mixed Liquor Suspended Solids %P
July 1997 to April 1998

Exp MLSS = 2892 mg/L
Cntl MLSS = 3393 mg/L

Exp P = 5.0%
Cntl P = 4.7%

Run #1 July to Oct | Run #2 Oct to Dec | Run #3A | Run #3B

Days from beginning of project

▲ Experiment %P   ○ Control %P   —■— Experiment MLSS —+— Control MLSS
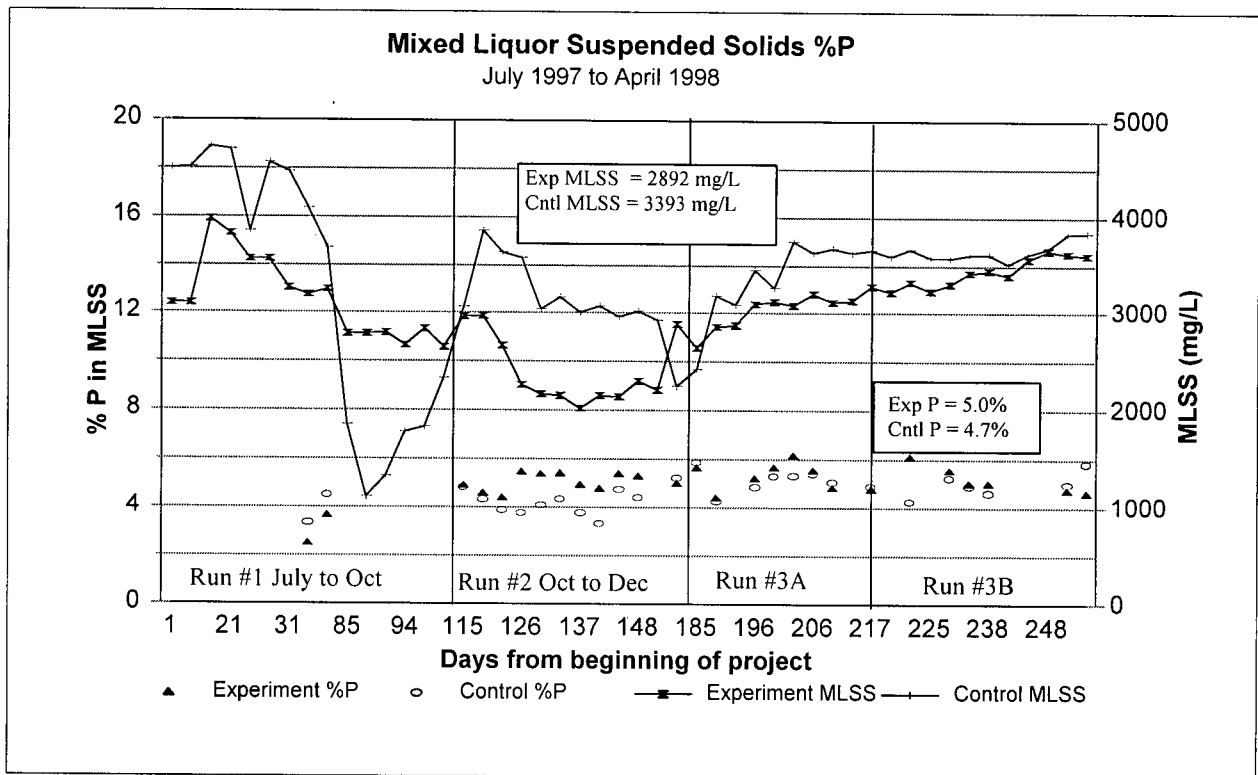
Figure 4.13   Phosphorus content in activated sludge mass

The 95% confidence intervals for TP and MLSS were +/- 2.2 mg/L and 190 mg/L respectively (Table 3.3). The average process MLSS concentration for the Experimental side was approximately 2890 mg/L measured in the aerobic zone. The average Total Phosphorus measured in the aerobic zone of the Experiment side was 146 mg/L. Percent P was calculated as follows:

$$\%P = \frac{146 \text{ mg/L } (+/- 2.2)}{(2892 \text{ mg/L } (+/- 190))} \times 100 = 5.0\% +/-$$

The percent phosphorus in the Experiment sludge was 5.0%, however, when the method confidence intervals were taken into account the % P ranged from 4.7% to 5.5%. Similarly, the

Control sludge ranged between 4.3% and 5.0%. Because of the overlap between ranges, the difference between Control and Experiment %P content is not definitive.

The literature cites several cases where %P in the mixed liquor of EBPR plants was in the range of 5%. Randall (1998), found total phosphorus levels in the MLSS to range between 4.5% and 7% in EBPR studies with excess phosphorus being added to the process. Zhao (1998) found %P in the MLSS to vary between 2% and 4% in studies involving the same sewage used in this research. Zhao (1998) also reported an average MLVSS/MLSS ratio of 0.74 from all runs in a laboratory scale 3-stage Bardenpho process. This value was used for conversion purposes in the analysis of these results.

4.3.2   Process Nitrification

Conversion of ammonia to NO_3 in both the Experimental and Control processes was consistent (Figure 4.14) with effluent NH_3 levels less than 0.5 mg/L in over 97% of the observations. Nitrification in both processes was complete as effluent ammonia concentration was below the calculated MDL 90% of the time. There were exceptions when NH_3 breakthrough did occur; however, there was no evidence to suggest that one side performed better than the other. Influent ammonia and effluent ammonia for both sides is plotted in Figure 4.14 and percent conversion of NH_3 to NO_3 is labelled for each run.

There were periods (See Appendix C - Experimental Data) in which Control side effluent ammonia was significantly higher than the method detection limit. Low dissolved oxygen (DO) concentration in the control side aerobic zone probably resulted in incomplete nitrification during these times as pH was controlled in the raw wastewater.
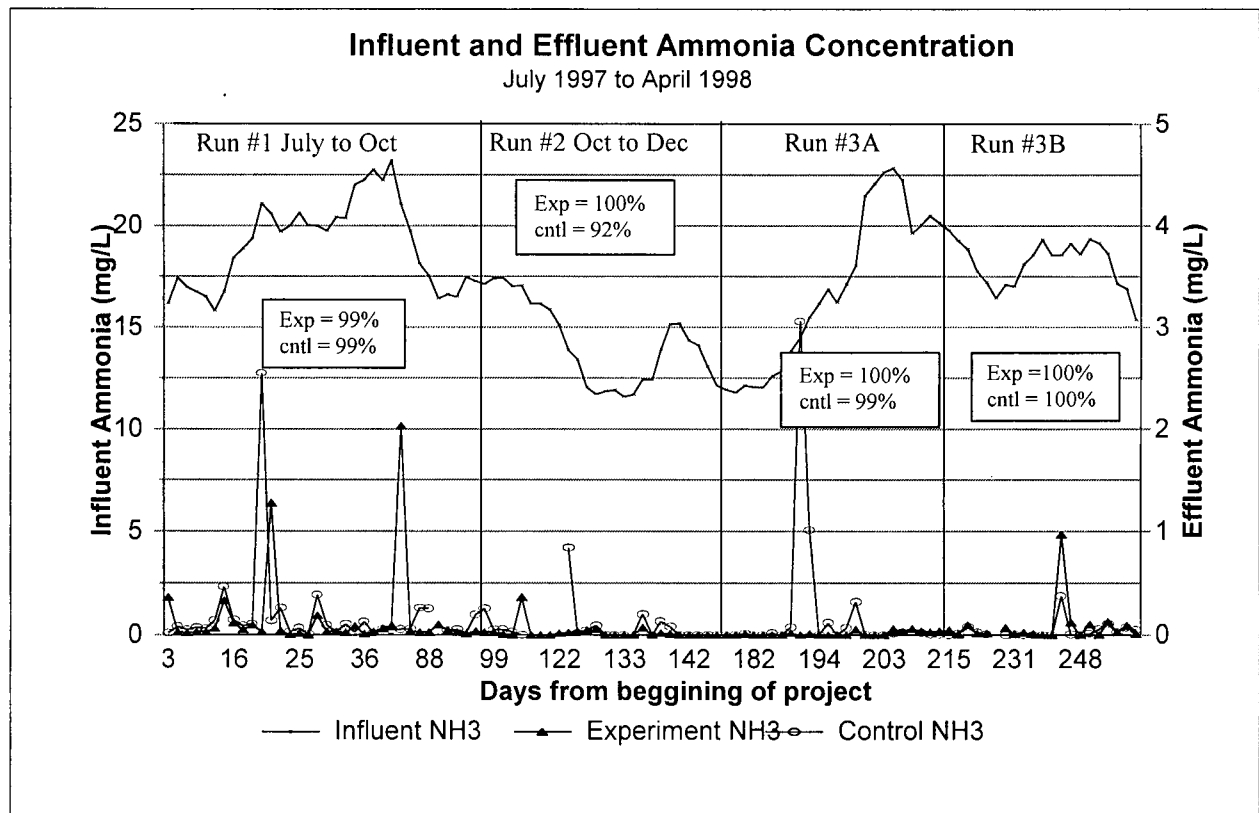
Figure 4.14 **Influent and Effluent Ammonia**

Incomplete nitrification may have been an indirect result of salt water intrusion into the collection system. Salt added to icy roads, followed by a subsequent thaw condition, could have resulted in saline water infiltrating the sewage system. With the infiltration of street runoff · (which was visible in the colour of the raw sewage), oxygen transfer may have been negatively

affected (Metcalf and Eddy, 1991). There was no online monitoring of DO during this study to confirm that insufficient dissolved oxygen was the cause of incomplete nitrification. There were fewer cases of ammonia break through in the Experiment process, indicating that sufficient oxygen was provided to the process most of the time.

4.3.3 Nitrogen Removal

Nitrogen removal, measured in terms of total nitrogen (TN_{in} -TN_{out} in mg/L) is represented in Figure 4.15. Process performance expressed as % TN removal and effluent nitrate/nitrite (NO_3) in mg/L, is shown in Figure 4.16, as is frequently the case for effluent discharge limits.

Influent TKN and TN removal, plotted in Figure 4.15, demonstrate the effectiveness of the 3-Stage Bardenpho process with regards to nitrogen removal. Influent spikes, caused by upsets (Section 4.1), are matched by a corresponding increase in total nitrogen removal demonstrating the ability of the process to respond to increased loadings. The process was able to handle peak nitrogen loads and maintain a fairly consistent percentage removal indicative of a stable process.

Inspection of Figure 4.16, and a paired two-sample test for the difference of means, revealed that the Control process appeared to outperform the Experimental process with regards to effluent NO_3 during Run #2 and Run #3A. This disparity is obvious in Figure 4.16 where TN removal frequently drops below 80% on the experimental side but rarely so on the control side. As shown in Figure 4.16, Experiment effluent NO_3 is consistently higher than Control NO_3 during Runs #2 and #3A. Thus, it was concluded that better Control side denitrification was one reason for

superior nitrogen removal in the Control process. Once carbon lost during flushing of the fermenters was returned to the head of the process in Run #3B, the experiment and control side perform equally well in terms of NO_3 removal (Table 4.7).

Table 4.7   TN removal and effluent NO_3

	TN removal (mg/L)		Effluent NO_3 (mg/L)		Effluent TKN (mg/L)	
Run	Experiment	Control	Experiment	Control	Experiment	Control
#1	26.89	26.91	3.83	3.70	1.4	1.4
#2	22.31	24.70	4.03	3.00	1.1	0.3
#3A	25.55	26.02	4.30	3.90	1.5	1.4
#3B	28.80	29.50	3.20	3.20	1.7	1.0

From the data in Table 4.7, denitrification in the Experiment process was negatively affected by flushing the fermenters and the subsequent loss of readily available COD necessary for efficient denitrification. This was especially true during Run #2, when VFA production in the fixed-film fermenters, which might have mitigated the flushing, was at its lowest.

Effluent TKN, shown in Table 4.7, varies between Control and Experiment and also contributes to the disparity in TN removal between processes. It is unclear why TKN appears to vary between processes. The method for TKN analysis was sensitive to effluent solids and equipment (Lachat) preparation and therefore less precise as measurement a tool. Because of this, experimental error and/or increased effluent solids (from the Experiment process) are likely causes for the effluent TKN variance.

Total Nitrogen Removal
July 1997 to April 1998
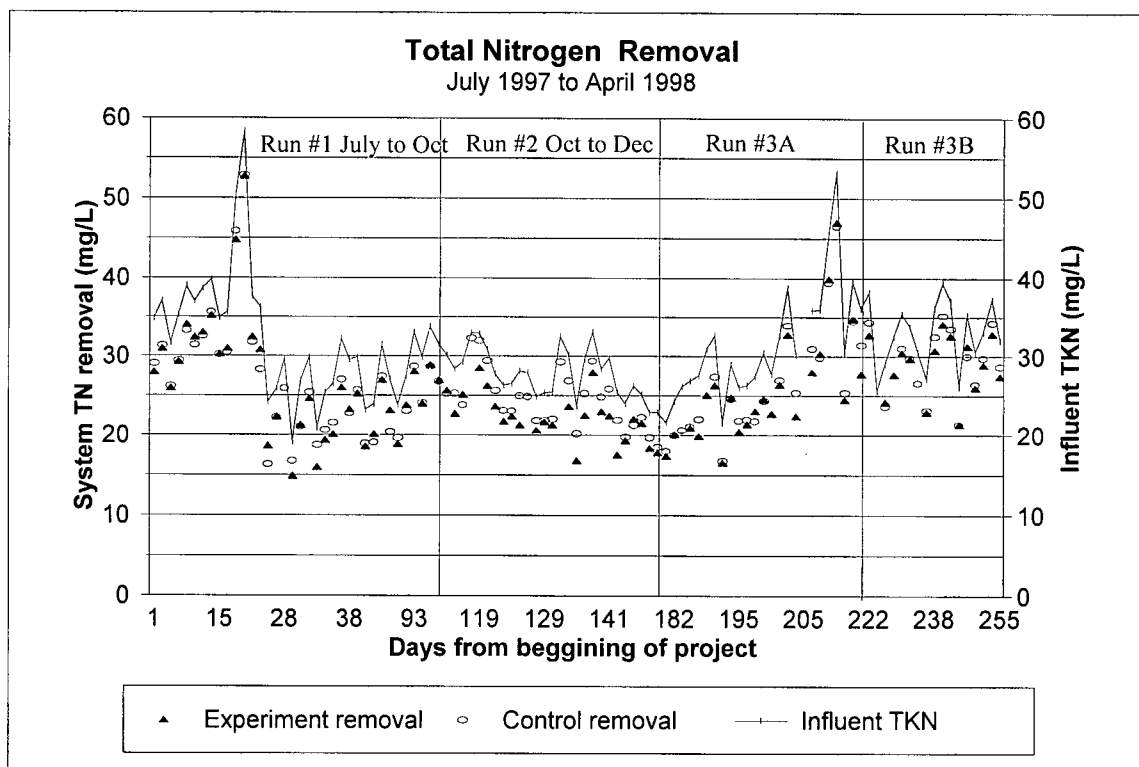
Figure 4.15　Process total nitrogen removal

% Total Nitrogen Removal
July 1997 to April 1998
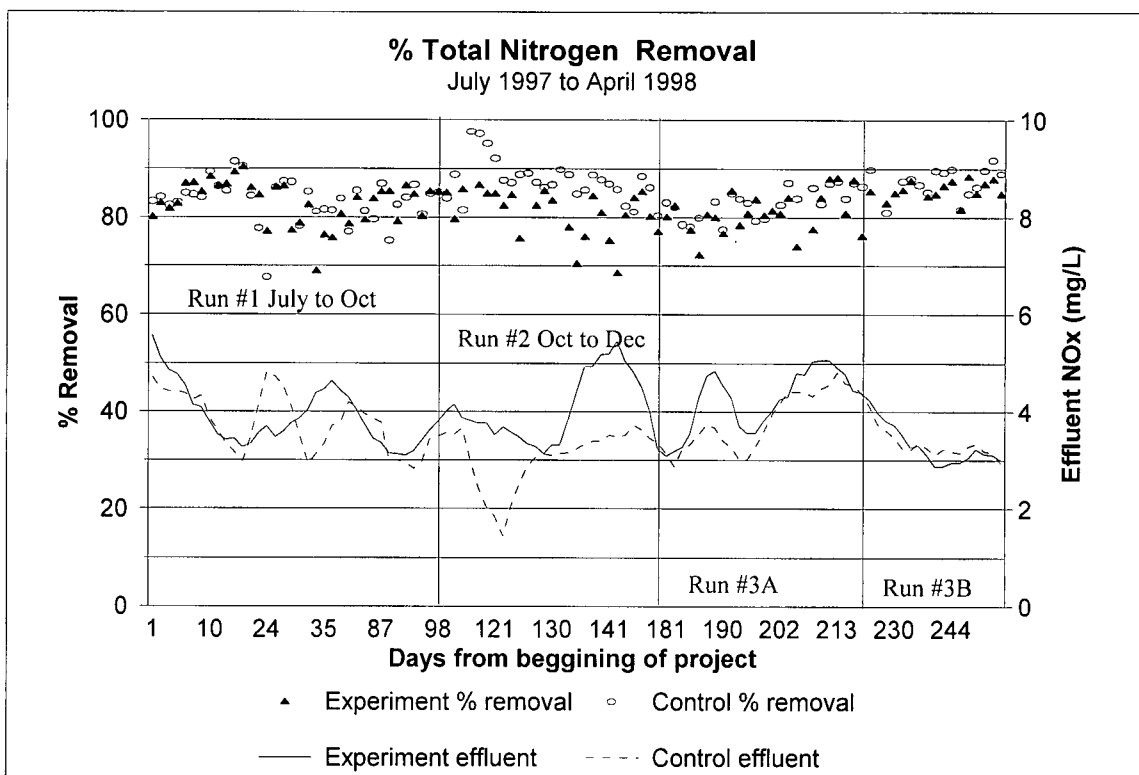
Figure 4.16　Process nitrogen removal efficiency

In summary, total nitrogen removal in both the Experiment and Control Processes ranged between 70% and 90% for the duration of the project. Percentage nitrogen removal and phosphorus removal was similar during the first two runs, but then percentage P-removal dropped significantly once soluble phosphorus was added during Run #3. Nitrogen removal was not affected by the addition of phosphorus to the processes during Run #3.

4.3.3.1 Activated Sludge Nitrogen Content

Percent nitrogen content was calculated, similar to %P, by measuring TKN in the process mixed liquor and dividing by MLSS concentration. Percent N in sludge is important when considering overall nitrogen removal for the same reasons %P removal is important; this fraction of N removed with the waste activated sludge supplements the N removal achieved through biological denitrification. As depicted in Figure 4.17, the average percent nitrogen in the experiment and control processes was consistently around 8%, once the process MLSS stabilized. This compares well nitrogen content of 8.4% reported by Zhao (1998) in a similarly operated system. It should be noted, that if N removal due to sludge wasting was desired, then process NO_3 should be accounted for, in addition to TKN as both forms of nitrogen will be present in the waste sludge. Because process NOx concentration is small compared to process TKN concentration for this study (NOx = 4 mg/L vs TKN = 250 mg/L) , process NOx was not considered significant to the nitrogen content.
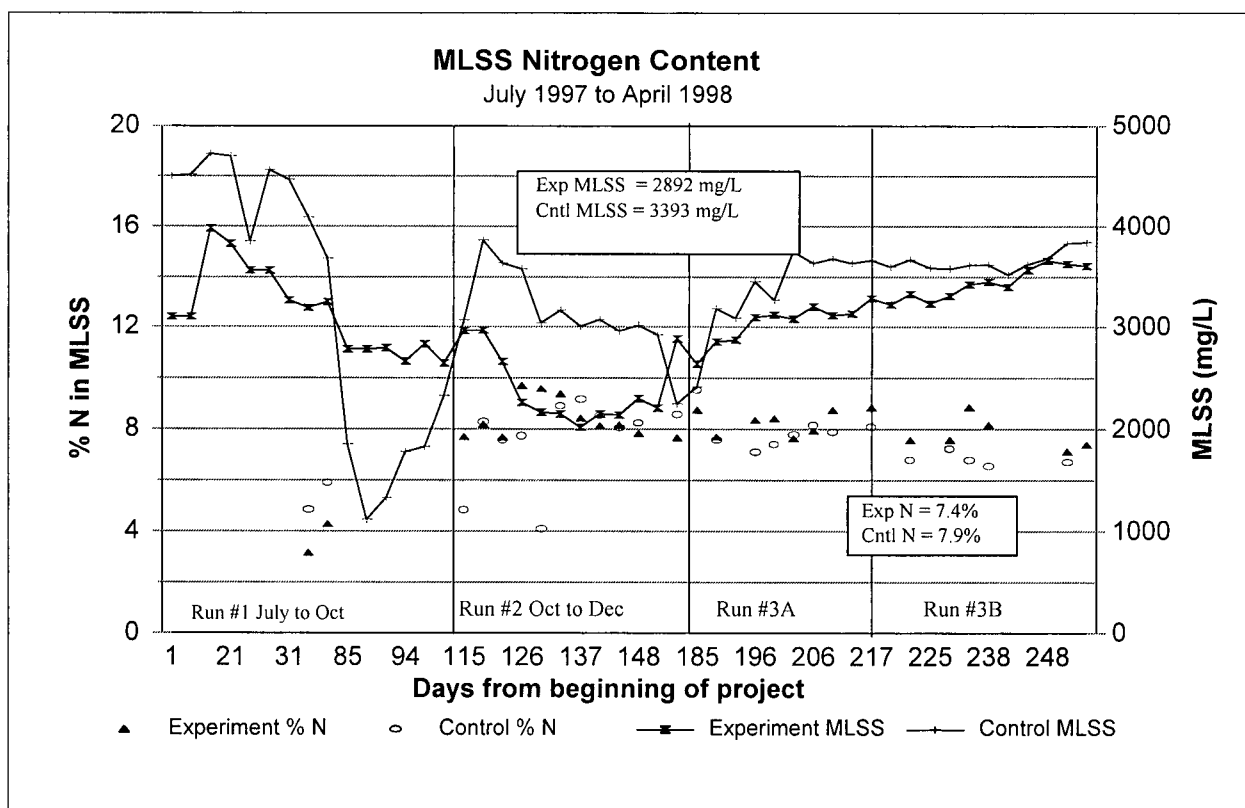
Figure 4.17   Nitrogen content in activated sludge mass

4.4   Auxiliary Fermentation Studies

Beginning in Year 1 of the Fixed-Film Fermentation study, it was recognized that solids build-up

in the fermenter units could result in increased SCVFA production. On days when flushing was

missed or less rigorous, the production of SCVFA increased compared to days when solids were

completely removed. Allowing solids to accumulate in the fermenters resulted in plugging of the

reactors and piping though, so solids were eliminated from the reactors as described in Section

3.2.2. It was also reasoned that since VFA production from a fixed-film was of primary interest,

the effects of solids should be minimized as much as possible.

An auxiliary study was conducted to quantify SCVFA production resulting from solids present in the primary effluent by allowing the solids to accumulate and ferment in spare reactor units. This auxiliary study was operated independent of the Experiment and Control BNR processes but was considered significant for future research possibilities.

4.4.1 Settled Solids Fermentation

Two fermenter reactors in series, with a total HRT of 1 hour, were fed surplus primary effluent from the UBC Pilot Plant; fermented effluent was directed to waste. There was no draining or flushing of solids, and no media for attached growth other than the pipe walls themselves. Sampling was conducted on the same days as process sampling, as per the established protocols until the system plugged after four weeks of operation.

Acetic acid and propionic acid concentration (as HAc) are plotted in Figure 4.18. The experiment started in November and showed similar results to the fixed-film fermenters for the first four weeks (1.94 mg/L versus 2.79 mg/L) until the reactors plugged. After flow was reinstated, VFA production appeared to show an improving trend, bolstered by a raw wastewater storage upset; this resulted in a surge of readily fermentable substrate to the pilot plant (as explained in Section 4.1) after which, the reactors plugged and flow stopped again.

During this auxiliary study, the fermenters were, once again, operated as down-flow reactors, with no flushing of solids and no Ringlace media. All VFA production was a result of settled solids fermentation as the only fixed-film growth occurred on the reactor walls and piping.
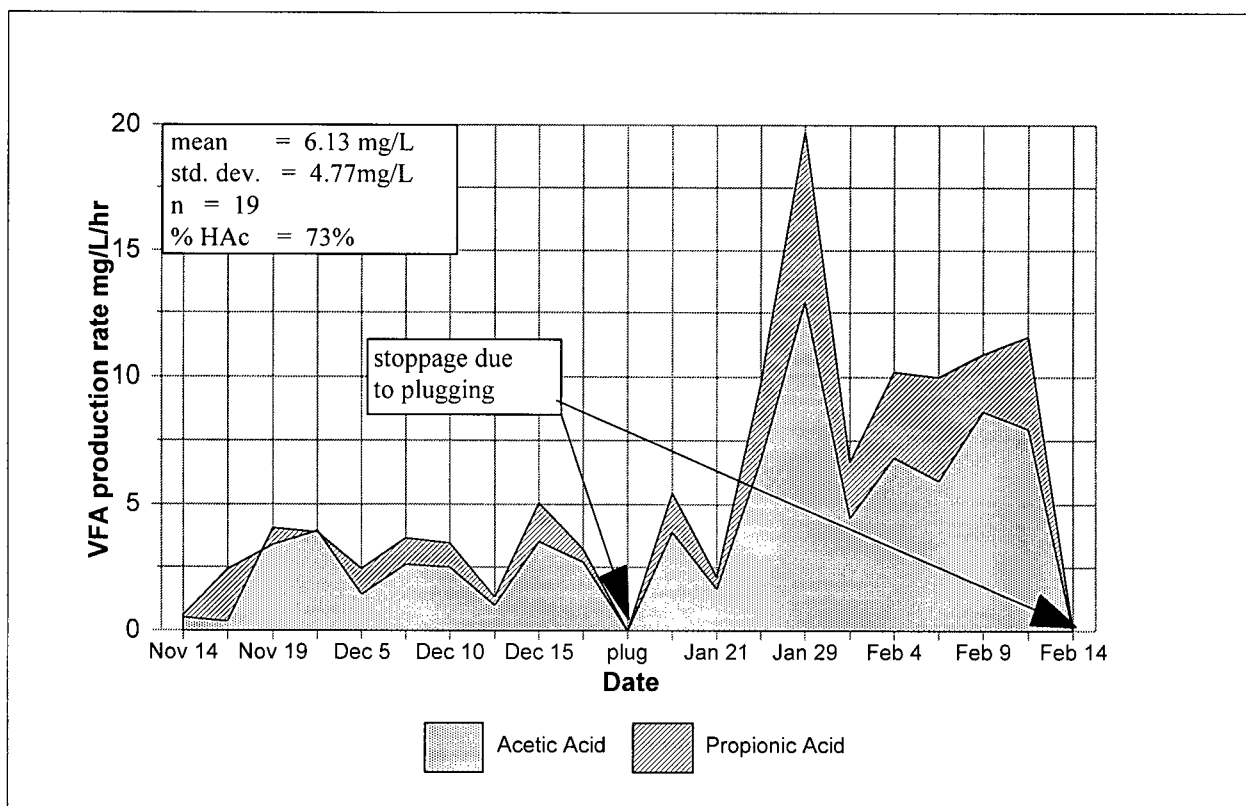
Figure 4.18   SCVFA production in a primary effluent fermenter with settled solids

4.4.2   Combined Fixed-Film and Settled Solids Fermentation

The previous test, in which solids build-up from primary effluent was allowed to occur, showed

some promise with regards to VFA production; however, plugging was a problem. As a result,

the fermenters were drained and cleaned and the plumbing was changed to that of an upflow

reactor. Once again, the retention time was one hour and two reactors were operated in series.

Ringlace® media was installed in the top third of the last fermenter where the sampling port was

located. Testing of the fixed-film, settled-solids fermenter (hereafter called the Solids

Fermenter) began on February 27.

After two weeks of continuous operation, primary effluent TSS (in mg/L) was similar to fermenter effluent TSS indicating that the reactor solids content had reached steady state (solids in = solids out). Sampling began during the first week of the test and continued for a period of five weeks until April 5. The VFA production results from the solids reactors are plotted in Figure 4.19 which also includes corresponding VFA production data from the fixed-film fermenters, being operated "free" of settled solids as per Section 3.2.2. Sampling from the Solids Fermenter began on March 2 and continued until April 5 concurrent with other process sampling. In the first few weeks, acetic acid production steadily increased until reactor solids reached steady state (TSSin = TSSout), whereas propionic acid was fairly consistent right from the start. The disparity in total VFA produced in the Solids Fermenter compared to the F^3 fermenter is obvious in Figure 4.19, with 11.7 mg/L versus 2.6 mg/L VFA, recorded during the sampling period (35 days, 18 observations). It is evident from the bottom two plots in Figure 4.19 that VFA yield from suspended solids and colloidal solids exceeds VFA yield from fixed-films by a large margin. Once steady state was reached in the Solids Fermenter by mid-March, 13 mg/L/hr of SCVFA yield was observed. Additionally, there was no plugging or operational difficulties associated with running the fermenters in the absence of flushing due to the upflow configuration. Maintenance to the Solids Fermenters during the test period was limited to periodic release of any trapped air which entered the reactors during sampling.
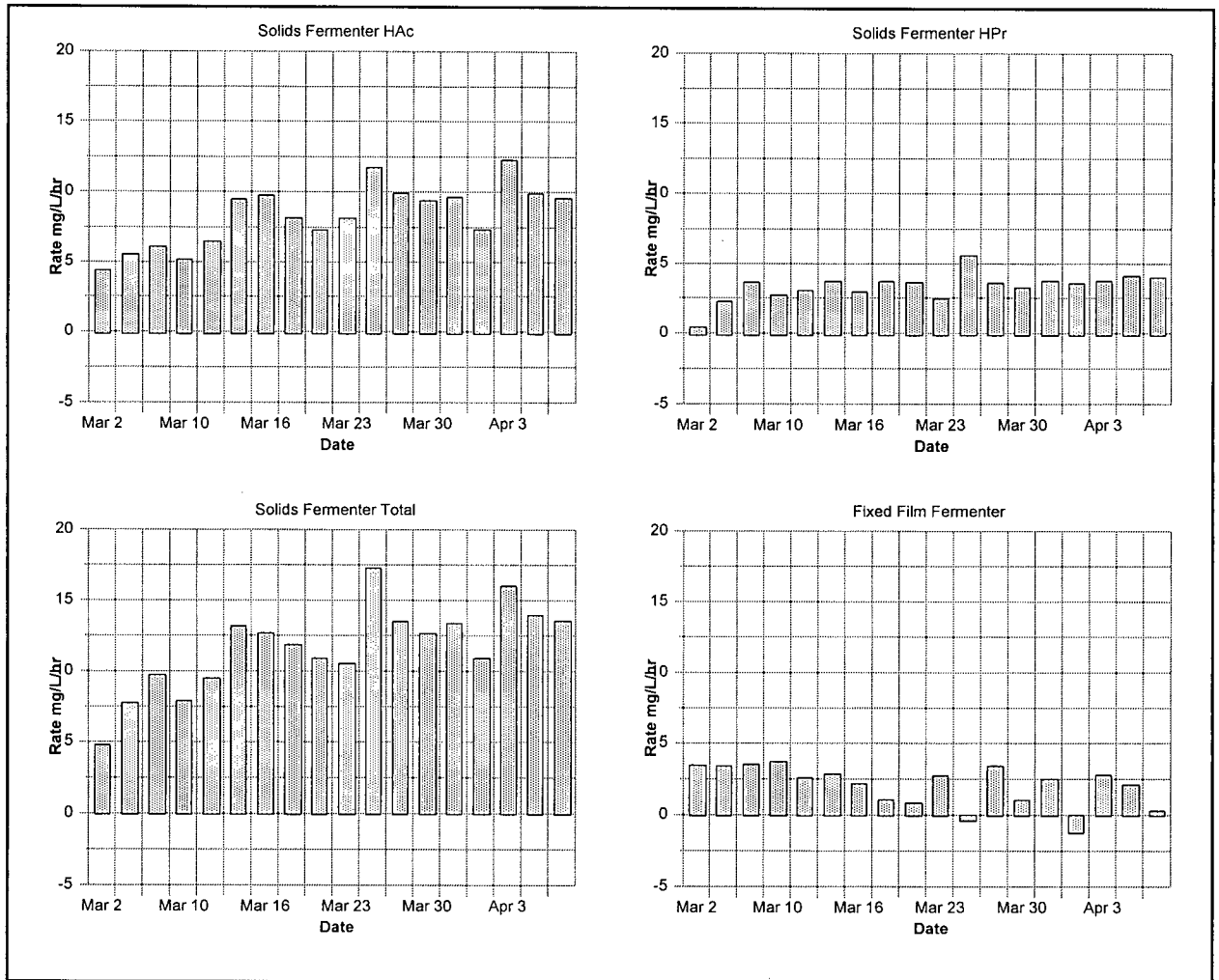
Figure 4.19   VFA Production in Solids Fermenter and Fixed Film Fermenter

CHAPTER 5

5.0   OVERVIEW AND SUMMARY

The primary objective of this research, to investigate the effects of fixed-film fermentation on

BNR performance, was explored in detail through a series of experiments over a period of nine

months. The primary objective, was really two-fold with fixed-film fermentation of wastewater

being one facet of the research and the effect of such fermentation on BNR plant performance

being the other. Both of these objectives are summarized and related to full-scale applications in

the following sections.

5.1   High-Rate, Fixed-Film Fermentation of Primary Effluent and Prefermentation of Primary Sludge.

During this research, the average SCVFA production resulting from fixed-film fermentation of

primary effluent was between 1.9 mg/L and 9.1 mg/L. The average SCVFA production resulting

from a combined fixed-film and solids fermenter (described in section 4.4) was 13 mg/L.   These

results were achieved in one hour of retention time (HRT = SRT) within the fermenters.

Supernatant from primary sludge fermenters currently operating in Western Canada often

contains 150 mg/L SCVFA (HAc). Because primary sludge fermenters typically have long SRTs

(4 to 12 days), long HRTs (6 to 16 hours) and often operate in a side-stream configuration,

concentration of supernatant is not an equitable method for comparison of fermenter

performance. A more suitable measurement for comparing performance is rate of VFA

production in mg/L/hr (Munch *et al.* 1997) or yield expressed as mg SCVFA per mg VSS

applied (Rabinowitz, *et al.* 1997); where mg SCVFA is measured leaving the fermenter and mg

VSS is measured entering the fermenter.

In this experiment, fermenter HRT was equal to one hour, and so the rate of VFA production in

mg/L/hr was equal to the average effluent concentration divided by 1 hr or 4.7 mg/L/hr. The

average TSS entering the fermenter was 97 mg/L, of which 85% was volatile. This represented a

yield of 0.06 mg VFA/mg VSS since the fermenters were in-line. To calculate yield for a side-

stream fermenter (flow rate less than plant flow rate), it would be necessary to calculate the mass

of VFA leaving the fermenter and divide by the mass of VSS that entered the fermenter.

Performance data from full-scale plants operating in Western Canada is presented in Table 5.1.

Table 5.1   Fermenter performance data

WWTP Plant	VFA$_{eff}$ (mg/L)	VFA$_{rate}$ (mg/L/hr)	mg VFA/ mg VSS	VFA to plant (mg/L)
UBC Pilot Plant	4.7	4.7	0.057	4.7
UBC auxiliary fermenter	13	13	0.16	13
Kelowna, BC[1,2]	173	17.3	0.083	11
Westbank, BC[1,2]	108	8.3	0.25	26
Bonnybrook, AB[1,2]	160	10.0	0.060	4

[1]Data from Rabinowitz et al, 1997;   [2] Data from Munch *et al*, 1998

Another important consideration when evaluating a fermenter's performance is measuring the

impact to process influent. For an in-line system where fermenter flow equals plant flow, the

total SCVFA entering the plant will be equal to the SCVFA leaving the fermenter. Side-stream primary sludge fermenters typically have a sludge flow rate somewhere between 5% and 25% of the plant flow rate and so VFA leaving the fermenter will be diluted accordingly. The data in the last column of Table 5.1 represents the increase in VFA to the process after fermenter effluent is introduced to the plant flow.

From the data in Table 5.1, the primary effluent fermenters under investigation performed comparably to those reported in the literature. Advantages over sludge fermenters may be as follows:

- smaller tank size

- lighter equipment for pumping

- reduced operating expenses

5.2   Process Performance

There was probably sufficient VFA present in the raw wastewater, at 27 mg/L, for EBPR to remove 2.9 mg/L phosphates (4.9 mg/L T-P) without the addition of fermentation by-products. The SCVFA/P-removal reported in the literature was between 6 and 9 mg of SCVFA per mg phosphorus removed (Barnard 1994; Randall *et al.* 1997). This ratio would indicate that 27 mg/L of VFA present in the wastewater would be sufficient for removal of 3 to 4.5 mg phosphate, which supports the earlier conclusion that fermentation was not required for good EBPR during this study. This became apparent after Run #2 and so phosphorus in the form of Sodium Phosphate Mono-basic (NaH_2PO_4-H_2O) and Sodium Phosphate ($NaHPO_4$-$7H_2O$) was

added to the process during Run #3. Both the Experiment and the Control processes continued to perform equally , although after additional phosphorus was added, the processes became less stable.

Tables 5.2 and 5.3 summarize other parameters that were measured.

Table 5.2   Summary of BNR process results (corrected average values)

analyte	run	n	PC effluent	anarobic zone control	exp'ment	anoxic zone control	exp'ment	aerobic zone control	exp'ment	Effluent control	exp'ment
PO4	**1**	**37**	2.55	7.81	8.95	1.68	1.36	0.08	0.09	0.28	0.25
	2	**25**	2.75	7.17	3.93	1.59	0.46	0.03	0.04	0.06	0.05
	3a	**25**	3.20	16.51	10.65	8.17	6.67	3.14	3.91	2.70	3.67
	3b	**18**	3.32	18.80	15.22	8.12	7.87	4.12	3.74	3.67	3.85
TP	**1**	"	5.6					152	119	0.5	0.5
	2		4.3					134	120	0.3	0.3
	3a		7.7					1983	160	3.2	3.8
	3b		8.5					227	179	4.3	3.9
NH3	**1**	"	18.94	7.89	8.69	3.85	3.77	0.325	0.293	0.179	0.147
	2		13.23	6.28	5.78	3.36	2.16	1.13	0.293	0.068	0.026
	3a		18.13	8.88	6.81	3.34	3.26	0.390	0.020	0.195	0.020
	3b		17.52	8.70	7.27	3.29	3.53	0.020	0.039	0.044	0.093
NOx	**1**	"	0.103	0.300	0.256	0.377	0.499	4.33	4.13	3.70	3.83
	2		0.052	0.212	0.716	0.193	1.325	2.89	3.97	3.00	4.03
	3a		0.095	0.157	0.143	0.291	0.518	4.01	4.15	3.90	4.30
	3b		0.081	0.177	0.163	0.266	0.203	3.77	3.73	3.20	3.20
TKN	**1**	"	31.9					208	144	1.4	1.4
	2		27.9					245	201	0.3	1.1
	3a		29.7					259	250	1.4	1.5
	3b		33.1					250	269	1.0	1.8

Notes:
1.   Primary Clarifier had a negligible effect on nutrient levels except TP (-20%)
2.   n = number of observations

Table 5.3   Summary of process solids (corrected average values)

analyte	run	n	aerobic zone control	exp'ment
MLSS	1		2694	2936
	2		3136	2440
	3a		3015	2974
	3b		3658	3462
%P	1	2	3.9	3.1
	2	10	4.2	5.1
	3	15	6.0	5.2
SVI	1		290	128
	2		87	232
	3		138	136

Note: 1.   % P in MLSS calculated by measuring TP in aerobic zone and dividing by MLSS.

CHAPTER 6

6.0 CONCLUSIONS AND RECOMMENDATIONS

The primary objective of this research was to investigate the effects of fixed-film fermentation of wastewater on BNR plant performance. To achieve this objective, pilot-scale fermenters pretreated primary effluent before entering twin, 3-stage Bardenpho pilot plants operated over a period of nine months. BNR at the UBC Pilot Plant was not significantly affected as discussed below; however, the results of this research have contributed towards a better understanding of high-rate fermentation of primary effluent. Based on the results of the experimental studies, the following conclusions are made.

6.1 Conclusions

1. 1.9 to 9.0 mg/L of SCVFA was produced by fermenting primary effluent in a high-rate, fixed-film, fermenter using the commercially available media, Ringlace®. Considerable effort was made to ensure the fixed-film was responsible for net SCVFA gain by eliminating solids build-up from the fermenters.

2. Two, 3-stage Bardenpho processes were operated in parallel for a period of nine months; the Experimental process train had a fixed-film, high-rate fermenter attached to the anaerobic zone, while the other served as a Control with no fermenter through most of the testing. SCVFA produced in the high-rate fermenters did not improve phosphorus or nitrogen removal (Runs #1 to #3) in the Experimental process as was hoped. The high

concentration of SCVFA already present in the raw wastewater (27 mg/L average)

entering the pilot plant and the confounding effects of NO_3 (Rabinowitz, 1985) present in

the recycle may have masked any positive impacts from the fermenters.

3. The specific yield SCVFA production per unit VSS applied ranged from 0.024 to 0.11 mg

VFA/ mg VSS. The VFA production rate ranged between 1.9 and 9.1 mg/L/hr. All

production rates were temperature dependant; mean temperatures were between 15.1 °C

for minimum production rates and 19.8 °C for maximum production rates.

4. The results from Run #3A and #3B, in which excess orthophosphate was added to the

anaerobic zone, indicated that between 5.3 and 7.8 mg VFA (as acetic acid) was required

to remove 1.0 mg of total phosphorus at the UBC Pilot Plant, which was operating as a 3-

stage Bardenpho process. For a wastewater, with insufficient SCVFA concentration

entering the process, a high-rate, fixed-film fermenter fed primary effluent could be

expected to produce sufficient SCVFA to enable EBPR of an additional 0.4 to 1.7 mg/L

of total phosphorus.

5. The percentage phosphorus content in the process MLSS was a minimum of 4.1% during

Run #2, when phosphorus was limiting, and a maximum of 5.9% during Run #3 (excess

PO_4 was added), when readily available carbon was limiting.

6. An upflow primary effluent fermenter system utilizing a reduced quantity of Ringlace®,

in which SCVFA from settled solids augmented fixed-film fermentation, produced a much higher SCVFA concentration over a period of 3 months, compared to fixed-film fermentation alone. Net SCVFA production rates averaged 13 mg/L•hr once steady state operation was attained. The specific yield SCVFA production per unit VSS was 0.16 mg VFA/mg VSS, at a mean temperature of 16.0°C.

7. In wastewaters that have not undergone considerable fermentation during transport from source to treatment facility, the feasibility of high-rate, primary effluent fermentation for the purpose of SCVFA production has been established. Significant SCVFA production can be achieved with short HRT, and minimal maintenance, in such wastewater treatment facilities.

8. In wastewater subject to anaerobic conditions during transmission or handling, the readily fermentable component is likely to be converted to SCVFA, and therefore, may not be available for high-rate fermentation.

6.2   Recommendations

Further research in the following areas and consideration for the following points are recommended.

1.   It is recommended that further studies, involving primary effluent fermentation, be conducted prior to implementing a high-rate, fixed-film fermenter with Ringlace. Where the objectives of such studies include ascertaining the effects on EBPR, the plant influent should be SCVFA deficient.

2.   Further investigation of the potential for SCVFA production in an upflow, high-rate, primary effluent fermenter system where solids passing the primary clarifier are allowed to accumulate and ferment is needed.   Parameters such as HRT/SRT and operational considerations should be further developed.

3.   While the 3-stage Bardenpho process was successful in removing phosphates and nitrates from the influent wastewater, the confounding effects of nitrate in the recycle may have masked attempts to evaluate phosphate removal differences between the Experimental and Control processes. For this reason, it is recommended that future UBC Pilot Plant studies aimed at phosphorus removal, be operated with return activated sludge to the anoxic zone (UCT configuration) versus the anaerobic zone.

4.   Future researchers investigating prefermentation for the purpose of enhancing EBPR, must be cognizant of a high SCVFA concentration intrinsic to the raw wastewater

entering the UBC Pilot Plant. It is recommended that phosphorus addition to the process be considered, to ensure that VFAs present in the wastewater are limiting nutrients.

CHAPTER 7

7.0   REFERENCES

American Public Health Association; American Water Works Association; Water Environment Federation (1992) *Standard Methods for the Examination of Water and Wastewater.* 18th Ed., Washington, DC.

Argaman, Y. (1991) Biological Nutrient Removal. In *Biological Degradation of Wastes.* A.M. Martin (Ed.), Elsevier Science Punblishers Ltd. New York, NY, 85.

Arun, V. Mino, T., and Matsuo, T. (1989) Metabolism of carboxylic acids located in and around the glycolitic pathway and the TCA cycle in the biological phophorus removal process. *Water Science and Technology.* **21** (4/5), 363.

Arvin, E. (1983) Observations supporting phosphate removal by biologically mediated chemical precipitation - a review. *Water Science and Technology,* **15**, 43.

Barnet, V. and Lewis, T. (1978) *Outliers in Statistical Data.* John Wiley and Sons Ltd. Toronto, Canada.

Barnard, J.L. (1974) Cut P and N without chemicals. *Water and Wastes Engineering,* **11** (7), 33.

Barnard, J.L. (1984) Activated primary tanks for phosphate removal. *Water S.A.,* **10**, 121.

Barnard, J. L.; Rabinowitz, B.; and Coleman, P. (1995) Biological nutrient removal - a Western Canadian experience. *Proceedings from the National Conference on Innovative Technologies for Site Remediation and Hazardous Waste Management,* Pittsburgh, PA.

Barnard, J.L. (1994) Alternate prefermentation system. *Proceedings of the 67th Annual Conference and Exposition of the Water Environment Federation.* Chicago, IL.

Barnard, J.L. and Rabinowitz, B. (1998) Biological Phosphorous Removal. *Class notes from Civil 559 - Advanced Tertiary Treatment Technologies for Water and Wastewater.* University of British Columbia, Vancouver, Canada.

Berthouex, P.M. and Gan, R.D. (1997) A model of measurement precision at low concentrations. *Water Environment Research,* **65** (9), 759.

Brock, T.D.; Madigan, M.T.; Martinko, J.M.; and Parker, J. (1994) *Biology of Microorganisms.* 7th Ed., Prentice Hall Publishers, Englewood Cliffs, NJ.

Burdick, C.R. and Dallaire, G. (1978) Florida plant first to remove nutrients with bacteria alone. *Civil Engineering-ASCE,* **10,** 51.

Carlsson, H.; Aspegren, H.; Lee, N.; and Hilmer, A. (1997) Calcium phosphate precipitation in biological phosphorus removal systems. *Water Research,* **31** (5), 1047.

Christensson,M.; Lie, E.; Jonsson, K.; Johansson, P.; and Welander, T. (1998) Increasing substrate for polyphosphate-acculmulating bacteria in municipal wastewater through hydrolysis and fermentation of sludge in primary clarifiers. *Water Environment Research,* **70** (2), 139.

Chu, A. (1995) *Volatile fatty acid metabolism in thermophilic aerobic digestion of sludge.* Ph.D. thesis, Civil Engineering, University of British Columbia, Vancouver, Canada.

Cole, M. (1997) A personal communication.

Comeau, Y.; Hall, K.J.; Hancock, R.E.W.; and Oldham, W.K. (1986) Biochemical model for enhanced biological phosphorous removal. *Water Research,* **20** (12), 1511.

Cuevas-Rodriguez, G.; Gonzalez-Barcelo, O.; and Gonzalez-Martinez, S. (1998) Wastewater fermentation and nutrient removal in sequencing batch reactors. *Proceedings of Water Quality Internationa IAWQ 19th Biennial International Conference,* Vancouver, Canada.

Dawson, R.N.; Abraham, K.N.; Oldham, W.; and Udala, B. (1995) Performance improves at Penticton. *Water Quality International,* **1,** 20.

Danesh, S. and Oleszkiewicz, J.A. (1995) Volatile fatty acids production using prefermentation of raw wastewater. *Proceedings from the National Conference on Innovative Technologies for Site Remediation and Hazardous Waste Management,* Pittsburgh, PA.

Dumitrescu, A.C. (1998) *The design and testing of a short HRT attached growth pre-fermenter system: SCVFA production by two media types and two feed sources.* M.Sc. thesis, Civil Engineering, University of British Columbia, Vancouver, Canada.

Elefsiniotis, P. and Oldham, W.K. (1995) Organic Substrate Degradation in Acid-Phase Anaerobic Digestion Systems. *Proceedings from the National Conference on Innovative Technologies for Site Remediation and Hazardous Waste Management,* Pittsburgh, PA.

Felipe, C.D.M. and Daigger, G.T. (1998) Development of a revised metabolic model for the growth of phosphorus-accumulating organisms. *Water Environment Research,* **70** (1), 67.

Fothergill, S. (1996) *The effect of primary and secondary sludge mix ratios on VFA production in thermophillic aerobic digestion using pilot scale ATAD units.* M.A.Sc. thesis, Civil Engineering, University of British Columbia, Vancouver, Canada.

Fuhs, G.W. and Chen, M. (1975) Microbial Basis of Phosphate Removal in the Activated Sludge Process for the Treatment of Wastewater. *Microbial Ecology*, **2**, 119.

Gujer, W. and Zehnder, A.J.B. (1983) Conversion processes in anaerobic digestion. *Water, Science and Technology*, **15**, 127.

Gupta, A.K. (1986) *The effects of temperature, pH and retention time on volatile fatty acids production from primary sludge.* M.A.Sc. thesis, Civil Engineering, University of British Columbia, Vancouver, Canada.

Horne, G. (1977) Nitrogen fixation - A review of this phenomenon as a polluting process. *Progress in Water Technology*, **8** (4/5), 359.

IAWQ Nutrient Removal Specialty Group, (1998) *4th IAWQ Conference on Modelling of Activated Sludge: Modelling and Microbiology of Activated Sludge Processes*, Copenhagen, Denmark. http://www.iawq.org.uk/newsletter1/nr1-98.htm#reviews

Jorgensen, P.E. (1990) Biological hydrolysis of sludge from primary precipitation. In *Chemical Water and Wastewater Treatment*. Hann, H.H. and Klute, K. (Ed.), Springer-Verlag, Berlin/Heidelberg, Germany.

Koch, K.A. (1992 to 1994) Unpublished data from a study involving fermentation of raw sewage at short HRTs. University of British Columbia, Vancouver, Canada.

Kuba, T.; Van Loosdrecht, M.C.M.; Brandse, F.A.; and Heijnen, J.J. (1997) The occurrence of denitrifying phosphorous removing bacteria in modified UCT-type wastewater treatment plants. *Water Research*, **31** (4), 777.

Lilley, I.D. Wentzel, M.C. Loewenthal, R.E. Ekama, G.A. Marais, G.v.R. 1990. *Acid fermentation of primary sludge at 20 °C.* Research Report W64, Department of Civil Engineering University of Cape Town, South Africa.

Llabres-Luengo, P. and Mata-Alvarez, J. (1988) The hydrolytic step in dry digestion. *Biological Wastes*, **23**, 25.

Metcalf and Eddy, revised by Tchabanoglous, G. and Burton, F.L. (1991) *Wastewater Engineering: Treatment, Disposal, Reuse*, 3rd Ed., McGraw-Hill Inc., Montreal, Canada.

Mino T.; Arun, V.; Tsuzuki, Y.; and Matsuo, T. (1987) Effect of phosphorus accumulation on acetate metabolism in the biological phosphorus removal process. In *Biological Phosphorus Removal From Wastewaters. Advances in Water Pollution Control*, Pergamon Press, Oxford, England.

Münch E. V. and Lant P.A. (1997a) Prefermenter design and performance evaluation based on rates instead of yields. *CHEMECA '97- 25th meeting of the Australian and New Zealand Chemical Engineers*, Rotorua, New Zealand.

Münch E.V.; Keller J.; Newell R.B.; and Lant P.A. (1997b) A dynamic mathematical model of anaerobic wastewater prefermentation for VFA production. In *8th International Conference on Anaerobic Digestion*, Sendai, Japan.

Münch, E.V. and Koch, F.A. (1997c) A survey of prefermenter design, operation and performance in Australia and Canada. *Proceedings of BNR 3*, Brisbane, Australia, 274.

Murnleitner, E.; Kuba, T.; van Loosdrecht, M.C.M.; and Heijnen, J.J. (1997) An integrated metabolic model for aerobic and denitrifying biological phosphorus removal. *Biotechnology and Bioengineering*, **54** (5), 434.

Nicholls, H.A.; Pitman, A.R.; and Osborn, D.W. (1985) The readily biodegradable fraction of sewage: its influence on phosphorus removal and measurement. *Water Science and Technology*, **17**, 73.

Ostgaard, K.; Christensson, M.; Lie, E.; Jonsson, J.; and Welander, T. (1997) Anoxic biological phosphorous removal in a full-scale UCT process. *Water Research*, **31** (11), 2719.

Pitman, A.R. (1984) Settling of nutrient removal activated sludges. *Water Science and Technology*, **17**, 493.

QuickChem, (1990) *Methods Manual for the QuickChem Automated Ion Analyser, LACAHT Instruments*. Milwaukee, WI.

Rabinowitz, B. (1985) *The role of specific substrates in excess biological phosphorus removal*. Ph.D. thesis, Civil Engineering, University of British Columbia, Vancouver, Canada.

Rabinowitz, B. and Oldham, W.K. (1986) Excess biological phosphorus removal in the activated sludge process using primary sludge fermentation. *Canadian Journal of Civil Engineering*, **13**, 345.

Rabinowitz, B.; Koch, F.A.; Vassos, T.A.; Oldham, W.K. (1987) A novel design of a primary sludge fermenter for use with the enhanced biological phosphorus removal process. *Proceedings from the IAWQ Specialized Confernece on Biological Phosphorus Removal from Wastewaters*, Rome, Italy.

Rabinowitz, B. and Barnard, J. (1995) Biological nutrient removal in western Canada. *National Conference on Innovative Tchnologies for Site Remediation and Hazardous Waste Management*, Pittsburg, PA.

Rabinowitz, B. and Barnard, J. (1997) The use of primary sludge fermentation in biological nutrient removal processes. *Proceedings of BNR 3*, Brisbane, Australia, 478.

Randall, A.A.; Khouri, T.Z.; Benefield, L.D.; Hill, W.E. (1998). Comparisons of EBPR removal populations under ten different environmental conditions. Poster presentation at *Water Quality International 1998.* Vancouver, Canada.

Randall, A. A.; Benefield, L.D.; Hill, W.E.; Nicol, J.P.; Boman, G.K.; and Jing, S.R. (1997) The effect of volatile fatty acids on enhanced biological phophorus removal and population structure in anaerobic/aerobic sequencing batch reactors. *Water Science and Technology*, **35** (1), 153.

Randall C.W.; Chapin, R.W. (1997) Acetic acid inhibition of biological phosphorus removal. *Water Environment Research*, **69** (5), 955.

Randall, C.W. (1994) Why use fermentation? *Precedings of specialty conference seminar entitled "Use of Fermentation to Enhance Biological Nutrient Removal".* Water Environment Federation Conference and Exposition, Chicago, IL.

Randall, C.W.; Barnard, J.L.; and Stensel, H.D. (1992) *Design and Retrofit of Wastewater Treatment Plants for Biological Nutrient Removal.* Water Quality Management Library - Volume 5. Technomic Publishing Company, Lancaster, PA.

Ringlace®, (1998) Product literature online at http://www.ringlace.com/

Setter, K.J. (1995) *Attached growth nitrification using Ringlace® media.* M.A.Sc. thesis, Bio-Resource Engineering, University of British Columbia, Vancouver, Canada.

Sharma, A. (1998) A personal correspondence.

Sincich, T. (1987) *Statistics by Example* 3rd Ed. Dellen Publishing Company, c/o Macmillan Publishing Company, Trenton, New Jersey.

Smolders, G.J.F.; Klop, J.M.; van Loosdrecht, M.C.M.; and Heijnen, J.J. (1995a) A metabolic model of the biological phosphorus removal process: I. Effect of sludge retention time. *Biotechnology and Bioengineering.* **48**, 222.

Smolders, G.J.F.; Bullstra, D.J.; Jacobs, R.; van Loosdrecht, M.C.M.; Heijnen, J.J.; (1995b) A metabolic model of the biological phosphorus removal process: II. Validation during start-up conditions. *Biotechnology and Bioengineering.* **48**, 234.

Stevens, G.M. (1994) Operational issues static fermenters - cold weather. *Proceedings of specialty conference seminar entitled "Use of Fermentation to Enhance Biological Nutrient Removal"*. Water Environement Federation Conference and Exposition, Chicago, IL.

Tandoi, V.; Majone, M.; May, J.; and Ramadori, R. (1998) The behaviour of polyphosphate accumulating *Acinetobacter* isolates in an anaerobic-aerobic chemostat. *Water Research*, **32** (10),2903.

United States Environmental Protection Agency (1987) *Design Manual - Phophorus Removal*. USEPA Office of Research and Development, 625/1-87/001, Washington, DC.

Water Pollution Control Federation (1976) The Operation of Wastewater Treatment Plants Manual of Practice No. 11. Washington, DC.

Wentzel, M.C.; Lotter, L.H.; Ekama, G.A.; Lowenthal, R.E.; and Marais, G.v.R. (1991) Evaluation of biochemical models for biological excess phosphorus removal. *Water Science and Technology*, **23**, 567.

Wentzel, M.C. and Ekama, G.A. (1997). Principals in the design of single-sludge activated-sludge systems for biological removal of carbon, nitrogen and phophorus. *Water Environment Research*, **69** (7), 1222.

APPENDICES

APPENDIX A - STATISTICAL ANALYSES

Determination of outliers.

Rejection of outliers was based on calculated statistics and consideration of events or conditions which may have caused the outlier. T values for each observation were calculated as follows (Barnett, 1978).

$$T = | (x - \bar{x}) | / s$$

x = the observation

$\bar{x}$ = data set mean (run #2)

s = data set standard deviation

Table a.1 Sample T-statistics for effluent ammonia during a two week period.

Effluent ammonia - Run #2: Tcr = +/- 2.060 @ 25 degrees freedom				
Date	**Effluent**	**T stat**	**comment**	**log entry**
Nov 13 (Th)	0.030	-0.429	ok	first day Run#2; heavy solids in raw
Nov 14 (F)	0.000	-0.442	ok	All OK, maintenance on RAS pumps
Nov 17 (M)	8.090	3.071	outlier	Raw sewage opaque; possibly from salty run-off; heavy rain after cold spell
Nov 18 (T)	7.457	2.796	outlier	Increased air to the process after pH was running high in aerobic zone.
Nov 19 (W)	4.905	1.688	ok	all OK
Nov 20 (Th)	3.552	1.100	ok	Raw sewage Opaque again; all OK
Nov 21 (F)	0.840	-0.077	ok	all OK; BCRI turned off air after sampling.
Nov 24 (M)	0.020	-0.433	ok	all OK
Nov 25 (T)	0.045	-0.422	ok	all OK; control has lot of anoxic scum
Nov 26 (W)	0.090	-0.403	ok	all OK; TOC : COD test today
Average	1.017			Average from all of Run #2
Std Dev.	2.303			Standard Deviation " "

If the absolute value calculated for T exceeded Tcr, an outlier was identified and a decision to either drop or include the data point was made based on the existence of possible explanations for the upset. All of the raw data collected in this experiment was subject to the same test and evaluated in a similar manner.

Precision

Precision of the data was calculated through analysis of duplicates as per Standard Methods (1995). Precision was expressed as a 95% confidence interval (CI) and also as standard deviation. The raw data and calculations can be found in Tables a.3 thru a.9 at the end of this Appendix.

Accuracy

Accuracy of the analytical equipment was checked by trained laboratory technicians each time the equipment was used to run samples. Accuracy was ascertained by measuring the recovery of samples with known concentrations. If unacceptable values were noted, adjustments were made to the equipment and the samples were run over again until accurate recoveries were made.

Method Detection Limit

The method detection limit (MDL) was calculated using the Total Variance Model as described by Berthouex, et. al. (1997). The MDL is significant to this experiment for parameters where concentrations are often close to zero such as Total Phosporus in the effluent or VFA in the anoxic zone.

The data in Table a.2 were generated from replicates of the same effluent grab sample and should, in theory, all equal the population mean (μ). Two sources of error responsible for

Table a.2   Total Phosphorus data

sample replicate observations							$\bar{x}$ mg/L	$\bar{x}^2$ (mg/L)^2	σ_e^2 (mg/L)^2
A-Effluent 0.23	0.24	0.24	0.28	0.23	0.14		0.23	0.0517	0.0018
B-Effluent 0.67	0.64	0.60	0.65	0.62	0.61		0.63	0.3994	0.0005
PC-Effluent 1.12	1.16	1.13	1.07	1.13	1.11	1.11	1.12	1.2532	0.0007
A-Effluent 1.12	1.16	1.28	1.26	1.15	1.19	0.89	1.15	1.3232	0.0140
B-Effluent 5.77	5.65	5.93	5.81	5.90	5.40	4.91	5.62	31.6233	0.1132

deviations are defined as background error (σ_b)and analytical error (σ_a) and together account for the sample error variance ($\sigma_e^2 = \sigma_b^2 + \sigma_a^2$). Background error is always present, even in blanks, and is assumed to have a fixed standard deviation. Analytical error is assumed to be proportional to the concentration of the analyte - a characteristic often observed with chemical data (Berthouex et. al. 1997).

Given the above assumptions for σ_b and σ_a it is possible to plot the variance (σ_e^2), versus the square of the arithmetic mean to determine both σ_b and σ_a from the intercept and slope respectively. In Figure a.1, the Y-intercept represents the background "noise" or error attributable to equipment and processing while in the lab.
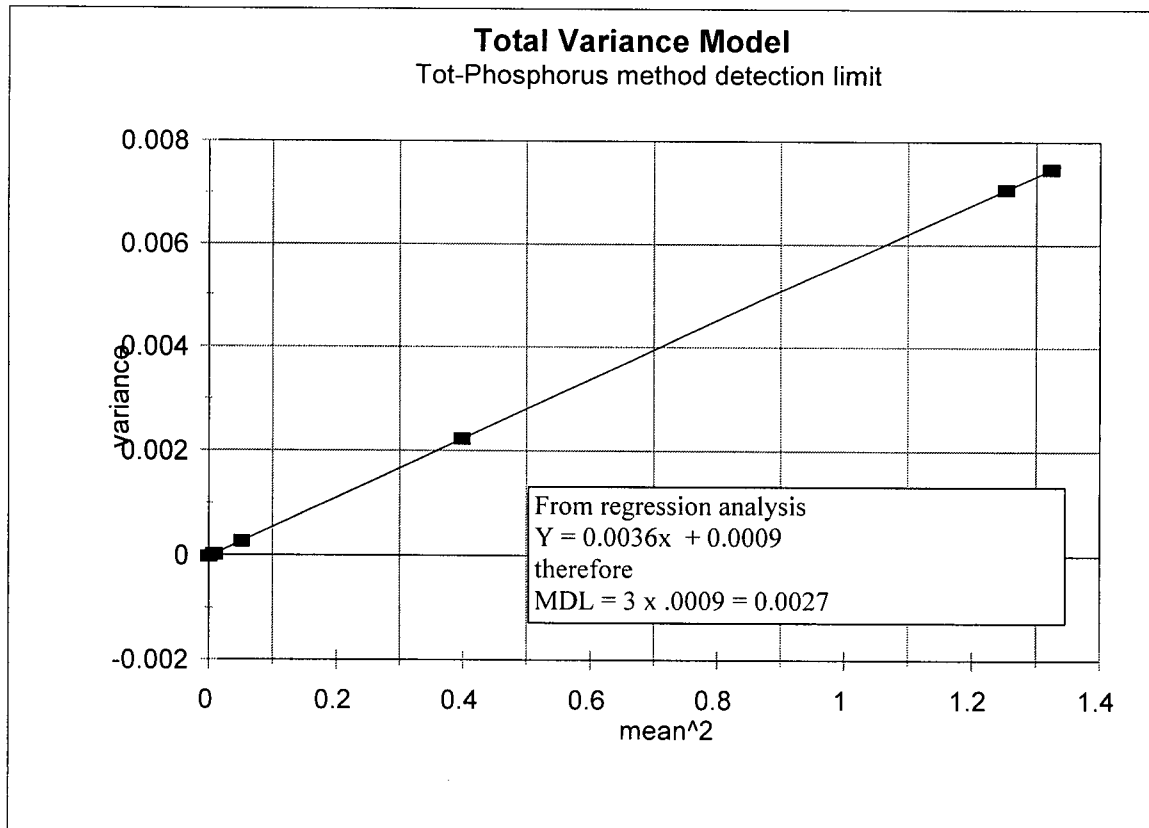
Figure a.1   Plot of Total Variance Model for determination of method detection limit for Total Phosphorus.

A regression analysis finds the intercept σ_b to be 0.0009 mg/L, thus the MDL is estimated as $3\sigma_b$ or 0.003 mg/L with a certainty of 95%. The implication is that an observation for T-P less than 0.003 could be considered non-detectable. There are several important things to note regarding the significance of the MDL to T-P results in this research: :

- The errors are assumed to be independent and normally distributed

- Observations less than the MDL are still reported and considered real values in the document. Where statistical tests for significance are concerned, a concentration less

than 0.003 mg/L will be assumed to have zero T-P.

- The method is assumed consistent for each analysis meaning the background errors do

  not change.

- The calculated MDL is pertinent for T-P observations processed as per the protocols used

  in this experiment.

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Table a.3 Phosphates (mg/L)

sample	duplicate	|delta|
3.279	3.207	0.072
0.604	0.805	0.201
1.392	1.003	0.389
3.585	3.877	0.292
21.422	20.762	0.660
9.043	10.024	0.981
7.410	8.875	1.465
4.645	4.538	0.107
1.642	1.256	0.386
1.527	1.841	0.314
1.813	1.229	0.584
1.688	1.806	0.118
4.414	4.172	0.242
2.076	1.716	0.360
5.934	6.698	0.764
3.605	3.275	0.330
17.604	16.064	1.540
9.700	9.671	0.029
7.116	7.547	0.431
6.698	6.688	0.010
4.510	3.860	0.650
5.404	5.465	0.061
4.416	3.572	0.844
5.624	5.458	0.166
3.890	3.475	0.415
4.240	4.056	0.184
5.311	4.705	0.606
4.489	4.542	0.053
3.716	3.87	0.151
3.225	3.23	0.004
3.986	3.97	0.020
4.566	4.55	0.013
4.778	2.16	2.621
14.910	14.54	0.368
9.77	9.67	0.099
7.45	7.40	0.055
4.86	4.83	0.025
4.83	4.81	0.018
6.04	6.01	0.032
4.16	2.39	1.771

Table a.4 Nitrate/Nitrite (mg/L)

sample	duplicate	|delta|
0.177	0.033	0.144
3.017	3.438	0.421
0.061	0.138	0.077
0.195	0.210	0.015
0.125	0.161	0.036
0.186	0.236	0.050
0.173	0.208	0.035
4.479	4.503	0.024
3.079	4.734	1.655
4.251	3.814	0.437
3.674	5.113	1.439
0.113	0.096	0.017
5.025	4.560	0.465
4.815	5.698	0.883
0.160	0.081	0.079
0.134	0.131	0.003
0.121	0.120	0.001
0.134	0.139	0.005
0.711	0.762	0.051
4.545	4.272	0.273
4.030	4.318	0.288
4.523	3.975	0.548
4.120	4.293	0.173
0.118	0.102	0.016
4.033	4.136	0.103
4.461	4.283	0.178
4.64	3.06	1.583
0.13	0.10	0.034
4.80	4.62	0.176
4.70	4.55	0.148
0.00	0.10	0.103
5.68	5.52	0.154
5.36	5.24	0.114
0.00	0.03	0.026
0.15	0.14	0.011
0.17	0.15	0.022
0.89	1.41	0.518
0.52	0.46	0.067
4.88	4.60	0.281
3.90	5.90	1.998

4.07	4.04	0.035
5.41	5.36	0.053
3.28	3.23	0.044
16.42	16.02	0.401
13.62	13.36	0.257
6.37	6.32	0.049
6.82	6.79	0.034
4.07	4.04	0.028
3.28	3.25	0.027
2.88	2.85	0.034
3.64	3.61	0.029
3.60	3.55	0.054
4.14	4.11	0.029
4.37	4.32	0.046
2.96	2.87	0.091

sum   18.642

count   55.000

avg delta (R)   0.339

s = R/1.128   0.301

C.I. = 1.96s   +/- 0.59

4.11	3.86	0.254
4.22	4.03	0.183
0.00	0.03	0.031
4.13	3.87	0.264
4.06	3.80	0.255
0.13	0.18	0.051
0.17	0.16	0.014
0.20	0.17	0.032
0.88	0.76	0.120
0.28	0.25	0.029
4.91	4.63	0.284
4.50	4.23	0.272
4.25	4.01	0.241
4.54	4.36	0.186
0.05	0.10	0.043

sum   14.910

count   55.000

avg delta (R)   0.271

s = R/1.128   0.240

C.I. = 1.96s   +/- 0.46

Table a.5 Ammonia (mg/L)

sample	duplicate	|delta|
20.197	25.626	5.429
0.066	0.118	0.052
22.410	23.490	1.080
12.224	14.281	2.057
9.903	8.650	1.253
2.991	4.483	1.492
4.820	4.353	0.467
0.009	0.167	0.158
0.317	0.058	0.259
0.050	0.000	0.050
34.251	22.194	12.057
0.007	0.000	0.007
18.303	18.522	0.219
9.097	10.873	1.776
8.230	7.119	1.111
3.633	3.594	0.039

Table a.6 Volatile Fatty Acids (mg/L)

sample	duplicate	|delta|
18.59	18.04	0.544
18.66	18.76	0.101
20.48	20.01	0.466
19.96	20.00	0.038
20.83	20.94	0.106
17.35	17.90	0.557
19.23	19.48	0.251
19.00	19.10	0.097
20.40	20.53	0.135
22.39	22.44	0.052
22.54	22.29	0.244
20.35	20.91	0.565
21.66	21.68	0.021
22.43	22.34	0.091
22.78	22.98	0.201
24.56	24.08	0.485

3.027	3.045	0.018
0.000	0.015	0.015
18.001	21.076	3.075

sum	30.614
count	19.000
avg delta (R)	1.611
s = R/1.128	1.428
C.I. = 1.96s	+/- 2.8

Table a.7 Total Kjeldahl Nitrogen and Total Phosphorus (mg/L)

TKN*	|delta|	TP*	|delta|
18.70	0.00	15.60	0.00
21.80	3.10	13.40	2.20
19.30	0.60	18.00	2.40
16.50	2.20	15.80	0.20
18.10	0.60	14.80	0.80
16.28	2.42	16.10	0.50
16.70	2.00	15.50	0.10
18.80	0.10	16.10	0.50
21.60	2.90	15.50	0.10
18.70	0.00		
16.20	2.50		

* Known standards of TKN=18.7 mg/L
  and TP=15.6 mg/L

avg	1.49	0.76
std	1.17	0.86
95% CI	2.3	1.7

Table a.8 MLSS (mg/L)

sample	duplicate	|delta|
4440	4590	150
4790	4660	130
4690	4700	10
3830	3880	50
4630	4490	140
4420	4510	90
4020	4160	140

20.52	20.33	0.185
22.33	22.05	0.275
22.48	22.26	0.221
22.35	21.00	1.356
20.60	20.55	0.047
21.81	21.84	0.028
22.09	24.03	1.937
22.78	22.49	0.292
22.35	22.39	0.040
23.81	23.79	0.023
24.09	24.97	0.875
25.54	25.19	0.351
28.05	27.91	0.136
28.17	27.18	0.988
22.64	22.91	0.277
23.12	23.65	0.532
23.55	23.53	0.021
23.73	23.67	0.058
24.74	24.26	0.474
21.21	21.07	0.136
23.66	23.61	0.048
23.15	22.62	0.532

sum	12.786
count	38.000
avg delta (R)	0.336
s = R/1.128	0.300
C.I. = 1.96s	+/- 0.6

Table a.9 TSS (mg/L)

sample	duplicate	|delta|
102.00	94.00	8.00
116.00	100.00	16.00
102.00	106.00	4.00
96.00	108.00	12.00
102.00	108.00	6.00
80.00	100.00	20.00
106.00	108.00	2.00
124.00	140.00	16.00
96.00	98.00	2.00
76.00	96.00	20.00

3650	3720	70		74.00	82.00	8.00
1460	1510	50		88.00	110.00	22.00
1720	1720	0		92.00	106.00	14.00
1780	1810	30		80.00	70.00	10.00
2120	2210	90		92.00	94.00	2.00
1960	2040	80		80.00	88.00	8.00
1270	1240	30		126.00	134.00	8.00
1370	1450	80		72.00	69.00	3.00
3320	3400	80		137.00	135.00	2.00
2850	3070	220		117.00	136.00	19.00
2310	2380	70		98.00	120.00	22.00
2050	2040	10		104.00	98.00	6.00
2130	1570	560		142.00	162.00	20.00
1090	1130	40		114.00	116.00	2.00
1320	1330	10		184.00	176.00	8.00
1790	1760	30		152.00	158.00	6.00
1490	2160	670		158.00	154.00	4.00
2300	2360	60		86.00	92.00	6.00
2690	2720	30		122.00	128.00	6.00
2870	2940	70				
2960	3010	50				
3020	3110	90		sum		282.0
3730	3990	260		count		29.0
3520	3750	230		avg delta (R)		9.7
3760	3400	360		s = R/1.128		8.6
3010	3060	50				
3170	3160	10		C.I. = 1.96s		17.0
2910	3100	190				
2960	3180	220				
2990	3040	50				
2940	2900	40				
3080	3000	80				
3000	3100	100				
2470	2610	140				
1720	1730	10				
2150	2170	20				
2160	2150	10				
2230	2270	40				
2460	2380	80				
3220	3140	80				
3010	3160	150				
3420	3490	70				
3240	3300	60				

3740	3760	20
3590	3680	90
3640	3720	80
3580	3690	110
3590	3740	150
3500	3700	200
3610	3730	120
3600	3580	20
3540	3620	80
3560	3670	110
3560	3680	120
3510	3530	20
3560	3690	130
3620	3750	130
3740	3920	180
3770	3910	140
3660	3830	170
3220	3370	150
3330	3360	30

sum	7430.0
count	69.0
avg delta (R)	107.7
s = R/1.128	95.7

C.I. = 1.96s   +/- 190

APPENDIX B - FILTER TEST

Results of the fractionation testing for nutrients and COD

The purpose of this test was to gain insight into how filter pore size affects filtrate concentration measured from grab samples taken at the UBC Pilot Plant. A 500 mL stock sample was taken from locations in the process as indicated in the following tables. From the initial stock sample, sub-samples of 50 mL or less were taken and filtered through each of the four filter types. It was reasoned that if filter size had a negligible effect, the concentration of each filtrate would be the same. Throughout this procedure, it was important to ensure the initial stock sample was completely (and continuously) mixed. It was also important to conduct the experiment quickly to avoid biological or chemical changes in the stock grab sample. The filters used were as follows:

- Wh# 4 = Whatman No. 4 filter paper. Pore size 20μm.

- 934-AH = Whatman 934-AH glass fibre. Pore size 1.5μm

- 934-AH* = Whatman 934-AH glass fibre in funnel. Pore size approximately 1.5μm

- 0.45 μm = Whatman membrane filters. Pore size 0.45 μm

Results of the fractionation testing for VFA

A similar testing scheme was conducted for VFAs; however, replicate samples were used and sampling was limited to the raw sewage and the fermented sewage as VFA was negligible at other locations in the process. A stock sample (500 mL) of sewage was taken from each location from which 4 subsamples and 4 replicates were filtered through the aforementioned filters. Each subsample and its corresponding replicate required enough liquid to fill the 2 mL VFA vials. In total, 8 filtrates were prepared in separate vials and each filtrate was measured twice at the lab.

Filter Test Oct. 3/97

Table b.1 Soluble phosphate results using different filter sizes from the same sample.

Filter	Raw	Anaerobic	Anoxic	Aerobic	Effluent
Wh#4	2.65	1.09	0.06	0.09	0.08
934-AH*	2.46	1.16	0.06	0.05	0.11
934-AH	2.68	1.11	0.06	0.06	0.04
0.45um	2.59	1.41	0.10	0.10	0.11

Table b.2 Nitrate/Nitrite results using different filter sizes from the same sample.

Filter	Raw	Anaerobic	Anoxic	Aerobic	Effluent
Wh#4	0.03	0.21	1.58	4.27	4.17
934-AH*	0.03	0.05	1.41	4.18	4.11
934-AH	0.03	0.16	1.48	4.38	3.44
0.45um	0.03	0.07	1.51	4.85	4.18

Table b.3 Ammonia results using different filter sizes from the same sample.

Filter	Raw	Anaerobic	Anoxic	Aerobic	Effluent
Wh#4	13.23	6.27	2.48	0.06	0.11
934-AH*	13.03	6.27	2.35	0.04	0.03
934-AH	12.70	6.33	2.60	0.03	0.04
0.45um	13.87	6.24	2.51	0.03	0.03

Table b.4 Chemical oxygen demand using different filter sizes from the same sample.

Filter	Raw	Anaerobic	Anoxic	Aerobic	Effluent
Wh#4	71	16	5	99	3
934-AH*	39	6	6	30	5
934-AH	42	8	7	16	7
0.45um	31	7	0	0	6

Table b.5 Raw sewage VFA results using different filter sizes from the same sample and corresponding replicates.

	Raw x 2		Raw replicate x 2	
	H-Ac	mean AC	H-Ac	Mean Ac
Wh#4	9.74		9.84	
	9.98	9.86	9.57	9.71
934-AH*	10.74		8.74	
	9.93	10.34	8.52	8.63
934-AH	9.71		9.30	
	9.46	9.59	8.32	8.81
0.45um	9.65		9.50	
	9.59	9.62	9.25	9.37

Table b.6 Fermented sewage VFA results using different filter sizes from the same sample and corresponding replicates

	Fermenter B4 x 2				Fermenter B4 replicate x 2			
	H-Ac	H-Pr	H-Pr as Ac	Mean Ac	H-Ac	H-Pr	H-Pr as Ac	
Wh#4	19.96	2.74	2.22		18.33	2.54	2.05	
	20.11	2.81	2.27	22.28	19.01	2.60	2.10	20.75
934-AH*	19.26	2.72	2.20		19.20	2.65	2.15	
	19.41	2.74	2.22	21.55	18.46	2.64	2.14	20.97
934-AH	18.91	2.72	2.20		18.20	2.60	2.11	
	18.57	2.65	2.15	20.91	18.30	2.64	2.14	20.37
0.45um	16.00	2.42	1.96		18.06	2.48	2.01	
	18.02	2.40	1.95	18.96	15.70	2.41	1.95	18.86

Table b.7 Fermented sewage VFA replicate results with Whatman #4

Sample	H-Ac	H-Pr	H-Pr as Ac	Mean Ac
	19.25	3.55	2.87	
1	18.97	3.681	2.98	22.04
	19.48	3.722	3.01	
2	19.31	3.659	2.96	22.38
	19.66	3.717	3.01	
3	19.84	3.768	3.05	22.78
	19.34	3.738	3.03	
4	20.38	3.709	3.00	22.88
	19.98	3.78	3.06	
5	20.13	3.785	3.07	23.12

Tables b.1 thru b.7 consist of raw data expressed in mg/L from the filter testing. VFA results are expressed in terms of mg/L of acetic acid (H-Ac, or Ac). At the time testing was carried out, propionic acid (H-Pr) was evident in the fermented sewage but not in the raw sewage. Figures b.1 thru b.5 are plots of the data, from which the effects of filter pore size can be deduced. A discussion of the results and their impact on analytical methods was presented in Section 3.5.
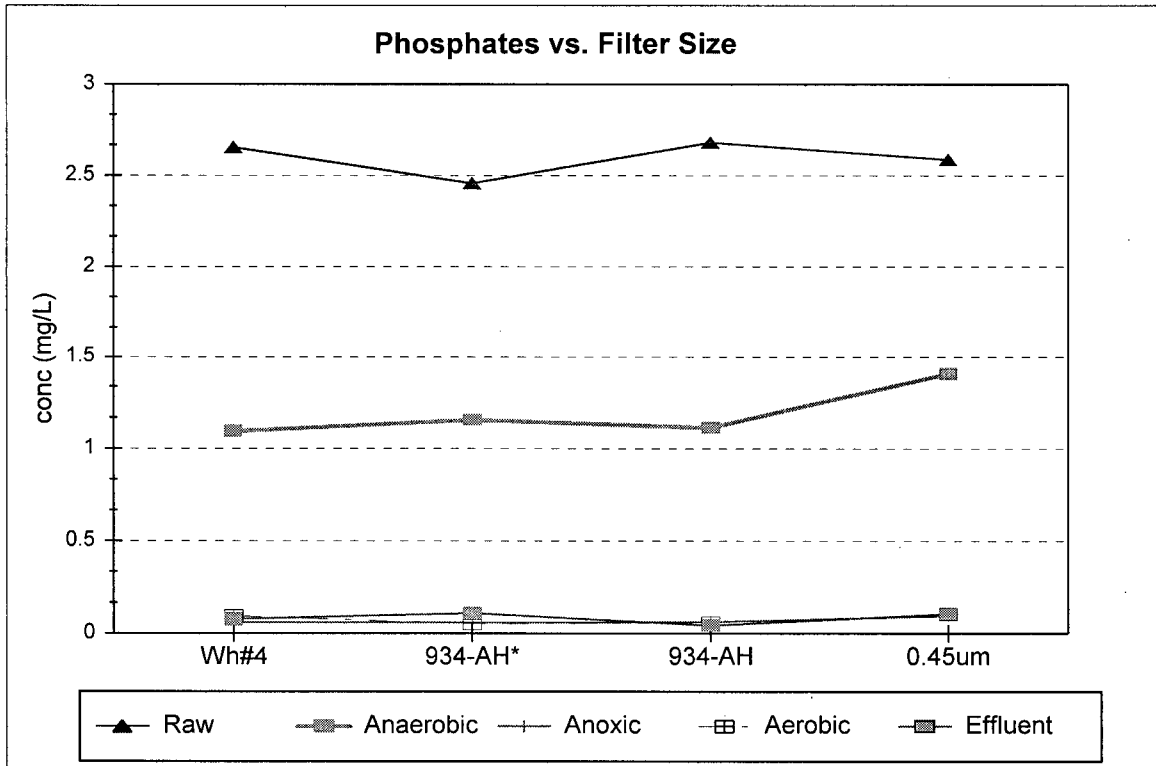
Figure b.1   **Effect of filter pore size on soluble phosphorus concentration**
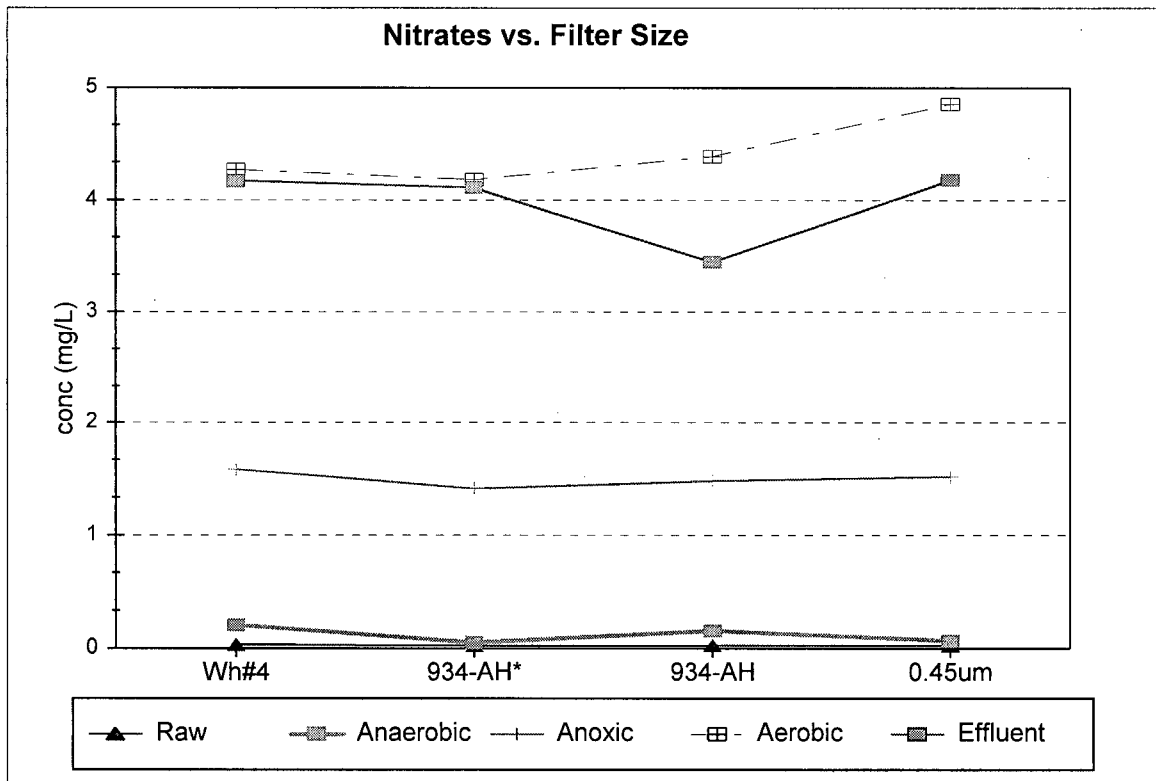
Figure b.2   **Effect of filter pore size on nitrate/nitrite concentration**

Ammonia vs. Filter Size
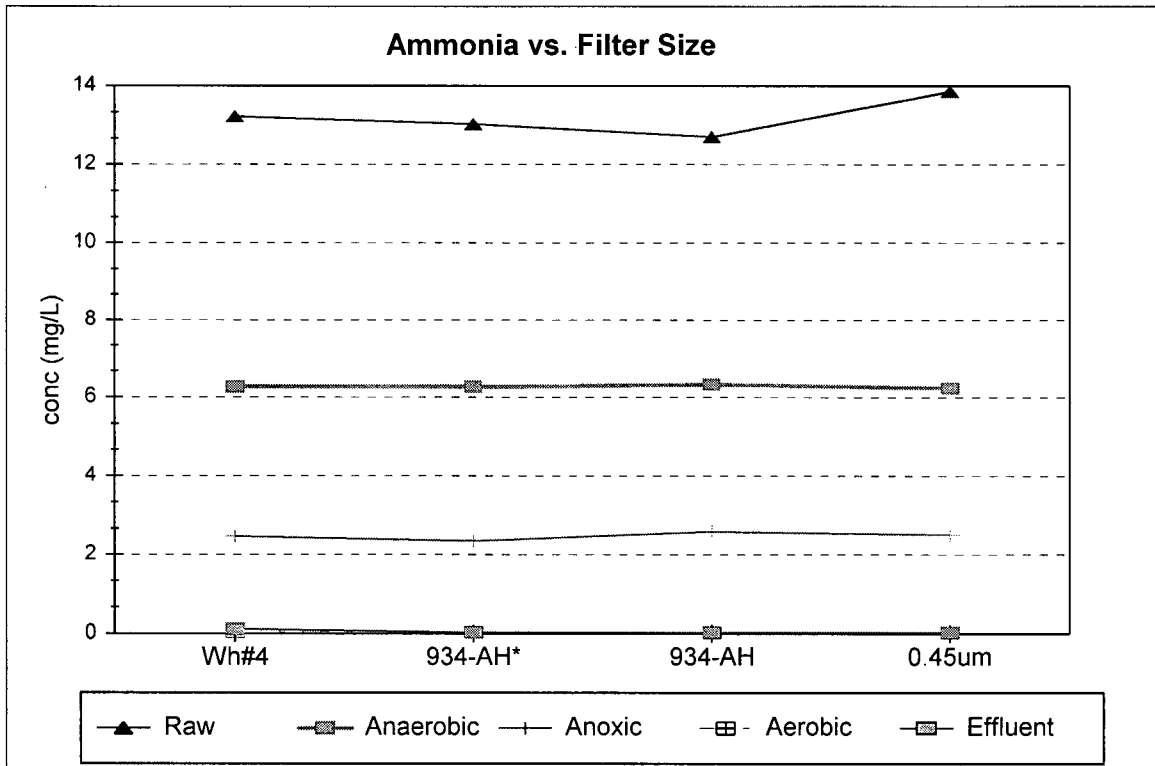
Figure b.3   Effect of filter pore size on ammonia concentration

Chemical Oxygen Demand vs. Filter Size
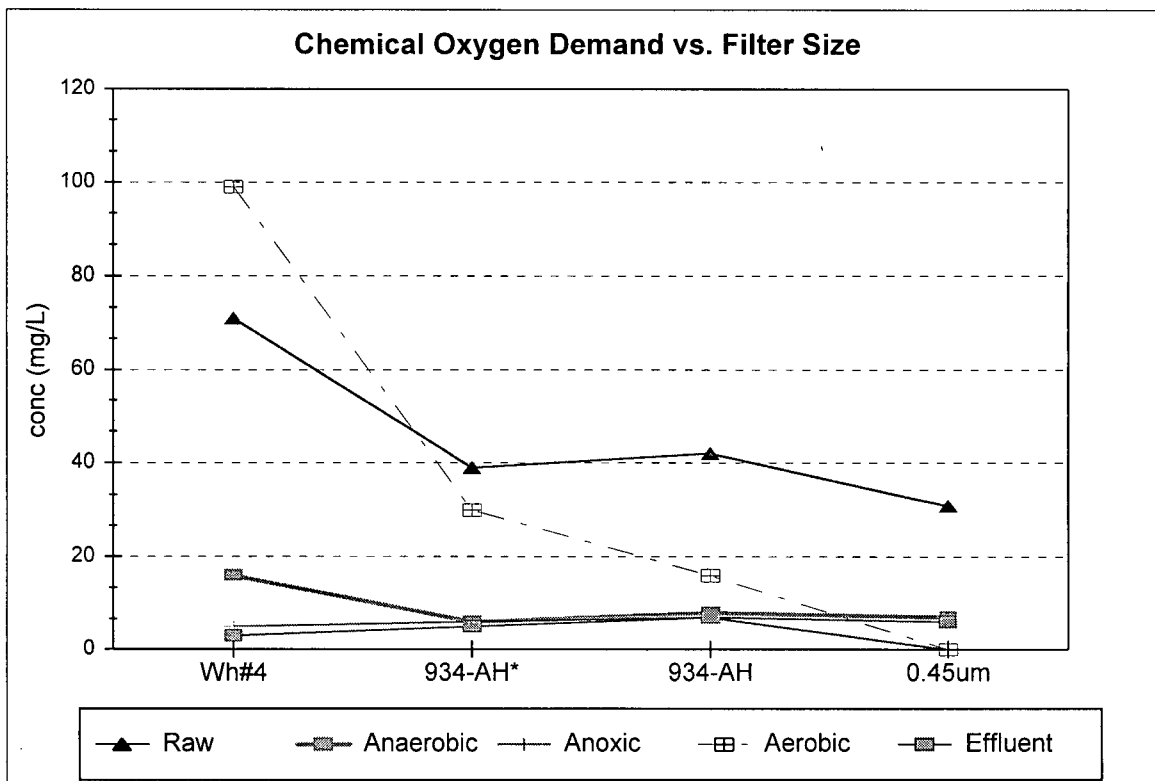
Figure b.4   Effect of filter pore size on chemical oxygen demand
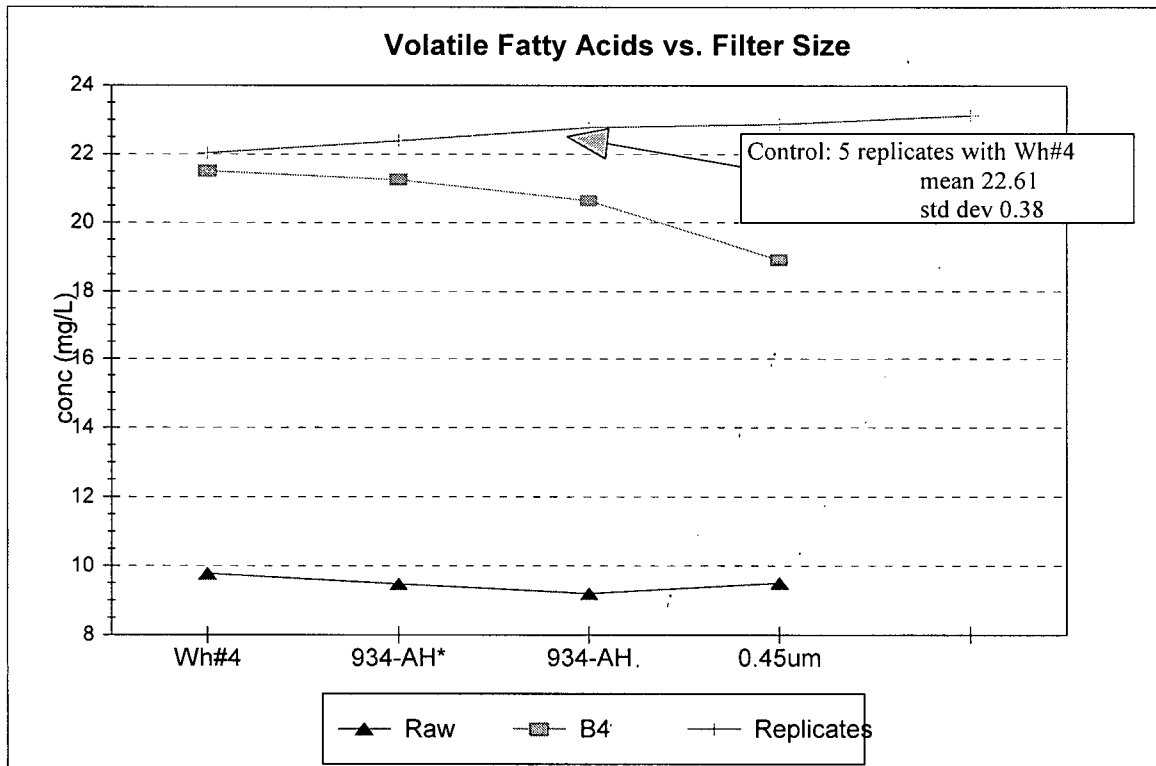
Figure b.5   Effect of filter pore size on volatile fatty acid concentration.

APPENDIX C - EXPERIMENTAL RESULTS

RUN #1

RAW DATA - RUN #1 SCVFAs
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L as acetic acid

Date	Raw Sewage			Prim Effluent			A side process - Control Fermenters							
							15 min		30 min		45 min		60 min	
	HAc	HPr	Pr as HAc	HAc	HPr	Pr as HAc	HAc	HPr	HAc	HPr	HAc	HPr	HAc	HPr
Jul 22 (T)														
Jul 23 (W)														
Jul 24 (Th)	24.98	3.59	2.91	25.64	5.13	4.15	38.29	5.00	30.23	5.26	24.99	5.03	26.04	5.06
Jul 25 (F)	19.56	2.89	2.34	20.99	6.00	4.86	4.95	0.00	6.86	3.06	34.63	4.98	28.47	4.05
Jul 28 (M)	17.09	3.03	2.45										32.30	10.52
Jul 29 (T)	26.55	4.23	3.43										41.02	9.02
Jul 30 (W)	31.32	5.52	4.47										37.68	8.50
July 31(Th)	23.00	3.37	2.73	28.08	6.81	5.52	9.73	2.92	11.19	3.37	42.47	6.26	35.74	7.94
Aug. 5 (T)	22.68	0.00	0.00	28.22	8.52	6.90	11.68	3.89	10.93	2.80	39.99	3.25	25.98	6.68
Aug 6 (W)	22.26	0.00	0.00										23.78	2.71
Aug 7(Th)	18.05	2.59	2.09	16.57	2.93	2.37	5.57	0.00	8.38	0.00	25.52	3.29	18.83	3.67
Aug 8 (F)	19.70	8.41	6.81										20.08	2.94
Aug 11(M)	34.04	17.94	14.53	20.01	3.66	2.96	7.72	2.85	5.92	2.85	10.29	0.00	18.73	3.85
Aug 12 (T)	19.53	7.32	5.93										25.16	4.06
Aug 13(W)	19.07	2.51	2.04										25.96	3.32
Aug 14(Th)	19.45	0.00	0.00	14.69	0.00	0.00	15.52	0.00	16.83	0.00	0.00	0.00	18.66	2.84
Aug 15(F)	16.19	0.00	0.00										18.33	2.64
Aug 18(M)	17.19	0.00	0.00	17.49	0.00	0.00	13.02	0.00	13.53	2.69	20.78	4.00	19.92	2.67
Aug 19 (T)	19.80	0.00	0.00										21.40	2.78
Aug 20(W)	11.86	0.00	0.00										22.69	4.22
Aug 21(Th)	32.21	5.06	4.10	31.60	5.43	4.40	31.13	7.23	28.44	6.16	28.79	5.74	29.33	5.82
Aug 22(F)	27.54	5.34	4.33										30.68	7.45
Aug 25(M)	29.55	5.70	4.62	30.76	5.96	4.83	34.12	5.78	32.83	5.89	32.86	5.83	33.05	6.09
Aug 26 (T)	29.20	4.79	3.88										31.19	6.24
Aug 27(W)	32.20	5.48	4.44										33.63	6.84
Aug 28(Th)	24.33	0.00	0.00	25.37	0.00	0.00	24.70	0.00	23.97	0.00	27.14	0.00	27.36	0.00
Aug 29(F)	24.19	0.00	0.00										27.10	5.02

Oct 14 (T)	30.22	7.30	5.91	29.14	7.39	5.99	31.30	8.05	31.70	8.75	31.90	8.73	31.84	8.70
Oct 15 (W)	15.73	0.00	0.00										19.40	3.94
Oct 16 Th	13.53	0.00	0.00	18.99	3.72	3.02	20.50	3.95	21.55	4.49	21.72	4.66	22.55	4.77
Oct 17 (F)	16.88	0.00	0.00										21.07	4.06
Oct 20 (M)	17.67	0.00	0.00										20.37	3.55
Oct 21 (T)	24.78	3.65	2.95	25.84	4.30	3.48	26.17	4.50	27.01	4.52	26.71	4.52	26.71	4.34
Oct 22 (W)	14.26	0.00	0.00										15.32	0.00
Oct 23 Th	22.06	4.41	3.57	23.02	5.06	4.10	21.61	5.13	24.62	5.28	22.18	5.43	22.87	5.38
Oct 24 (F)	7.90	2.09	1.69										19.91	4.82
Oct 27 (M)	13.91	2.77	2.24										18.17	3.27
Oct 28 (T)	8.88	1.64	1.33	12.73	2.36	1.91	13.48	2.78	12.77	2.55	13.43	3.24	14.16	3.34
Oct 29 (W)	21.97	12.52	10.14										16.63	4.18
Means	21.33	3.30	2.67	23.07	4.20	3.41	19.34	3.25	19.17	3.43	25.21	4.06	24.92	4.74
Std Dev.	6.51	3.83	3.10	5.71	2.54	2.06	10.35	2.59	9.10	2.50	10.50	2.35	6.48	2.29

Note: Standard Deviation are sample standard deviations (N-1) degrees of freedom

RAW DATA - SCVFAs RUN#1

Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L as acetic acid

B side process - Experiment Fermenters

Date	15 min		30 min			45 min			60 min			
	HAc	HPr	Pr as H/HAc	HAc	HPr	Pr as H/HAc	HAc	HPr	Pr as H/HAc	HAc	HPr	Pr as HA
Jul 22 (T)												
Jul 23 (W)												
Jul 24 (Th	7.74	0.00	0.00	28.67	5.93	4.80	26.69	5.94	4.81	29.69	6.37	5.16
Jul 25 (F)			0.00			0.00			0.00	27.56	4.91	3.97
Jul 28 (M)	28.39	8.19	6.64	31.70	9.39	7.61	30.01	8.48	6.87	40.53	12.81	10.38
Jul 29 (T)			0.00			0.00			0.00	39.09	14.77	11.96
Jul 30 (W)			0.00			0.00			0.00	44.43	15.13	12.26
July 31(Th	28.29	7.26	5.88	33.38	9.71	7.87	26.24	8.52	6.90	40.28	13.83	11.20
Aug. 5 (T)	21.03	5.88	4.77	33.77	8.17	6.62	21.09	6.20	5.03	38.18	11.33	9.18
Aug 6 (W)			0.00			0.00			0.00	26.37	5.15	4.17
Aug 7(Th)	10.01	4.06	3.29	22.67	5.46	4.42	17.43	3.59	2.91	22.84	4.71	3.81
Aug 8 (F)			0.00			0.00			0.00	21.64	3.06	2.48
Aug 11(M)	9.63	2.52	2.04	16.60	2.99	2.43	15.94	2.99	2.42	26.11	4.46	3.61
Aug 12 (T)			0.00			0.00			0.00	30.12	5.19	4.21
Aug 13(W)			0.00			0.00			0.00	28.49	3.38	2.74
Aug 14(Th	18.75	2.71	2.20	16.99	2.63	2.13	18.49	2.95	2.39	23.90	3.01	2.44
Aug 15(F)			0.00			0.00			0.00	21.40	2.72	2.21
Aug 18(M)	20.65	3.49	2.83	22.88	4.45	3.60	23.03	3.85	3.12	24.20	3.23	2.61
Aug 19 (T)			0.00			0.00			0.00	25.55	2.74	2.22
Aug 20(W)			0.00			0.00			0.00	24.68	4.27	3.46
Aug 21(Th	29.77	6.12	4.96	30.72	6.73	5.45	31.19	6.98	5.65	31.51	7.00	5.67
Aug 22(F)			0.00			0.00			0.00	32.44	9.16	7.42
Aug 25(M)	34.22	6.86	5.55	35.10	7.44	6.03	33.92	7.61	6.16	34.93	7.48	6.06
Aug 26 (T)			0.00			0.00			0.00	36.14	8.35	6.76
Aug 27(W)			0.00			0.00			0.00	37.16	9.11	7.38
Aug 28(Th	26.21	4.23	3.43	27.65	5.35	4.33	29.40	5.25	4.25	31.20	5.47	4.43
Aug 29(F)			0.00			0.00			0.00	30.58	7.29	5.91
Oct 14 (T)	32.18	8.26	6.69	32.24	9.33	7.56	32.12	9.66	7.82	33.24	10.29	8.34
Oct 15 (W)			0.00			0.00			0.00	22.77	4.89	3.96

Oct 16 Th	20.42	4.07	3.30	20.42	4.27	3.45	21.88	4.57	3.70	22.99	4.85	3.93
Oct 17 (F)			0.00			0.00			0.00	25.05	5.08	4.12
Oct 20 (M)			0.00			0.00			0.00	23.23	4.45	3.61
Oct 21 (T)	25.31	4.52	3.66	26.27	4.71	3.82	26.97	5.01	4.06	27.68	5.32	4.31
Oct 22 (W)			0.00			0.00			0.00	18.75	3.66	2.97
Oct 23 Th	21.52	5.14	4.16	21.30	5.52	4.47	23.45	6.00	4.86	24.72	6.20	5.02
Oct 24 (F)			0.00			0.00			0.00	20.27	5.24	4.25
Oct 27 (M)			0.00			0.00			0.00	20.99	4.02	3.26
Oct 28 (T)	13.65	2.68	2.17	14.39	3.20	2.59	16.77	3.74	3.03	17.15	4.14	3.35
Oct 29 (W)			0.00			0.00			0.00	17.31	4.97	4.02
Means	21.74	4.75	3.85	25.92	5.95	4.82	24.66	5.71	4.62	28.19	6.43	5.21
Std Dev.	7.93	2.19	2.24	6.52	2.23	2.67	5.59	2.02	2.53	6.92	3.38	2.74

RAW DATA - SCVFAs RUN#1

Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L as acetic acid

Date	Production mg/L							
	A-side				B-side			
	HAc	HPr	as Ac	Tot-HAc	HAc	HPr	as Ac	Tot-HAc
Jul 22 (T)								
Jul 23 (W)								
Jul 24 (Th)	0.40	0.91	0.74	1.13	4.05	2.21	1.79	5.84
Jul 25 (F)	8.91	1.16	0.94	9.85	8.00	2.01	1.63	9.63
Jul 28 (M)	11.31	5.66	4.59	15.90	19.54	7.95	6.44	25.98
Jul 29 (T)	14.47	4.79	3.88	18.35	12.54	10.54	8.54	21.07
Jul 30 (W)	6.36	2.97	2.41	8.77	13.11	9.61	7.78	20.89
July 31(Th	7.66	2.42	1.96	9.63	12.20	8.32	6.74	18.94
Aug. 5 (T)	-2.24	-0.22	-0.18	-2.42	9.96	4.43	3.59	13.55
Aug 6 (W)	1.52	2.71	2.19	3.71	4.11	5.15	4.17	8.29
Aug 7(Th)	2.25	1.30	1.05	3.30	6.27	2.33	1.89	8.16
Aug 8 (F)	0.38	-5.47	-4.43	-4.06	1.94	-5.35	-4.33	-2.39
Aug 11(M)	-1.28	0.89	0.72	-0.56	6.10	1.50	1.21	7.32
Aug 12 (T)	5.63	-3.26	-2.64	2.98	10.58	-2.13	-1.72	8.86
Aug 13(W)	6.89	0.81	0.66	7.55	9.43	0.87	0.70	10.13
Aug 14(Th	3.97	2.84	2.30	6.27	9.21	3.01	2.44	11.64
Aug 15(F)	2.14	2.64	2.14	4.27	5.21	2.72	2.21	7.42
Aug 18(M)	2.44	2.67	2.17	4.60	6.71	3.23	2.61	9.33
Aug 19 (T)	1.61	2.78	2.25	3.86	5.76	2.74	2.22	7.98
Aug 20(W)	10.83	4.22	3.41	14.25	12.82	4.27	3.46	16.28
Aug 21(Th	-2.27	1.42	1.15	-1.12	-0.09	2.60	2.11	2.01
Aug 22(F)	3.14	2.11	1.71	4.85	4.90	3.81	3.09	7.99
Aug 25(M)	2.29	1.26	1.02	3.31	4.17	2.66	2.15	6.32
Aug 26 (T)	1.99	1.45	1.17	3.17	6.94	3.56	2.88	9.82
Aug 27(W)	1.43	1.35	1.10	2.53	4.97	3.63	2.94	7.91
Aug 28(Th	1.99	0.00	0.00	1.99	5.82	5.47	4.43	10.26
Aug 29(F)	2.91	5.02	4.07	6.98	6.39	7.29	5.91	12.29
Oct 14 (T)	2.70	2.71	2.20	4.90	4.10	4.31	3.49	7.59
Oct 15 (W)	3.67	3.94	3.19	6.86	7.05	4.89	3.96	11.01

Oct 16 Th	3.56	1.76	1.42	4.98	4.00	1.83	1.48	5.48
Oct 17 (F)	4.19	4.06	3.29	7.48	8.17	5.08	4.12	12.29
Oct 20 (M)	2.71	3.55	2.87	5.58	5.56	4.45	3.61	9.17
Oct 21 (T)	0.87	0.85	0.69	1.56	1.84	1.84	1.49	3.33
Oct 22 (W)	1.05	0.00	0.00	1.05	4.49	3.66	2.97	7.46
Oct 23 Th	-0.15	1.28	1.03	0.89	1.70	2.10	1.70	3.40
Oct 24 (F)	12.02	2.73	2.21	14.23	12.38	3.15	2.55	14.93
Oct 27 (M)	4.26	0.50	0.41	4.66	7.08	1.25	1.01	8.09
Oct 28 (T)	1.43	1.43	1.16	2.59	4.42	2.23	1.81	6.22
Oct 29 (W)	-5.34	-8.34	-6.76	-12.10	-4.66	-7.55	-6.12	-10.78
Means	3.40	1.54	1.25	4.64	6.67	3.23	2.62	9.29
Std Dev.	4.10	2.64	2.14	5.55	4.31	3.38	2.73	6.37

Note: Standard Deviation are sample standard deviations (N-1) degrees of freedom

RAW DATA - RUN #1 NITRATES
Effect of Fixed Film Prefermentation on BNR Process Performance

Results as Nitrogen in mg/L

Date	Raw Se	Prim Ef	A side process - Control				Process B side process - Experiment Pro			
			Anaerol	Anoxic	Aerobic	Effluent	Anaerol	Anoxic	Aerobic	Effluent
Jul 22 (T)	0.376	0.433	0.775	0.343	7.435	6.551	1.042	2.831	8.840	7.820
Jul 23 (W)	0.055					4.708				5.583
Jul 24 (Th)	0.143	0.156	0.423	0.341	4.818	4.248	0.244	1.212	5.188	4.680
Jul 25 (F)	0.022					4.288				4.297
Jul 28 (M)	0.060	0.149	0.263	0.419	4.828	4.391	0.269	0.869	4.865	4.546
Jul 29 (T)	0.111					4.242				3.719
Jul 30 (W)	0.106					4.045				3.464
July 31(Th)	0.049	0.055	0.528	0.379	5.498	4.641	0.331	0.404	5.088	4.422
Aug. 5 (T)	0.000	0.035	0.384	0.325	2.691	1.911	0.331	0.200	2.837	2.830
Aug 6 (W)	0.000					3.190				3.195
Aug 7(Th)	0.062	0.056	0.332	0.346	4.237	2.935	0.306	0.318	3.811	3.188
Aug 8 (F)	0.002					3.308				3.278
Aug 11(M)	0.000	0.082	0.333	0.262	4.910	3.134	0.383	0.261	4.100	3.656
Aug 12 (T)	0.003					3.729				3.462
Aug 13(W)	0.000					4.453				3.187
Aug 14(Th)	0.100	0.059	0.353	2.420	6.969	6.496	0.336	0.896	6.912	4.323
Aug 15(F)	0.000					6.296				3.881
Aug 18(M)	0.015	0.149	0.264	0.355	3.877	2.582	0.221	0.224	3.826	2.541
Aug 19 (T)	0.028					2.798				4.008
Aug 20(W)	0.000					2.292				4.098
Aug 21(Th)	0.086	0.059	0.213	0.220	4.330	3.626	0.384	0.181	4.995	4.818
Aug 22(F)	0.000					3.327				4.724
Aug 25(M)	2.252		0.487	0.289	4.177	3.532	0.580	0.357	4.673	4.276
Aug 26(T)	0.000					3.844				4.394
Aug 27(W)	0.000					4.203				4.995
Aug 28(Th)	0.043	0.026	0.229	0.222	4.366	4.024	0.144	4.502	4.200	3.815
Aug 29(F)	0.000					5.351				4.012
Oct 14 (T)	0.170	0.130	0.179	0.128	3.526	3.049	0.187	0.150	3.097	2.965
Oct 15 (W)	0.078					3.120				2.975
Oct 16 Th	0.064	0.148	0.327	0.041	4.117	3.789	0.022	0.392	4.245	3.517
Oct 17 (F)	0.134					3.597				3.370
Oct 20 (M)	0.048					1.334				2.855
Oct 21 (T)	0.027	0.021	0.023	0.018	3.632	3.104	0.024	0.334	3.083	2.885

Oct 22 (W	0.020					2.925				2.874
Oct 23 Th	0.070	0.120	0.206	0.122	3.450	3.100	0.148	0.680	4.086	3.940
Oct 24 (F)	0.034					4.336				4.463
Oct 27 (M)	0.037					3.703				3.927
Oct 28 (T)	0.000	0.141	0.260	0.145	3.795	3.408	0.190	1.011	3.898	3.809
Oct 29 (W	0.000					3.221				3.899
Means	0.108	0.114	0.328	0.375	4.509	3.765	0.302	0.872	4.573	3.915
Std Dev.	0.355	0.095	0.162	0.524	1.174	1.095	0.228	1.105	1.421	0.934

RAW DATA - RUN #1 TOTAL KJELDAHL NITROGEN
Effect of Fixed Film Prefermentation on BNR Process Performance

Results as Nitrogen in mg/L

Date	ug	Raw Se	ug	Prim Ef	Control		Experiment	
					ug	A- Efflu	ug	B-Efflue
Jul 22 (T)	165.83	33.17	177.95	35.59	27.67	1.38	33.77	1.69
Jul 23 (W)	174.19	34.84			22.12	1.11	26.09	1.30
Jul 24 (Th)	185.46	37.09	169.83	33.97	33.01	1.65	32.85	1.64
Jul 25 (F)	158.44	31.69			25.11	1.26	29.07	1.45
Jul 28 (M)	176.51	35.30	197.23	39.45	31.60	1.58	29.65	1.48
Jul 29 (T)	195.02	39.00			32.73	1.64	27.11	1.36
Jul 30 (W)	185.11	37.02			33.20	1.66	25.60	1.28
July 31(Th	193.43	38.69	190.37	38.07	30.15	1.51	25.60	1.28
Aug. 5 (T)	199.29	39.86	185.24	37.05	45.91	2.30	36.23	1.81
Aug 6 (W)	174.70	34.94			30.97	1.55	29.74	1.49
Aug 7(Th)	177.99	35.60	144.52	28.90	44.97	2.25	29.84	1.49
Aug 8 (F)	356.35	71.27			29.57	1.48	31.63	1.58
Aug 11(M)	250.95	50.19	164.90	32.98	22.72	1.14	33.96	1.70
Aug 12 (T)	292.00	58.40			36.01	1.80	43.65	2.18
Aug 13(W)	188.19	37.64			28.08	1.40	40.40	2.02
Aug 14(Th	181.70	36.34	160.99	32.20	32.19	1.61	25.41	1.27
Aug 15(F)	120.92	24.18			30.77	1.54	32.29	1.61
Aug 18(M)	129.33	25.87	98.68	19.74	20.13	1.01	20.16	1.01
Aug 19 (T	148.18	29.64			18.94	0.95	0.00	0.00
Aug 20(W	96.14	19.23			3.21	0.16	4.70	0.23
Aug 21(Th	134.34	26.87	91.70	18.34	44.17	2.21	17.09	0.85
Aug 22(F)	149.12	29.82			21.10	1.06	8.99	0.45
Aug 25(M)	104.53	20.91	114.47	22.89	16.49	0.82	58.10	2.90
Aug 26 (T)	126.79	25.36			16.32	0.82	31.04	1.55
Aug 27(W)	132.53	26.51			14.19	0.71	28.10	1.41
Aug 28(Th	161.02	32.20	149.06	29.81	23.82	1.19	47.74	2.39
Aug 29(F)	147.80	29.56			27.86	1.39	45.03	2.25
Oct 14 (T)	149.38	29.88	152.53	30.51	26.18	1.31	35.70	1.79
Oct 15 (W)	116.28	23.26			24.82	1.24	35.63	1.78
Oct 16 Th	119.75	23.95	150.54	30.11	21.74	1.09	7.06	0.35
Oct 17 (F)	157.22	31.44			11.03	0.55	24.83	1.24
Oct 20 (M	135.47	27.09			107.61	5.38	22.01	1.10
Oct 21 (T)	119.18	23.84	145.31	29.06	21.05	1.05	40.97	2.05

Date								
Oct 22 (W)	137.31	27.46			29.00	1.45	15.88	0.79
Oct 23 Th	165.18	33.04	153.38	30.68	25.89	1.29	21.75	1.09
Oct 24 (F)	149.43	29.89			28.64	1.43	28.22	1.41
Oct 27 (M)	168.83	33.77			27.96	1.40	19.68	0.98
Oct 28 (T)	157.70	31.54	145.16	29.03	25.81	1.29	16.03	0.80
Oct 29 (W)	150.73	30.15			32.43	1.62	11.57	0.58
Means	32.986		30.492		1.442		1.376	
Std Dev.	9.612		5.720		0.766		0.595	

RAW DATA - RUN #1 PHOSPHATES
Effect of Fixed Film Prefermentation on BNR Process Performance

Results as Phosphorus in mg/L

Date	Raw Se	Prim Ef	A side process - Control				Process B side process - Experiment Pro			
			Anaerot	Anoxic	Aerobic	Effluent	Anaerot	Anoxic	Aerobic	Effluent
Jul 22 (T)	3.508	3.236	5.137	5.625	1.160	0.778	5.413	2.606	1.432	1.027
Jul 23 (W)	3.106					0.099				5.583
Jul 24 (Th)	3.425	3.367	7.137	1.080	0.223	0.920	7.629	1.002	0.177	0.148
Jul 25 (F)	2.333					0.081				0.133
Jul 28 (M)	3.373	3.596	9.553	2.256	0.104	0.114	11.848	1.690	0.077	0.129
Jul 29 (T)	3.594					0.080				0.119
Jul 30 (W)	3.416					0.077				0.123
July 31(Th	1.202	0.642	9.782	2.707	0.049	0.390	11.197	1.581	0.050	0.042
Aug. 5 (T)	3.725	2.240	14.971	6.109	0.041	0.083	14.932	3.816	0.047	0.146
Aug 6 (W)	2.436					0.158				0.073
Aug 7(Th)	1.760	1.972	7.910	2.727	0.077	0.104	8.638	1.363	0.209	0.201
Aug 8 (F)	3.669					0.155				0.051
Aug 11(M)	3.084	2.852	11.244	3.196	0.089	0.099	9.568	1.040	0.084	0.054
Aug 12 (T)	3.362					0.095				0.049
Aug 13(W)	2.814					0.495				0.087
Aug 14(Th)	3.251	3.407	4.845	1.397	0.377	0.289	5.504	0.638	0.388	0.055
Aug 15(F)	3.370					0.802				0.245
Aug 18(M)	2.381	2.808	8.545	0.864	0.033	0.156	7.888	2.221	0.069	0.109
Aug 19 (T)	2.940					0.099				0.053
Aug 20(W)	3.231					0.065				0.103
Aug 21(Th	0.518	1.120	11.203	1.465	0.021	0.063	13.092	2.943	0.045	0.042
Aug 22(F)	1.856					0.064				0.056
Aug 25(M)	0.792	n/a	11.473	1.755	0.076	0.072	16.517	4.100	0.080	0.067
Aug 26 (T)	0.242					0.052				0.150
Aug 27(W)	0.305					0.054				0.080
Aug 28(Th	3.073	3.167	6.662	0.428	0.051	0.065	10.537	0.022	0.044	0.062
Aug 29(F)	2.578					0.030				0.136
Oct 14 (T)	3.080	3.189	6.168	1.740	0.027	0.039	11.531	1.113	0.044	0.043
Oct 15 (W)	2.163					0.014				0.040
Oct 16 Th	2.659	2.537	3.080	0.243	0.021	0.032	2.428	0.036	0.035	0.036
Oct 17 (F)	2.862					0.010				0.037
Oct 20 (M)	2.550					1.741				0.013
Oct 21 (T)	2.889	2.461	4.496	0.506	0.028	0.038	5.568	0.059	0.038	0.041

Oct 22 (W)	2.312					0.015			0.032
Oct 23 Th	2.861	2.813	4.824	0.379	0.054	0.063	4.742	0.055	0.065	0.066
Oct 24 (F)	2.483					4.738			0.041
Oct 27 (M)	2.383					0.008			0.040
Oct 28 (T)	2.808	2.522	2.981	0.080	0.036	0.042	1.545	0.039	0.037	0.037
Oct 29 (W)	2.095					0.029			0.051
Means	2.577	2.466	7.648	1.915	0.145	0.316	8.740	1.431	0.172	0.246
Std Dev.	0.904	0.985	3.263	1.705	0.268	0.791	4.104	1.281	0.327	0.880

RAW DATA - RUN #1 TOTAL PHOSPHORUS
Effect of Fixed Film Prefermentation on BNR Process Performance

Results as Phosphorus in mg/L

Date	ug	Raw Se	ug	Prim Ef	ug	A- Efflu	ug	B-Efflue
Jul 22 (T)	33.03	6.61	24.11	4.82	28.30	1.42	19.16	0.96
Jul 23 (W)	26.21	5.24			17.44	0.87	7.49	0.37
Jul 24 (Th	27.12	5.42	23.15	4.63	1.82	0.09	4.67	0.23
Jul 25 (F)	22.91	4.58		2.01	27.67	1.38	11.97	0.60
Jul 28 (M)	26.37	5.27	24.25	4.85	10.63	0.53	6.59	0.33
Jul 29 (T)	33.91	6.78			5.97	0.30	34.86	1.74
Jul 30 (W)	25.77	5.15			17.34	0.87	30.04	1.50
July 31(Th	26.42	5.28	21.42	4.28	27.67	6.57	17.12	0.86
Aug. 5 (T)	29.73	5.95	25.08	5.02	5.58	0.28	9.36	0.47
Aug 6 (W)	34.00	6.80			6.23	0.31	14.30	0.72
Aug 7(Th)	24.31	4.86	18.97	3.79	7.63	0.38	5.98	0.30
Aug 8 (F)	68.97	13.79			22.34	1.12	11.65	0.58
Aug 11(M)	49.14	9.83	27.64	5.53	5.04	0.25	16.47	0.82
Aug 12 (T	54.52	10.90			12.08	0.60	25.83	1.29
Aug 13(W	33.93	6.79			21.08	1.05	15.56	0.78
Aug 14(Th	35.54	7.11	28.30	5.66	16.69	0.83	4.60	0.23
Aug 15(F)	26.84	5.37					17.81	0.89
Aug 18(M)	27.06	5.41	20.93	4.19	29.76	1.49	18.76	0.94
Aug 19 (T)	28.35	5.67			14.48	0.72	9.60	0.48
Aug 20(W)	31.44	6.29			13.19	0.66	16.04	0.80
Aug 21(Th	37.59	7.52	24.53	4.91	7.10	0.35	7.58	0.38
Aug 22(F)	33.04	6.61			6.54	0.33	6.52	0.33
Aug 25(M)	35.24	7.05	30.04	6.01	12.60	0.63	0.00	0.00
Aug 26 (T	18.79	3.76			14.40	0.72	9.17	0.46
Aug 27(W	32.42	6.48			6.37	0.32	12.39	0.62
Aug 28(Th	23.94	4.79	15.76	3.15	2.82	0.14	22.13	1.11
Aug 29(F)	13.60	2.72			6.20	0.31	15.29	0.76
Oct 14 (T)	22.46	4.49	21.28	4.26	2.19	0.11	1.40	0.07
Oct 15 (W)	21.92	4.38			3.76	0.19	4.38	0.22
Oct 16 Th	18.23	3.65	22.89	4.58	4.15	0.21	5.73	0.29
Oct 17 (F)	23.31	4.66			4.04	0.20	5.62	0.28
Oct 20 (M)	23.60	4.72			42.58	2.13	4.25	0.21
Oct 21 (T)	24.18	4.84	22.98	4.60	4.98	0.25	2.50	0.12

Oct 22 (W)	20.37	4.07			5.26	0.26	4.62	0.23
Oct 23 Th	23.49	4.70	25.15	5.03	5.34	0.27	5.61	0.28
Oct 24 (F)	21.19	4.24			5.48	0.27	5.37	0.27
Oct 27 (M)	24.93	4.99			5.58	0.28	8.96	0.45
Oct 28 (T)	22.49	4.50	22.27	4.45	4.88	0.24	4.56	0.23
Oct 29 (W)	21.92	4.38			7.43	0.37	5.28	0.26
Means		5.786		4.542		0.719		0.550
Std Dev.		2.019		0.892		1.062		0.391

RAW DATA - RUN #1 AMMONIA
Effect of Fixed Film Prefermentation on BNR Process Performance

Results as Nitrogen in mg/L

Date	Raw Se	Prim Ef	A side process - Control				B side process - Experiment			
			Anaerob	Anoxic	Aerobic	Effluent	Anaerob	Anoxic	Aerobic	Effluent
Jul 22 (T)										
Jul 23 (W)										
Jul 24 (Th)	16.137	15.739	9.405	4.709	0.081	0.021	11.370	3.396	0.102	0.359
Jul 25 (F)	18.705					0.084				0.029
Jul 28 (M)	16.030	20.421	7.575	4.076	0.021	0.050	8.459	3.425	0.033	0.021
Jul 29 (T)	16.068					0.071				0.029
Jul 30 (W)	15.573					0.063				0.027
July 31(Th)	12.612	22.394	9.358	4.829	0.114	0.139	10.682	4.408	0.109	0.063
Aug. 5 (T)	23.313	23.540	10.393	5.205	1.046	0.464	10.253	6.889	0.801	0.330
Aug 6 (W)	24.541					0.143				0.120
Aug 7(Th)	18.283	18.158	7.170	4.118	0.101	0.085	9.159	3.756	0.079	0.050
Aug 8 (F)	18.078					0.101				0.095
Aug 11(M)	21.253	22.263	9.590	5.228	0.140	2.545	9.879	4.155	1.779	0.031
Aug 12 (T)	20.787					0.136				1.274
Aug 13(W)	20.152					0.255				0.040
Aug 14(Th)	19.738	18.820	8.386	3.432	0.031	0.030	7.692	3.194	0.001	0.004
Aug 15(F)	21.190					0.069				0.016
Aug 18(M)	18.262	16.472	7.210	3.142	2.910	0.006	7.323	3.371	1.282	0.000
Aug 19 (T)	20.664					0.385				0.186
Aug 20(W)	18.910					0.095				0.032
Aug 21(Th)	23.069	22.187	8.801	3.654	0.048	0.027	9.440	4.962	0.038	0.032
Aug 22(F)	20.877					0.101				0.023
Aug 25(M)	26.538	19.824	7.486	3.842	0.000	0.025	8.778	4.410	0.020	0.082
Aug 26 (T)	21.848					0.128				0.012
Aug 27(W)	21.448					0.020				0.031
Aug 28(Th)	20.391	21.113	9.656	3.171	0.065	0.056	8.760	3.424	0.333	0.064
Aug 29(F)	25.802					0.046				0.091
Oct 14 (T)	15.867	15.645	6.390	3.208	0.097	0.055	7.818	2.921	0.005	2.031
Oct 15 (W)	15.250					0.059				0.037
Oct 16 Th	13.357	15.561	5.481	3.415	0.341	0.255	6.752	2.937	0.027	0.027
Oct 17 (F)	17.336					0.253				0.027
Oct 20 (M)	20.210					3.158				0.097
Oct 21 (T)	16.854	17.029	5.920	3.026	0.077	0.043	6.904	2.825	0.029	0.045

Oct 22 (W)	14.609					0.050				0.027
Oct 23 Th	18.278	17.037	7.299	3.257	0.060	0.025	8.117	3.614	0.033	0.010
Oct 24 (F)	16.330					0.195				0.036
Oct 27 (M)	19.542					0.252				0.028
Oct 28 (T)	18.225	20.279	6.059	3.242	0.071	0.053	7.569	2.596	0.014	0.028
Oct 29 (W)	14.680					0.057				0.006
Means	18.941	19.155	7.886	3.847	0.325	0.259	8.685	3.768	0.293	0.147
Std Dev.	3.277	2.621	1.472	0.739	0.710	0.632	1.323	1.021	0.514	0.378

RAW DATA - RUN #1 Total Carbon
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L

Total Carbon

Date	Raw Se	Prim Ef	A side process - Control				B side process - Experiment			
			A-1	A-2	A-3	A-4	B-1	B-2	B-3	B-4
Jul 24 (Th)	62	68	115	85	95	82	94	81	31	80
Jul 28 (M)	24	31	105	104	102	91	120	113	94	79
Jul 31 (Th)	84	72	99	150	69	80	74	94	26	
Aug 4 (M)	101	96	96	92	100	95	102	130	67	89
Aug 7 (Th)	73	69	82	100	90	65	113	81	94	127
Aug 11 (M)	65	63	77	66	75	86	93	82	94	83
Aug 14 (T)	79	66	79	78	78	77	77	76	37	79
Aug 18 (M)	76	70	79	80	77	34	84	42	61	70
Aug 21 (T)	78	61	97	75	82	76	68	74	72	64
Aug 25 (M)	20	30	81	91	85	87	83	88	83	55
Aug 28 (T)	60	61	64	64	57	72	46	64	65	65
Oct 14 (T)	90	38	86	96	96	112	116	116	116	108
Oct 16 Th	92	90	96	104	84	66	84	84	104	108
Oct 21 (T)	86	84	78	74	86	30	78	84	86	58
Oct 23 Th	86	80	80	88	52	48	72	82	70	76
Oct 28 (T)	72	83	68	65	64	50	70	60	70	118

Inorganic Carbon

Date	Raw Se	Prim Ef	A side process - Control				B side process - Experiment			
			A-1	A-2	A-3	A-4	B-1	B-2	B-3	B-4
Jul 24 (Th)	40	43	77	56	64	55	69	58	7	48
Jul 28 (M)	0	0	73	72	73	68	76	75	37	56
Jul 31 (Th)	26	29	45	40	40	33	39	37	3	34
Aug 4 (M)	45	50	50	44	60	49	54	56	35	48
Aug 7 (Th)	49	43	50	55	46	30	54	10	36	33
Aug 11 (M)	28	25	45	32	40	27	39	35	37	28
Aug 14 (T)	25	20	25	26	25	25	26	24	7	25
Aug 18 (M)	31	28	31	31	31	9	33	18	24	27
Aug 21 (T)	20	17	27	20	21	23	17	19	20	16
Aug 25 (M)	0	0	46	47	44	44	45	48	46	27
Aug 28 (T)	19	20	30	31	27	22	19	31	32	31

Oct 14 (T)	35	14	35	35	30	37	38	38	50	40
Oct 16 Th	32	30	32	32	28	23	29	31	29	30
Oct 21 (T)	37	40	36	34	39	10	38	42	40	21
Oct 23 Th	26	26	29	28	16	15	25	29	24	25
Oct 28 (T)	0	0	0	0	0	0	0	0	0	0

Total Organic Carbon

	Raw Se	Prim Ef	A side process - Control				B side process - Media			
Date			A-1	A-2	A-3	A-4	B-1	B-2	B-3	B-4
Jul 24 (Th)	22	25	38	29	31	27	25	23	24	32
Jul 28 (M)	24	31	32	32	29	23	44	38	57	23
Jul 31 (Th)	58	43	54	110	29	47	35	57	23	
Aug 4 (M)	56	46	46	48	40	46	48	74	32	41
Aug 7 (Th)	24	26	32	45	44	35	59	71	58	94
Aug 11 (M)	37	38	32	34	35	59	54	47	57	55
Aug 14 (T)	54	46	54	52	53	53	52	52	30	54
Aug 18 (M)	45	41	48	49	45	25	50	25	37	42
Aug 21 (T)	58	44	70	55	61	54	50	54	53	48
Aug 25 (M)	20	30	35	44	41	43	38	40	37	28
Aug 28 (T)	41	41	33	33	30	50	27	33	33	34
Oct 14 (T)	55	24	51	61	66	75	78	78	66	68
Oct 16 Th	60	60	64	72	56	43	55	53	75	78
Oct 21 (T)	49	44	42	40	47	20	40	42	46	37
Oct 23 Th	60	54	51	60	36	33	47	53	46	51
Oct 28 (T)	72	83	68	65	64	50	70	60	70	118
mean	45.95	42.24	46.91	51.83	44.27	42.59	48.33	49.96	46.45	53.53
std dev	16.15	14.89	12.92	19.99	12.68	14.80	13.98	16.31	16.38	26.17

RAW DATA - RUN #1 Chemical Oxygen Demand
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L

TCOD

Date	Raw Se	Effluent (Control)	Effluent (Experiment)
Jul 24 (Th)	465	44	41
Jul 25 (F)	450		
Jul 28 (M)	437	74	51
Jul 29 (T)	429		
Jul 30 (W)	463	51	44
July 31(Th)	302	143	501
Aug. 5 (T)	177	31	13
Aug 6 (W)	202		
Aug 7(Th)	462	44	44
Aug 8 (F)	862		
Aug 11(M)	867	44	44
Aug 12 (T)			
Aug 13(W)	568		
Aug 14(Th)	425	0	0
Aug 15(F)	319		
Aug 18(M)	359	0	0
Aug 19 (T)	319		
Aug 20(W)	343		
Aug 21(Th)	449	0	0
Aug 22 (F)	359		
Aug 25(M)	284	0	17
Aug 26(T)	361		
Aug 27(W)	479		
Aug 28 (T)			
Aug 29(F)			
Oct 14 (T)	390		
Oct 15 (W)	323		
Oct 16 Th	348	50	43
Oct 17 (F)	415		
Oct 20 (M)	307		
Oct 21 (T)	348	36	32
Oct 22 (W)	211		
Oct 23 Th	322	53	40

SCOD — Control Experiment

Raw Se	PC Effl	A-4 Ferm	B4-Ferm
220	205	215	223
225	238	251	268
529	258	161	169
302	159	166	177
181	166	220	199
246	197	173	350
132	145	188	153
142	161	164	182
180	134	174	140
188	169	153	158
77	62	76	64
204	230	238	300
201	188	197	197
250	240	273	229
215	326	159	182

Oct 24 (F)	196		
Oct 27 (M)	334		
Oct 28 (T)	306	48	33
Oct 29 (W)	324		
Means	388	41	60
Std Dev.	147	35	119

217	204	161	367
219	193	186	210
94	58	45	76

RUN #2

RAW DATA - RUN #2 SCVFA
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L as acetic acid
Each sample was analysed two times by gas chromatograph and the average used in the report.

Date	Prim Effl HAc	HAc	Avg HAc	HPr	HPr	Avg-HPr	Pr as H	Total H	B-1 - 15 min HAc	HAc	Avg HAc	HPr	HPr	Avg-Pr	Pr as HAc
Nov 13(Th)	21.39	22.50	21.94	6.52	6.63	6.57	5.32	27.27	21.25	21.10	21.18	5.95	5.91	5.93	4.80
Nov 14(F)	18.70	18.95	18.83	5.57	5.72	5.65	4.57	23.40							0.00
Nov 17(M)	16.64	16.87	16.75	7.12	7.00	7.06	5.72	22.47							0.00
Nov 18(T)	18.98	18.56	18.77	4.34	4.28	4.31	3.49	22.26	18.34	18.26	18.30	4.12	4.00	4.06	3.29
Nov 19(W)	18.08	17.87	17.97	3.73	3.65	3.69	2.99	20.96							0.00
Nov 20(Th)	21.83	21.17	21.50	4.74	4.70	4.72	3.82	25.32	22.43	22.63	22.53	5.53	5.63	5.58	4.52
Nov 21(F)	20.88	20.87	20.87	4.34	4.44	4.39	3.56	24.43							0.00
Nov 24(M)	26.20	25.91	26.05	5.02	5.07	5.05	4.09	30.14							0.00
Nov 25(T)	24.27	24.42	24.35	4.75	4.74	4.75	3.85	28.19	23.37		23.37	4.16	4.85	4.50	3.65
Nov 26(W)		22.14	22.14	3.91	3.92	3.91	3.17	25.31							0.00
Nov 27(Th)	24.19	24.42	24.30	4.46	4.51	4.49	3.63	27.94	24.67	24.42	24.54	4.86	4.82	4.84	3.92
Nov 28(F)	23.47	24.22	23.84	3.77	3.75	3.76	3.05	26.89							0.00
Dec 1(M)	27.66	27.69	27.68	5.38	5.63	5.50	4.46	32.13							0.00
Dec 2(T)	51.64	48.00	49.82	31.25	29.14	30.20	24.46	74.27	45.28	48.72	47.00	28.31	28.65	28.48	23.07
Dec 3(W)	23.99	26.66	25.33	9.16	9.14	9.15	7.41	32.74							0.00
Dec 4(Th)	22.36	21.00	21.68	4.74	4.70	4.72	3.82	25.50	20.60	20.55	20.58	4.54	4.48	4.51	3.65
Dec 5(F)	22.35	22.39	22.37	3.78	3.74	3.76	3.04	25.41							0.00
Dec 8(M)	25.54	25.19	25.37	5.41	5.34	5.37	4.35	29.72							0.00
Dec 9(T)	22.64	22.91	22.77	4.62	4.67	4.64	3.76	26.54	23.12	23.65	23.38	4.62	4.51	4.57	3.70
Dec 10(W)	21.21	21.07	21.14	4.06	4.01	4.03	3.27	24.41							0.00
Dec 11(Th)	22.10	21.74	21.92	4.89	4.79	4.84	3.92	25.85	22.69	22.10	22.39	5.22	5.16	5.19	4.20
Dec 12(F)	25.33	25.80	25.56	5.90	6.03	5.97	4.83	30.40							0.00
Dec 15(M)	30.07	29.54	29.81	7.69	7.54	7.61	6.17	35.97							0.00
Dec 16(T)	26.39	26.64	26.52	5.88	5.84	5.86	4.75	31.26	26.86	27.62	27.24	5.74	5.85	5.80	4.69
Dec 17(W)	22.60	22.66	22.63	3.99	4.02	4.01	3.25	25.88							0.00
Means	24.10	23.97	24.00	6.20	6.12	6.16	4.99		24.86	25.45	25.05	7.30	7.39	7.34	5.95
Std Dev.	6.50	5.79	6.07	5.28	4.87	5.07	4.11		7.14	8.59	7.66	7.03	7.11	7.07	5.73

RAW DATA - RUN #2 SCVFA
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L as acetic acid
Each sample was analysed two times by gas chromatograph and the average used in the report.

B side process - Experimental Fermenters

Date	B-2 30 min							B-3 45 min						
	HAc	HAc	avg-Ac	HPr	HPr	HPr	Pr as H	HAc	HAc	Avg HAc	HPr	HPr	Avg HPr	Pr as H
Nov 13(Th)	22.17	23.73	22.95	6.24	6.08	6.16	4.99	24.19	21.23	22.71	6.48	6.28	6.38	5.17
Nov 14(F)							0.00							0.00
Nov 17(M)							0.00							0.00
Nov 18(T)	19.74	20.24	19.99	4.89	4.94	4.92	3.98	21.04	21.25	21.14	5.26	5.23	5.24	4.25
Nov 19(W)							0.00							0.00
Nov 20(Th)	21.81	21.71	21.76	4.97	4.96	4.96	4.02	22.63	23.20	22.91	5.73	5.88	5.80	4.70
Nov 21(F)							0.00							0.00
Nov 24(M)							0.00							0.00
Nov 25(T)	25.94	24.45	25.20	4.85	4.95	4.90	3.97	25.75	24.86	25.30	5.00	5.04	5.02	4.07
Nov 26(W)							0.00							0.00
Nov 27(Th)	26.48	27.46	26.97	4.96	4.93	4.94	4.01	26.08	25.92	26.00	5.12	5.09	5.11	4.14
Nov 28(F)							0.00							0.00
Dec 1(M)							0.00							0.00
Dec 2(T)	46.93	47.20	47.06	27.64	27.67	27.65	22.40	45.23	46.60	45.91	25.66	26.66	26.16	21.19
Dec 3(W)							0.00							0.00
Dec 4(Th)	21.81	21.84	21.83	4.64	4.67	4.66	3.77	22.09	24.03	23.06	4.72	5.25	4.98	4.04
Dec 5(F)							0.00							0.00
Dec 8(M)							0.00							0.00
Dec 9(T)	23.55	23.53	23.54	4.86	4.82	4.84	3.92	23.73	23.67	23.70	4.90	4.91	4.91	3.98
Dec 10(W)							0.00							0.00
Dec 11(Th)	22.19	21.72	21.95	4.79	4.66	4.72	3.83	22.12	22.30	22.21	4.84	4.84	4.84	3.92
Dec 12(F)							0.00							0.00
Dec 15(M)							0.00							0.00
Dec 16(T)	28.58	28.27	28.43	6.06	5.96	6.01	4.86	28.50	28.10	28.30	6.01	5.94	5.98	4.84
Dec 17(W)							0.00							0.00
Means	25.92	26.01	25.97	7.39	7.36	7.38	5.98	26.14	26.11	26.13	7.37	7.51	7.44	6.03
Std Dev.	7.44	7.47	7.45	6.77	6.79	6.78	5.49	6.71	7.11	6.89	6.12	6.40	6.26	5.07

RAW DATA - RUN #2 SCVFA
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L as acetic acid
Each sample was analysed two times by gas chromatograph and the average used in the report.

B side process - Experimental Fermenters

| Date | B-4 60 min | | Avg Ac | HPr | | Avg HPr | Pr as HAc | Production mg/L | | | Ringlace |
	HAc							HAc	HPr	Pr as Ac	total HAc
Nov 13(Th)	21.77	21.66	21.71	6.39	6.30	6.34	5.14	21.71	6.34	5.14	26.85
Nov 14(F)	20.70	20.84	20.77	5.81	5.69	5.75	4.66	20.77	5.75	4.66	25.43
Nov 17(M)	15.62	15.21	15.42	3.33	3.37	3.35	2.71	15.42	3.35	2.71	18.13
Nov 18(T)	21.31	21.51	21.41	4.75	4.75	4.75	3.85	21.41	4.75	3.85	25.26
Nov 19(W)	24.21	24.36	24.29	7.67	7.77	7.72	6.25	24.29	7.72	6.25	30.54
Nov 20(Th)		23.92	23.92	5.77	5.69	5.73	4.64	23.92	5.73	4.64	28.56
Nov 21(F)	22.95	25.03	23.99	5.53	5.41	5.47	4.43	23.99	5.47	4.43	28.42
Nov 24(M)	26.06	26.37	26.22	5.61	5.66	5.63	4.56	26.22	5.63	4.56	30.78
Nov 25(T)	25.73	25.91	25.82	5.18	5.22	5.20	4.21	25.82	5.20	4.21	30.03
Nov 26(W)	22.60	22.29	22.45	4.34	4.24	4.29	3.48	22.45	4.29	3.48	25.92
Nov 27(Th)	26.25	27.10	26.68	5.35	5.38	5.36	4.34	26.68	5.36	4.34	31.02
Nov 28(F)	25.41	24.15	24.78	3.57	3.52	3.54	2.87	24.78	3.54	2.87	27.65
Dec 1(M)	29.54	29.16	29.35	4.93	4.94	4.94	4.00	29.35	4.94	4.00	33.35
Dec 2(T)	43.61	43.08	43.34	22.40	21.64	22.02	17.84	43.34	22.02	17.84	61.18
Dec 3(W)	25.21	28.07	26.64	8.94	8.93	8.94	7.24	26.64	8.94	7.24	33.88
Dec 4(Th)	22.78	22.49	22.64	4.92	4.88	4.90	3.97	22.64	4.90	3.97	26.61
Dec 5(F)	24.09	24.97	24.53	4.04	4.05	4.05	3.28	24.53	4.05	3.28	27.81
Dec 8(M)	28.17	27.18	27.68	5.75	5.73	5.74	4.65	27.68	5.74	4.65	32.33
Dec 9(T)	24.74	24.26	24.50	5.07	5.03	5.05	4.09	24.50	5.05	4.09	28.59
Dec 10(W)	23.15	22.62	22.89	4.99	4.81	4.90	3.97	22.89	4.90	3.97	26.86
Dec 11(Th)	23.02	23.39	23.20	5.27	5.34	5.30	4.30	23.20	5.30	4.30	27.50
Dec 12(F)	27.08	27.26	27.17	6.55	6.55	6.55	5.31	27.17	6.55	5.31	32.48
Dec 15(M)	31.59	31.55	31.57	8.36	8.29	8.33	6.75	31.57	8.33	6.75	38.32
Dec 16(T)	29.02	28.89	28.95	6.18	6.16	6.17	5.00	28.95	6.17	5.00	33.95
Dec 17(W)	24.76	24.81	24.79	4.02	3.97	4.00	3.24	24.79	4.00	3.24	28.02
Means	25.39	25.44	25.39	6.19	6.13	6.16	4.99	25.39	6.16	4.99	30.38
Std Dev.	4.98	4.84	4.84	3.56	3.43	3.50	2.83	4.84	3.50	2.83	7.35

RAW DATA - RUN #2 NITRATES
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L as Nitrogen

Date	Prim Ef	A side process - Control				B side process - Experiment			
		Anaerol	Anoxic	Aerobic	Effluent	Anaerol	Anoxic	Aerobic	Effluent
Nov 13 (T)	0.110	0.263	0.241	0.013	2.984	1.287	2.062	4.870	4.637
Nov 14 (F)	0.000				4.990				3.154
Nov 17 (M)	0.111				0.171				3.647
Nov 18 (T)	0.024	0.164	0.170	1.752	0.708	0.167	0.462	3.673	3.478
Nov 19 (W)	0.000				1.264				3.882
Nov 20 (T)	0.100	0.209	0.148	2.819	2.019	0.186	0.245	3.483	3.460
Nov 21 (F)	0.080				3.038				3.935
Nov 24 (M)	0.000				3.237				3.150
Nov 25 (T)	0.075	0.148	0.140	3.176	2.961	0.153	0.157	3.015	2.994
Nov 26 (W)	0.038				3.036				3.165
Nov 27 (T)	0.139	0.213	0.158	4.128	3.025	0.129	0.263	3.182	3.144
Nov 28 (F)	0.031				3.309				3.210
Dec 1 (M)	0.045				3.138				4.011
Dec 2 (T)	0.082	0.215	0.124	3.345	3.107	0.173	0.185	3.107	3.080
Dec 3 (W)	0.062				3.134				5.816
Dec 4 (Th)	0.210	0.201	0.092	3.616	3.435	2.322	3.648	5.606	5.842
Dec 5 (F)	0.000				3.838				5.888
Dec 8 (M)	0.000				3.410				4.031
Dec 9 (T)	0.000	0.204	0.213	3.454	3.132	0.663	2.357	4.479	4.318
Dec 10 (W)	0.000				3.737				5.874
Dec 11 (T)	0.187	0.288	0.399	3.674	3.320	1.928	3.477	5.466	7.197
Dec 12 (F)	0.000				3.893				3.850
Dec 15 (M)	0.000				4.554				2.827
Dec 16 (T)	0.000	0.215	0.247	2.911	2.637	0.151	0.397	2.856	2.853
Dec 17 (W)	0.000				2.886				3.394
Means	0.052	0.212	0.193	2.889	2.999	0.716	1.325	3.974	4.033
Std Dev.	0.061	0.039	0.083	1.134	1.029	0.790	1.349	0.991	1.159

RAW DATA - RUN #2 TOTAL KJELDAHL NITROGEN
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L as Nitrogen

Date	ug	Prim Ef	Control		Experiment		Control		Experiment	
			ug	Aero-A	ug	Aero-B	ug	A- Efflu	ug	B-Efflue
Nov 13 (T)	142.16	28.43	148.27	148.27	228.07	228.07	20.17	1.01	22.91	1.15
Nov 14 (F)	146.33	29.27					20.87	1.04	19.67	0.98
Nov 17 (M)	165.07	33.01					203.53	10.18		
Nov 18 (T)	164.28	32.86	320.12	320.12	242.94	242.94	194.23	9.71	18.01	0.90
Nov 19 (W)	154.41	30.88		0.00		0.00	170.66	8.53	14.89	0.74
Nov 20 (T)	138.70	27.74	275.41	275.41	204.56	204.56	104.53	5.23	14.62	0.73
Nov 21 (F)	131.59	26.32					46.99	2.35	13.47	0.67
Nov 24 (M)	132.53	26.51					2.75	0.14	18.30	0.92
Nov 25 (T)	140.33	28.07	277.27	277.27	219.85	219.85	9.21	0.46	76.72	3.84
Nov 26 (W)	139.72	27.94					29.07	1.45		
Nov 27 (T)	124.62	24.92	124.36	124.36	207.83	207.83	47.58	2.38	24.61	1.23
Nov 28 (F)	126.90	25.38					18.74	0.94	9.19	0.46
Dec 1 (M)	127.10	25.42					24.30	1.22	3.60	0.18
Dec 2 (T)	162.73	32.55	282.34	282.34	202.05	202.05	25.36	1.27		
Dec 3 (W)	151.04	30.21					25.45	1.27	15.94	0.80
Dec 4 (Th)	118.48	23.70	275.87	275.87	170.59	170.59	17.79	0.89	24.16	1.21
Dec 5 (F)	147.93	29.59					35.81	1.79	23.38	1.17
Dec 8 (M)	165.39	33.08					26.49	1.32	21.75	1.09
Dec 9 (T)	141.81	28.36	262.06	262.06	175.22	175.22	25.02	1.25	20.77	1.04
Dec 10 (W)	149.04	29.81					25.82	1.29	29.47	1.47
Dec 11 (T)	127.01	25.40	119.22	238.43	87.41	174.82	26.53	1.33	17.11	0.86
Dec 12 (F)	120.14	24.03					27.38	1.37	16.51	0.83
Dec 15 (M)	131.10	26.22					29.43	1.47	26.62	1.33
Dec 16 (T)	125.98	25.20	124.32	248.64	90.19	180.38	29.72	1.49	16.49	0.82
Dec 17 (W)	114.49	22.90					30.37	1.52	22.16	1.11
Means		27.91		222.98		182.39		2.44		1.07
Std Dev.		2.98		89.90		61.94		2.76		0.67

RAW DATA - RUN #2 PHOSPHATES
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L as Phosphorus

Date	A side process - Control					B side process - Experiment			
	Prim Ef	Anaerot	Anoxic	Aerobic	Effluent	Anaerot	Anoxic	Aerobic	Effluent
Nov 13 (T)	2.023	4.567	0.086	0.013	0.040	3.612	0.898	1.671	0.035
Nov 14 (F)	2.418				0.040				0.037
Nov 17 (M)	3.168				0.358				0.055
Nov 18 (T)	2.965	9.841	4.337	0.029	0.072	4.006	0.067	0.043	0.040
Nov 19 (W)	2.986				0.033				0.053
Nov 20 (T)	2.138	9.931	3.834	0.038	0.041	3.722	0.175	0.029	0.045
Nov 21 (F)	2.879				0.030				0.039
Nov 24 (M)	2.497				0.044				0.037
Nov 25 (T)	2.028	6.502	0.062	0.023	0.025	4.864	0.191	0.025	0.027
Nov 26 (W)	2.851				0.167				0.071
Nov 27 (T)	3.335	3.529	0.069	0.019	0.036	4.707	0.087	0.022	0.027
Nov 28 (F)	2.644				0.019				0.027
Dec 1 (M)	2.610				0.027				0.072
Dec 2 (T)	3.422	16.099	5.547	0.048	0.038	11.308	2.837	0.071	0.047
Dec 3 (W)	3.829				0.046				0.036
Dec 4 (Th)	2.559	4.071	0.035	0.017	0.030	0.671	0.043	0.032	0.032
Dec 5 (F)	2.803				0.048				0.054
Dec 8 (M)	3.148				0.069				0.126
Dec 9 (T)	2.903	4.930	0.341	0.020	0.031	1.074	0.025	0.019	0.025
Dec 10 (W)	2.794				0.015				0.020
Dec 11 (T)	2.450	4.564	0.630	0.034	0.052	1.295	0.048	0.035	0.037
Dec 12 (F)	2.426				0.037				0.044
Dec 15 (M)	3.106				0.063				0.111
Dec 16 (T)	2.416	7.615	0.954	0.025	0.042	4.076	0.217	0.036	0.044
Dec 17 (W)	2.400				0.020				0.036
Means	2.752	7.165	1.590	0.027	0.057	3.934	0.459	0.198	0.047
Std Dev.	0.432	3.696	2.011	0.010	0.068	2.860	0.830	0.491	0.025

RAW DATA - RUN #2 TOTAL PHOSPHORUS
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L as Phosphorus

Date	ug	Prim Eff	Control ug	Aero-A	Experiment ug	Aero-B	Control ug	A-Efflu	Experiment ug	B-Efflu
Nov 13 (T)	20.82	4.16	148.27	148.27	145.93	145.93	4.18	0.21	5.24	0.26
Nov 14 (F)	19.53	3.91					7.99	0.40	6.09	0.30
Nov 17 (M)	22.44	4.49					12.66	0.63		
Nov 18 (T)	23.58	4.72	167.18	167.18	136.77	136.77	4.18	0.21	5.53	0.28
Nov 19 (W)	23.08	4.62					4.63	0.23	2.20	0.11
Nov 20 (T)	23.77	4.75	141.47	141.47	117.73	117.73	3.52	0.18	4.64	0.23
Nov 21 (F)	21.27	4.25					4.72	0.24	3.72	0.19
Nov 24 (M)	23.61	4.72					3.75	0.19	4.40	0.22
Nov 25 (T)	24.12	4.82	134.77	134.77	123.86	123.86	3.74	0.19	17.42	0.87
Nov 26 (W)	20.81	4.16					0.87	0.04		
Nov 27 (T)	16.15	3.23	124.36	124.36	116.63	116.63	3.54	0.18	3.94	0.20
Nov 28 (F)	19.19	3.84					4.23	0.21	4.40	0.22
Dec 1 (M)	21.73	4.35					5.00	0.25	5.31	0.27
Dec 2 (T)	27.38	5.48	138.23	138.23	116.46	116.46	4.22	0.21		
Dec 3 (W)	21.85	4.37					5.05	0.25	5.26	0.26
Dec 4 (Th)	19.00	3.80	113.66	113.66	100.37	100.37	4.04	0.20	4.77	0.24
Dec 5 (F)	20.79	4.16					8.37	0.42	8.82	0.44
Dec 8 (M)	25.08	5.02					6.51	0.33	7.05	0.35
Dec 9 (T)	22.56	4.51	102.60	102.60	103.24	103.24	7.34	0.37	5.13	0.26
Dec 10 (W)	21.62	4.32					4.00	0.20	4.51	0.23
Dec 11 (T)	17.33	3.47	70.29	140.58	57.83	115.67	6.29	0.31	7.78	0.39
Dec 12 (F)	17.58	3.52					6.73	0.34	5.83	0.29
Dec 15 (M)	21.72	4.34					7.41	0.37	7.28	0.36
Dec 16 (T)	21.47	4.29	66.82	133.63	61.16	122.32	5.40	0.27	5.52	0.28
Dec 17 (W)	17.02	3.40					5.57	0.28	5.66	0.28
Means		4.27		134.47		119.90		0.27		0.30
Std Dev.		0.52		17.07		12.99		0.11		0.14

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RAW DATA - RUN #2 AMMONIA
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L as Nitrogen

Date	Prim Ef	A side process - Control				B side process - Experiment			
		Anaerol	Anoxic	Aerobic	Effluent	Anaerol	Anoxic	Aerobic	Effluent
Nov 13 (T)	16.176	6.806	3.009	0.144	0.030	8.495	2.840	0.028	0.000
Nov 14 (F)	16.538				0.000				0.361
Nov 17 (M)	15.154				8.090				0.000
Nov 18 (T)	18.149	12.383	9.486	7.841	7.457	7.869	2.876	0.008	0.000
Nov 19 (W)	13.246				4.905				0.000
Nov 20 (T)	12.368	7.562	5.592	3.230	3.552	5.665	2.688	0.018	0.017
Nov 21 (F)	10.433				0.840				0.023
Nov 24 (M)	12.882				0.020				0.037
Nov 25 (T)	11.369	4.924	2.104	0.045	0.045	5.197	1.727	0.044	0.045
Nov 26 (W)	11.544				0.090				0.057
Nov 27 (T)	13.054	5.448	2.648	0.000	0.000	6.142	2.491	0.000	0.000
Nov 28 (F)	10.720				0.000				0.000
Dec 1 (M)	11.215				0.000				0.000
Dec 2 (T)	11.934	5.545	2.680	0.000	0.000	4.995	2.121	0.000	0.000
Dec 3 (W)	15.201				0.197				0.073
Dec 4 (Th)	12.980	5.353	2.144	0.000	0.000	4.222	1.710	0.000	0.000
Dec 5 (F)	18.129				0.132				0.019
Dec 8 (M)	17.459				0.079				0.013
Dec 9 (T)	12.165	4.970	1.993	0.000	0.000	4.400	1.678	0.000	0.000
Dec 10 (W)	11.012				0.000				0.000
Dec 11 (T)	11.830	5.190	2.182	0.000	0.000	6.254	1.757	0.000	0.000
Dec 12 (F)	12.827				0.000				0.000
Dec 15 (M)	12.846				0.000				0.000
Dec 16 (T)	11.135	4.657	1.714	0.000	0.000	4.562	1.673	0.000	0.000
Dec 17 (W)	10.349				0.000				0.000
Means	13.229	6.284	3.355	1.126	1.017	5.780	2.156	0.010	0.026
Std Dev.	2.378	2.205	2.294	2.434	2.303	1.374	0.489	0.015	0.071

RAW DATA - RUN #2 TOC
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L

*Soluable Organic Carbon - Fermente*Total Organic Carbon - Process

B side process - Media

Date	Prim Ef	B-1	B-2	B-3	B-4
Nov 13 (T	72	78	32	43	68
Nov 14 (F)					
Nov 17 (M)					
Nov 18 (T	70	84	74	70	71
Nov 19 (W					
Nov 20 (T	64	73	71	73	60
Nov 21 (F					
Nov 24 (M					
Nov 25 (T	73	78	74	73	72
Nov 26 (W					
Nov 27 (T	49	49	92	50	61
Nov 28 (F)					
Dec 1 (M)					
Dec 2 (T)	82	82	84	82	76
Dec 3 (W)					
Dec 4 (Th)	53	51	53	51	51
Dec 5 (F)					
Dec 8 (M)					
Dec 9 (T)	50	49	49	46	48
Dec 10 (W					
Dec 11 (T	48	55	51	48	48
Dec 12 (F)					
Dec 15 (M)					
Dec 16 (T	55	56	61	42	37
Dec 17 (W					
Means	61	65	64	58	59
Std Dev.	11	14	17	14	12

Date	Prim Ef	A-Eff	B-Eff
Nov 13	83	26	16
Nov 14		27	28
Nov 17		24	14
Nov 18	67	26	18
Nov 19		27	20
Nov 20	73	25	21
Nov 21		23	22
Nov 24		17	19
Nov 25	86	21	23
Nov 26		25	25
Nov 27	54	7	8
Nov 28		9	7
Dec 1 (		8	8
Dec 2 (T	96	9	10
Dec 3 (W		8	9
Dec 4 (T	59	8	7
Dec 5 (F		8	8
Dec 8 (M		9	7
Dec 9 (T	55	8	9
Dec 10		9	9
Dec 11	53	9	9
Dec 12		9	10
Dec 15		10	10
Dec 16	62	9	11
Dec 17	51	8	8
	67	15	13
	15	8	6

*changed preservation methods from freezing to acidification.
all values before NOV 26 include IC

RUN #3A

RAW DATA - RUN #3A SCVFAs
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L as acetic acid

Experiment Fermenters

Date	Prim Effl acetic		Avg Ac	HPr		Avg Pr	Pr as Ac	Tot HAc	B1 15 minutes HAc		Avg Ac	HPr		AvgHPr	Pr as Ac
Jan 19 (M)	25.20	25.21	25.21	7.05	7.18	7.11	5.76	30.97							
Jan 20 (T)	24.71	24.04	24.38	6.22	5.97	6.09	4.94	29.31	24.39	25.33	24.86	5.85	6.52	6.18	5.01
Jan 21(W)	23.56	23.13	23.34	5.62	5.51	5.57	4.51	27.85							
Jan 23 (F)	22.10	22.04	22.07	5.34	5.25	5.30	4.29	26.36	22.57	22.43	22.50	5.34	5.19	5.26	4.26
Jan 27 (T)	21.80	21.91	21.85	8.03	7.98	8.00	6.48	28.33							
Jan 28 (W)	56.57	56.18	56.37	45.21	43.61	44.41	35.97		55.34	60.36	57.85	41.53	45.60	43.56	35.29
Jan 29 (Th)	30.94	29.53	30.23	14.64	13.85	14.25	11.54	41.77							
Feb 2 (M)	30.91	30.04	30.47	13.12	12.82	12.97	10.50	40.98							
Feb 3 (T)	29.09	29.22	29.15	11.57	11.60	11.59	9.38	38.54	29.01	29.26	29.13	11.09	11.16	11.12	9.01
Feb 4 (W)	29.53	29.03	29.28	13.46	13.33	13.39	10.85	40.13							
Feb 5 (Th)	26.89	27.24	27.07	9.24	9.13	9.19	7.44	34.51							
Feb 6 (F)	25.02	24.68	24.85	5.12	5.03	5.08	4.11	28.96							
Feb 9 (M)	21.13	23.73	22.43	5.05	4.96	5.01	4.05	26.48							
Feb 10 (T)	21.93	21.93	21.93	4.31	4.35	4.33	3.51	25.44	23.31	23.55	23.43	4.49	4.54	4.51	3.66
Feb 11 (W)	23.28	22.28	22.78	4.84	4.70	4.77	3.87	26.65							
Feb 12 (T)	17.35	17.90	17.62	2.54	2.60	2.57	2.08	19.70							
Feb 13 (F)	18.59	18.04	18.32	3.30	3.02	3.16	2.56	20.87	18.66	18.76	18.71	3.05	3.00	3.03	2.45
Feb 16 (M)	20.40	20.53	20.46	3.89	3.90	3.89	3.15	23.62							
Feb 17 (T)	20.35	20.91	20.63	3.83	3.89	3.86	3.12	23.75	21.66	21.68	21.67	3.93	3.97	3.95	3.20
Feb 18 (W)	20.52	20.33	20.43	3.83	3.82	3.82	3.09	23.52							
Feb 21 (S)	19.76	19.58	19.67	4.77	4.76	4.76	3.86	23.53							
Feb 23 (M)	20.30	20.51	20.40	4.50	4.38	4.44	3.60	24.00							
Feb 24 (T)	18.10	18.05	18.07	4.00	3.99	4.00	3.24	21.31	19.76	19.48	19.62	4.39	4.29	4.34	3.51
Feb 25 (W)	gc method abort		19.84			4.18	3.38	23.22							
Means	24.70	24.61	24.65	8.24	8.07	8.15	6.60	28.48	26.84	27.61	27.22	9.96	10.53	10.25	8.30
Std Dev.	7.84	7.66	7.74	8.59	8.27	8.43	6.83	6.52	11.17	12.76	11.96	12.15	13.46	12.81	10.37

RAW DATA - RUN #3A SCVFAs
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L as acetic acid

Experiment Fermenters

Date	B-2 30 minutes							B-3 45 Minutes						
	HAc		Avg Ac	HPr		Avg Pr	Pr as Ac	HAc		Avg Ac	HPr		Avg Pr	Pr as Ac
Jan 19 (M														
Jan 20 (T	25.50	24.83	25.17	6.49	5.91	6.20	5.02	25.09	25.40	25.24	5.93	5.91	5.92	4.79
Jan 21(W														
Jan 23 (F)	24.82	22.74	23.78	5.82	5.25	5.54	4.48	22.88	22.78	22.83	5.20	5.30	5.25	4.25
Jan 27 (T)														
Jan 28 (W	53.61	58.09	55.85	41.51	43.56	42.54	34.45	54.72	52.75	53.73	40.11	39.91	40.01	32.41
Jan 29 (Th														
Feb 2 (M)														
Feb 3 (T)	29.83	33.09	31.46	11.14	12.41	11.77	9.53	29.89	29.87	29.88	11.10	11.09	11.09	8.99
Feb 4 (W														
Feb 5 (Th)														
Feb 6 (F)														
Feb 9 (M)														
Feb 10 (T)	24.76	24.58	24.67	4.64	4.63	4.63	3.75	24.71	24.48	24.59	4.81	4.81	4.81	3.90
Feb 11 (W														
Feb 12 (T)														
Feb 13 (F)	20.48	20.01	20.25	3.30	3.22	3.26	2.64	19.96	20.00	19.98	3.54	3.52	3.53	2.86
Feb 16 (M														
Feb 17 (T)	22.43	22.34	22.39	4.09	4.08	4.09	3.31	22.78	22.98	22.88	4.16	4.19	4.17	3.38
Feb 18 (W														
Feb 21 (S)														
Feb 23 (M														
Feb 24 (T)	19.82	20.41	20.12	4.45	4.50	4.47	3.62	21.12	21.50	21.31	4.66	4.52	4.59	3.71
Feb 25 (W	21.03	21.29	21.16	4.44	3.84	4.14	3.35							
Means	27.66	28.26	27.96	10.18	10.44	10.31	8.35	27.64	27.47	27.56	9.94	9.90	9.92	8.04
Std Dev.	10.24	11.90	11.06	12.06	12.80	12.43	10.06	10.61	9.95	10.28	11.61	11.55	11.58	9.38

RAW DATA - RUN #3A SCVFAs
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L as acetic acid

Date	Experiment Fermenters B-4 60 Minutes							Sidestream Fermenter Study					
	HAc		Avg Ac	HPr		Avg Pr	Pr as Ac	HAc		Avg Ac	HPr		Avg Pr
Jan 19 (M)	28.11	29.07	28.59	7.29	7.43	7.36	5.96	28.13	30.07	29.10	8.76	9.30	9.03
Jan 20 (T)	25.91	28.66	27.29	6.01	6.81	6.41	5.19						
Jan 21 (W)	23.73	23.89	23.81	5.57	5.50	5.54	4.48	25.22	24.77	24.99	6.23	6.05	6.14
Jan 23 (F)	23.33	23.29	23.31	5.27	5.22	5.24	4.24						
Jan 27 (T)	26.85	24.42	25.64	8.87	8.08	8.48	6.87	27.36	29.83	28.60	11.30	12.14	11.72
Jan 28 (W)	52.98	52.68	52.83	40.35	39.52	39.94	32.35						
Jan 29 (Th)	31.18	29.11	30.14	12.28	12.21	12.25	9.92	42.63	43.71	43.17	22.55	22.80	22.67
Feb 2 (M)	31.56	31.13	31.35	12.04	12.04	12.04	9.75	35.26	34.61	34.93	15.71	15.67	15.69
Feb 3 (T)	29.97	29.65	29.81	11.10	11.03	11.06	8.96						
Feb 4 (W)	29.74	29.99	29.86	12.27	12.30	12.28	9.95	35.90	36.35	36.13	17.51	17.56	17.54
Feb 5 (Th)	27.74	28.11	27.93	10.30	10.28	10.29	8.33	32.84	33.15	33.00	14.22	14.18	14.20
Feb 6 (F)	27.15	27.13	27.14	10.83	10.87	10.85	8.79						
Feb 9 (M)	27.41	27.64	27.53	5.41	5.43	5.42	4.39	30.75	31.42	31.08	7.71	7.74	7.72
Feb 10 (T)	26.59	26.66	26.63	8.53	8.48	8.50	6.89						
Feb 11 (W)	26.26	25.57	25.92	5.48	5.43	5.45	4.42	30.99	30.50	30.75	9.19	9.20	9.20
Feb 12 (T)	19.23	19.48	19.35	2.80	2.84	2.82	2.29						
Feb 13 (F)	20.83	20.94	20.88	3.68	3.64	3.66	2.97						
Feb 16 (M)	22.39	22.44	22.41	4.32	4.29	4.31	3.49						
Feb 17 (T)	24.56	24.08	24.32	4.84	4.75	4.80	3.89						
Feb 18 (W)	22.48	22.26	22.37	4.25	4.22	4.24	3.43						
Feb 21 (S)	22.83	22.50	22.67	6.22	6.12	6.17	5.00						
Feb 23 (M)	23.58	23.61	23.59	5.11	5.13	5.12	4.15						
Feb 24 (T)	21.85	20.42	21.13	5.09	5.01	5.05	4.09						
Feb 25 (W)	23.24	23.12	23.18	4.34	4.29	4.31	3.49						
Means	26.79	26.64	26.72	8.61	8.55	8.58	6.95	32.12	32.71	32.42	12.57	12.74	12.66
Std Dev.	6.46	6.44	6.43	7.37	7.21	7.29	5.90	4.99	4.98	4.96	5.03	5.05	5.04

RAW DATA - RUN #3A SCVFAs
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L as acetic acid

Date	Ringlace Fermenters		Experiment		Sidestream Fermenter Study		Sidestream	
	Production mg/L		Pr as	Ac total	Production mg/L		Pr as	Ac total
	HAc	HPr			HAc	HPr		
Jan 19 (M)	3.38	0.24	0.20	3.58	3.89	1.92	1.55	5.44
Jan 20 (T)	2.91	0.32	0.26	3.17				
Jan 21(W)	0.47	-0.03	-0.03	0.44	1.65	0.57	0.70	2.35
Jan 23 (F)	1.24	-0.06	-0.05	1.20				
Jan 27 (T)	3.79	0.47	0.38	4.17	6.75	3.71	3.01	9.75
Jan 28 (W	-3.54	-4.47	-3.62	-7.16				
Jan 29 (Th	-0.09	-2.00	-1.62	-1.71	12.93	8.43	6.83	19.76
Feb 2 (M)	0.87	-0.93	-0.75	0.12	4.46	2.72	2.20	6.66
Feb 3 (T)	0.65	-0.52	-0.42	0.23				
Feb 4 (W	0.59	-1.11	-0.90	-0.31	6.85	4.14	3.35	10.20
Feb 5 (Th)	0.86	1.10	0.89	1.75	5.93	5.01	4.06	9.99
Feb 6 (F)	2.29	5.77	4.67	6.97				
Feb 9 (M)	5.10	0.41	0.33	5.43	8.66	2.72	2.20	10.86
Feb 10 (T)	4.70	4.17	3.38	8.07				
Feb 11 (W	3.13	0.68	0.55	3.69	7.97	4.42	3.58	11.55
Feb 12 (Th	1.73	0.26	0.21	1.94				
Feb 13 (F)	2.57	0.51	0.41	2.98				
Feb 16 (M	1.95	0.41	0.33	2.28				
Feb 17 (T)	3.69	0.94	0.76	4.45				
Feb 18 (W	1.95	0.42	0.34	2.28				
Feb 21 (S)	2.99	1.40	1.14	4.13				
Feb 23 (M)	3.19	0.68	0.55	3.74				
Feb 24 (T)	3.06	1.05	0.85	3.91				
Feb 25 (W	3.34	0.14	0.11	3.45				
Means	2.06	0.42	0.34	2.41	6.56	3.74	3.05	9.62
Std Dev.	1.81	1.87	1.51	3.04	3.04	2.10	1.66	4.56

RAW DATA - RUN #3A NITRATES
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L Nitrogen

Date	Prim Ef	A side process - Control				B side process - Experiment			
		Anaerol	Anoxic	Aerobic	Effluent	Anaerol	Anoxic	Aerobic	Effluent
Jan 19 (M	0.154				2.817				3.236
Jan 20 (T	0.105	0.221	0.148	2.914	2.702	0.111	0.196	3.279	3.120
Jan 21(W	0.085				3.253				3.303
Jan 22(Th	0.152				4.441				4.574
Jan 23 (F)	0.144	0.217	0.194	3.948	3.413	0.332	1.922	5.497	6.135
Jan 27 (T)	0.030				3.840				4.951
Jan 28 (W	0.183	0.126	0.172	2.514	1.984	0.118	0.098	3.732	
Jan 29 (Th	0.167				2.990				3.683
Feb 2 (M)	0.020				3.376				3.466
Feb 3 (T)	0.001	0.125	0.142	3.237	2.830	0.119	0.129	3.350	3.232
Feb 4 (W)	0.027				2.849				3.193
Feb 5 (Th)	0.177				3.017				4.230
Feb 6 (F)	0.061	0.195	0.186	4.479	4.251	0.125	0.173	3.079	3.674
Feb 9 (M)	0.113				5.025				4.815
Feb 10 (T)	0.160	0.134	0.134	4.545	4.523	0.121	0.711	4.030	4.120
Feb 11 (W	0.118				4.033				4.461
Feb 12 (T	0.122				4.240				4.508
Feb 13 (F)	0.030	0.118	0.136	5.475	4.245	0.115	0.749	4.372	6.033
Feb 16 (M	0.085				4.983				4.714
Feb 17 (T)	0.092	0.133	0.100	4.399	4.062	0.098	0.231	4.069	5.501
Feb 18 (W	0.086				4.845				4.585
Feb 21 (S)	0.096				4.624				4.553
Feb 23 (M	0.103				5.523				5.242
Feb 24 (T)	0.026	0.141	1.408	4.598	3.859	0.150	0.457	5.900	4.032
Feb 25 (W	0.031				3.867				3.801
Means	0.095	0.157	0.291	4.012	3.824	0.143	0.518	4.145	4.298
Std Dev.	0.054	0.039	0.396	0.894	0.860	0.068	0.548	0.923	0.855

RAW DATA - RUN #3A TOTAL KJELDAHL NITROGEN
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L Nitrogen

Date	ug	Prim Ef	Cntl Aerobic Zon ug	Aero-A	Exp Aerobic Zon ug	Aero-B	Cntl Effluent ug	A-Efflu	Exp Effluent ug	B-Efflu
Jan 19 (M)	114.63	22.93					34.00	1.70	40.22	2.01
Jan 20 (T)	108.02	21.60	96.57	193.13		221.00	19.48	0.97	23.39	1.17
Jan 21(W)	121.41	24.28					22.33	1.12	18.95	0.95
Jan 22(Th)	130.85	26.17					23.60	1.18	17.21	0.86
Jan 23 (F)	134.36	26.87	115.52	231.03		231.00	49.60	2.48	29.88	1.49
Jan 27 (T)	137.74	27.55					34.02	1.70	30.11	1.51
Jan 28 (W)	154.59	30.92	120.75	241.50		220.00	126.79	6.34	21.04	1.05
Jan 29 (Th)	163.51	32.70					49.70	2.48	57.17	2.86
Feb 2 (M)	107.97	21.59					29.07	1.45	30.69	1.53
Feb 3 (T)	144.90	28.98	122.95	245.89		259.00	30.63	1.53	19.00	0.95
Feb 4 (W)	130.35	26.07					27.70	1.38	48.00	2.40
Feb 5 (Th)	131.67	26.33					29.91	1.50	16.45	0.82
Feb 6 (F)	137.13	27.43	121.19	242.39		263.00	28.48	1.42	15.69	0.78
Feb 9 (M)	151.98	30.40					22.33	1.12	22.56	1.13
Feb 10 (T)	138.85	27.77	146.29	292.58		235.00		0.00	20.72	1.04
Feb 11 (W)	162.84	32.57					33.05	1.65	35.73	1.79
Feb 12 (Th)	194.20	38.84					15.81	0.79	33.73	1.69
Feb 13 (F)	151.14	30.23	148.45	296.91		254.00	12.45	0.62	36.23	1.81
Feb 16 (M)		0.00						0.00		0.00
Feb 17 (T)	179.53	35.91	145.50	290.99		273.00	19.20	0.96	50.41	2.52
Feb 18 (W)	179.98	36.00					27.15	1.36	23.21	1.16
Feb 21 (S)	226.48	45.30					26.12	1.31	18.35	0.92
Feb 23 (M)	266.26	53.25					23.87	1.19	21.37	1.07
Feb 24 (T)	151.28	30.26	148.23	296.46		291.00	20.62	1.03	34.77	1.74
Feb 25 (W)	198.09	39.62					24.97	1.25	22.05	1.10
Means		29.74		258.99		249.67		1.46		1.37
Std Dev.		9.43		34.75		23.10		1.14		0.62

RAW DATA - RUN #3A PHOSPHATES
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L Phosphorus

Date	Prim Eff	A side process - Control				B side process - Experiment			
		Anaerol	Anoxic	Aerobic	Effluent	Anaerol	Anoxic	Aerobic	Effluent
Jan 19 (M)	2.325				1.036				4.351
Jan 20 (T)	2.252	6.051	3.207	1.965	1.736	7.895	4.286	2.952	3.045
Jan 21 (W)	2.558				3.319				3.091
Jan 22 (Th)	2.799				4.058				
Jan 23 (F)	2.762	12.931	5.267	1.705	1.298	7.610	6.929	5.258	4.697
Jan 27 (T)	2.866				3.772				4.208
Jan 28 (W)	3.874	24.782	18.490	3.699	5.555	19.261	11.972	1.911	3.451
Jan 29 (Th)	2.268				0.045				0.055
Feb 2 (M)	2.409				1.150				1.227
Feb 3 (T)	2.331	18.715	6.855	1.161	1.012	11.012	4.810	1.489	1.354
Feb 4 (W)	2.209				1.385				1.421
Feb 5 (Th)	3.279				0.604				1.392
Feb 6 (F)	3.585	21.422	7.410	1.642	1.813	9.043	4.645	1.527	1.688
Feb 9 (M)	4.414				2.076				5.934
Feb 10 (T)	3.605	17.604	7.116	4.510	4.416	9.700	6.698	5.404	5.624
Feb 11 (W)	3.890				4.240				5.311
Feb 12 (Th)	2.923				3.994				4.290
Feb 13 (F)	3.249	15.417	6.638	4.379	3.344	8.006	5.257	4.304	6.419
Feb 16 (M)	3.127				0.464				1.476
Feb 17 (T)	3.348	16.749	8.292	4.344	4.282	13.544	7.998	5.975	7.710
Feb 18 (W)	3.133				0.465				1.487
Feb 21 (S)	4.638				4.489				3.716
Feb 23 (M)	3.225				3.986				4.566
Feb 24 (T)	4.778	14.910	10.264	4.855	4.827	9.772	7.452	6.353	6.038
Feb 25 (W)	4.160				4.073				5.413
Means	3.200	15.072	8.171	3.140	2.698	10.649	6.672	3.908	3.665
Std Dev.	0.751	7.194	4.079	1.403	1.649	3.508	2.256	1.853	2.001

RAW DATA - RUN #3A TOTAL PHOSPORUS
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L Phosporus

			Cntl Aerobic Zone		Exp Aerobic Zone		Cntl Effluent		Exp Effluent	
Date	ug	Prim Ef	ug	Aero-A	ug	Aero-B	ug	A- Efflu	ug	B-Efflue
Jan 19 (M)	19.42	3.88					23.65	1.18	95.72	4.79
Jan 20 (T	19.82	3.96	58.86	117.72		145.00	43.68	2.18	75.41	3.77
Jan 21 (W)	19.06	3.81					82.54	4.13	68.78	3.44
Jan 22(Th	17.03	3.41					74.42	3.72	2.36	0.12
Jan 23 (F)	17.82	3.56	71.02	142.03		149.00	29.33	1.47	88.87	4.44
Jan 27 (T)	17.98	3.60					85.62	4.28	113.84	5.69
Jan 28 (W	23.68	4.74	67.76	135.51		127.00	120.64	6.03	60.88	3.04
Jan 29 (Th	21.50	4.30					13.64	0.68	5.49	0.27
Feb 2 (M)	22.47	4.49					30.71	1.54	34.18	1.71
Feb 3 (T)	25.26	5.05	84.17	168.33		162.00	40.88	2.04	41.69	2.08
Feb 4 (W	26.51	5.30					38.96	1.95	32.17	1.61
Feb 5 (Th)	21.99	4.40					18.66	0.93	19.39	0.97
Feb 6 (F)	23.58	4.72	86.87	173.74		177.00	28.65	1.43	29.40	1.47
Feb 9 (M)	27.27	5.45					43.11	2.16	105.18	5.26
Feb 10 (T)	25.20	5.04	100.04	200.08		190.00	86.71	4.34	137.19	6.86
Feb 11 (W	25.47	5.09					85.77	4.29	128.75	6.44
Feb 12 (Th	21.89	4.38	98.24	196.49		178.00	91.28	4.56	89.47	4.47
Feb 13 (F)	24.17	4.83					75.00	3.75	95.21	4.76
Feb 16 (M)		0.00						0.00		0.00
Feb 17 (T)	28.28	5.66	93.28	186.57		151.00	92.79	4.64	143.13	7.16
Feb 18 (W	33.59	6.72					14.80	0.74	32.90	1.65
Feb 21 (S)	30.99	6.20					96.53	4.83	68.22	3.41
Feb 23 (M	21.69	4.34					128.47	6.42	8.44	0.42
Feb 24 (T)	24.40	4.88	89.74	179.48		158.00	95.67	4.78	125.92	6.30
Feb 25 (W	25.63	5.13					109.37	5.47	94.96	4.75
Means		4.52		166.66		159.67		3.10		3.40
Std Dev.		1.21		27.06		18.37		1.82		2.21

RAW DATA - RUN #3A AMMONIA
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L Nitrogen

Date	Prim Eff	A side process - Control				B side process - Experiment			
		Anaerob	Anoxic	Aerobic	Effluent	Anaerob	Anoxic	Aerobic	Effluent
Jan 19 (M)	13.544				0.012				0.012
Jan 20 (T)	12.409	4.237	1.977	0.000	0.000	4.851	2.087	0.000	0.000
Jan 21(W)	12.755				0.000				0.000
Jan 22(Th)	13.848				0.021				0.000
Jan 23 (F)	11.684	6.145	2.335	0.000	0.000	4.780	2.014	0.000	0.000
Jan 27 (T)	18.395				0.074				0.019
Jan 28 (W)	15.712	8.801	5.597	3.315	3.054	6.129	3.030	0.005	0.000
Jan 29 (Th)	17.761				1.012				0.010
Feb 2 (M)	17.109				0.000				0.003
Feb 3 (T)	15.312	8.038	2.955	0.095	0.115	5.641	2.848	0.021	0.000
Feb 4 (W)	15.110				0.000				0.000
Feb 5 (Th)	20.197				0.066				0.000
Feb 6 (F)	22.410	12.224	2.991	0.009	0.317	9.903	4.872	0.000	0.050
Feb 9 (M)	34.251				0.007				0.000
Feb 10 (T)	18.303	9.097	3.633	0.000	0.000	8.230	3.027	0.000	0.000
Feb 11 (W)	18.001				0.000				0.000
Feb 12 (Th)	21.123				0.016				0.060
Feb 13 (F)	19.626	10.554	3.801	0.034	0.028	7.662	3.852	0.010	0.032
Feb 16 (M)	21.074				0.030				0.061
Feb 17 (T)	20.344	10.835	3.905	0.063	0.022	7.111	3.557	0.084	0.034
Feb 18 (W)	20.343				0.006				0.028
Feb 21 (S)	19.314				0.009				0.035
Feb 23 (M)	17.806				0.000				0.048
Feb 24 (T)	18.560	10.006	2.882	0.014	0.014	7.014	4.052	0.022	0.009
Feb 25 (W)	18.200				0.080				0.096
Means	18.128	8.882	3.342	0.392	0.195	6.813	3.260	0.016	0.020
Std Dev.	4.384	2.330	1.003	1.034	0.617	1.572	0.874	0.026	0.026

RAW DATA - RUN #3A TOTAL CARBON
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L

*Soluable Organic Carbon - Fermente*Total Organic Carbon - Process

Soluable Organic Carbon - Fermente — B side process - Experiment

Date	Prim Eff	B-1	B-2	B-3	B-4
Jan 19 (M)					
Jan 20 (T)	53	56	48	47	61
Jan 21 (W)					
Jan 22 (Th)	44				
Jan 23 (F)	43	44	42	42	42
Jan 27 (T)	60				
Jan 28 (W)	88	97	90	89	91
Jan 29 (Th)	62				
Feb 2 (M)	66				
Feb 3 (T)	62	63	68	62	62
Feb 4 (W)	61				
Feb 5 (Th)	55				
Feb 6 (F)	52	52	51	52	53
Feb 9 (M)	55				
Feb 10 (T)	49	46	46	47	46
Feb 11 (W)	50				
Feb 12 (Th)	47				
Feb 13 (F)	78	47	46	31	66
Feb 16 (M)					
Feb 17 (T)	53	53	54	54	56
Feb 18 (W)	51				
Feb 21 (S)	61				
Feb 23 (M)	58	55	57	50	58
Feb 24 (T)	57				
Feb 25 (W)	63				
Means	57.7	56.9	55.6	52.7	59.5
Std Dev.	10.2	15.1	14.1	15.1	13.3

Total Organic Carbon - Process

		Cntrl	Exper
Date	Prim Ef	A-Eff	B-Eff
Jan 19	62	9	10
Jan 20	55	8	6
Jan 21	48	9	7
Jan 22	51	8	0
Jan 23	53	7	4
Jan 27	65	7	4
Jan 28	94	9	7
Jan 29	66	10	7
Feb 2	74	11	7
Feb 3	68	11	7
Feb 4	71	11	7
Feb 5	64	10	7
Feb 6	56	8	8
Feb 9	60	9	5
Feb 10	52	6	4
Feb 11	52	5	4
Feb 12	50	5	4
Feb 13	78	5	4
Feb 16		5	4
Feb 17	58	15	5
Feb 18	56	7	5
Feb 21	71	10	9
Feb 23	73	8	9
Feb 24	79	8	37
Feb 25	62	39	37
Means	63.2	9.6	8.3
Std Dev	11.1	6.5	8.7

RUN #3B

RAW DATA - RUN #3B SCVFAs
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L as acetic acid

Date	Prim Effl								Sidestream Solids Fermenter C-1					
	acetic		mean-Ac	propionic		mean-Pr	Pr as HA	Total HA	acidic		mean-Ac prop			Mean-Pr
Mar 2 (M)	20.11	19.78	19.94	4.14	3.98	4.06	3.29	23.23	23.56	24.08	23.82	5.69	5.59	5.64
Mar 4 (W)	18.51	18.32	18.42	3.92	3.89	3.90	3.16	21.58						
Mar 5 (Th)	22.81	22.43	22.62	6.35	6.25	6.30	5.10	27.72						
Mar 10 (T)	22.54	23.73	23.13	4.61	4.85	4.73	3.83	26.96						
Mar 11 (W	24.52	24.84	24.68	4.61	4.66	4.64	3.76	28.44	29.17	28.90	29.03	7.77	7.71	7.74
Mar 13 (F)	26.68		26.68	5.05		5.05	4.09	30.77	32.33	32.28	32.31	8.25	8.27	8.26
Mar 16 (M	28.89		28.89	5.53		5.53	4.48	33.37						
Mar 17 (T)	29.29	29.09	29.19	5.40	5.30	5.35	4.33	33.52	28.97	29.00	28.99	5.13	5.22	5.17
Mar 18 (W	30.39	30.39	30.39	6.44	6.41	6.42	5.20	35.59						
Mar 23 (M	29.23	28.37	28.80	5.24	4.86	5.05	4.09	32.89						
Mar 24 (T)	25.38	24.96	25.17	3.98	3.96	3.97	3.22	28.39						
Mar 28 (Sa	23.60	21.79	22.69	4.47	4.46	4.47	3.62	26.31						
Mar 30 (M	26.08	24.02	25.05	4.61	4.59	4.60	3.73	28.77						
Mar 31 (T)	23.91	22.34	23.13	4.03	4.05	4.04	3.27	26.40						
Apr 2 (Th)	24.74	24.61	24.68	4.67	4.65	4.66	3.77	28.45						
Apr 3 (F)	21.07		21.07	4.51	4.51	4.51	3.65	24.72						
Apr 4 (Sa)	23.07	22.94	23.00	5.15	5.22	5.19	4.20	27.20						
Apr 5 (Su)	25.26	25.34	25.30	5.07	5.15	5.11	4.14	29.44						
Means	24.78	24.20	24.60	4.88	4.80	4.87	3.94	28.54	28.51	28.57	28.54	6.71	6.70	6.70
Std Dev.	3.19	3.17	3.19	0.71	0.72	0.70	0.57	3.56	3.15	2.92	3.04	1.33	1.31	1.32

RAW DATA - RUN #3B SCVFAs
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L as acetic acid

Experiment Fermenter

B-2

acidic		Mean-Ac	prop		Mean-Pr
21.03	21.29	21.16	4.44	3.84	4.14
25.46	25.29	25.37	4.85	4.82	4.83
27.78	27.72	27.75	5.07	5.06	5.06
36.25	35.87	36.06	9.88	9.76	9.82
27.63	27.54	27.59	6.06	5.87	5.96
5.54	5.33	5.43	2.22	2.29	2.25

Sidestream Solids Fermenter

C-2

acidic		Mean-Ac	prop		Mean-Pr
24.24	24.41	24.33	4.54	4.55	4.54
23.91	23.95	23.93	6.67	6.62	6.64
28.37	29.03	28.70	10.71	10.89	10.80
28.28	28.38	28.33	8.01	8.05	8.03
31.19	31.07	31.13	8.41	8.38	8.40
36.14		36.14	9.63		9.63
38.73	38.52	38.62	9.23	9.10	9.17
37.11	37.57	37.34	9.87	9.99	9.93
37.68	37.67	37.68	10.87	10.90	10.89
37.32	36.49	36.90	8.11	7.96	8.03
37.21	36.52	36.87	10.91	10.75	10.83
32.60	32.58	32.59	8.91	8.90	8.90
34.73	34.12	34.43	8.74	8.51	8.62
32.72	32.79	32.76	8.60	8.69	8.65
32.11	31.89	32.00	9.14	9.01	9.08
33.51	33.15	33.33	9.16	9.12	9.14
32.76	32.94	32.85	10.26	10.27	10.26
34.97	34.72	34.84	10.09	10.02	10.05
32.98	32.69	32.93	8.99	8.92	8.98
4.30	4.19	4.22	1.52	1.57	1.53

RAW DATA - RUN #3B SCVFAs
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L as acetic acid
Experiment Fermenter

B-4					Production mg/L		Ringlace		Production mg/L		Solids	
acidic		Mean-Ac	prop	Mean-Pr	acidic	prop	Pr as Ac	total	acidic	prop	Pr as Ac	total
23.24	23.12	23.18	4.29	4.31	3.24	0.25	0.21	3.44	4.38	0.48	0.39	4.77
20.62	21.16	20.89	5.02	5.02	2.48	1.11	0.90	3.38	5.51	2.74	2.22	7.73
34.27	34.19	34.23	25.06	25.06	11.61	18.76	15.20	26.81	6.08	4.50	3.64	9.72
26.26	25.37	25.81	5.87	5.97	2.68	1.24	1.00	3.69	5.20	3.30	2.67	7.87
26.20	26.75	26.47	5.61	5.60	1.79	0.96	0.78	2.57	6.44	3.76	3.05	9.49
29.08	28.81	28.95	5.71	5.75	2.27	0.70	0.57	2.83	9.46	4.58	3.71	13.16
31.16	31.08	31.12	5.41	5.43	2.23	-0.10	-0.08	2.15	9.73	3.64	2.95	12.68
29.95	30.27	30.11	5.53	5.52	0.92	0.17	0.14	1.06	8.15	4.58	3.71	11.86
30.87	30.70	30.78	6.90	6.93	0.39	0.50	0.41	0.80	7.29	4.46	3.62	10.90
31.96	31.01	31.48	5.04	5.12	2.68	0.07	0.05	2.74	8.10	2.98	2.41	10.52
24.45	24.79	24.62	4.22	4.22	-0.55	0.24	0.20	-0.35	11.70	6.86	5.56	17.26
25.82	25.72	25.77	4.85	4.88	3.07	0.41	0.33	3.41	9.89	4.44	3.59	13.49
25.17	27.22	26.19	4.41	4.45	1.15	-0.15	-0.12	1.02	9.38	4.02	3.26	12.64
25.32	25.36	25.34	4.37	4.37	2.22	0.33	0.27	2.48	9.63	4.60	3.73	13.36
22.70	24.37	23.53	4.61	4.61	-1.14	-0.05	-0.04	-1.18	7.32	4.42	3.58	10.90
22.79	24.55	23.67	4.71	4.71	2.60	0.20	0.16	2.77	12.26	4.63	3.75	16.01
25.05	24.53	24.79	5.52	5.56	1.78	0.37	0.30	2.08	9.85	5.08	4.11	13.96
25.89	25.43	25.66	4.94	4.97	0.36	-0.14	-0.11	0.25	9.54	4.94	4.00	13.55
26.71	26.91	26.81	6.23	6.25	2.21	1.38	1.12	3.33	8.33	4.11	3.33	11.66
3.59	3.29	3.42	4.61	4.61	2.58	4.23	3.43	5.85	2.15	1.25	1.01	2.96

RAW DATA - RUN #3B NITRATES
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L Nitrogen

Date	Prim Ef	A side process - Control				B side process - Experiment			
		Anaerol	Anoxic	Aerobic	Effluent	Anaerol	Anoxic	Aerobic	Effluent
Mar 2 (M)	0.176	0.160	0.760	4.628	4.008	0.171	0.248	4.225	4.357
Mar 4 (W)	0.095				3.253				3.790
Mar 5 (Th)	0.075								
Mar 10 (T)	0.184				3.331				3.322
Mar 11 (W)	0.030	0.161	0.193	3.775	3.303	0.206	0.290	3.685	3.453
Mar 13 (F)	0.049	0.128	0.194	3.849	3.083	0.187	0.183	4.011	3.526
Mar 16 (M)	0.000				3.084				2.747
Mar 17 (T)	0.022	0.114	0.148	3.024	3.978	0.141	0.129	2.673	3.462
Mar 18 (W)	0.030				2.771				2.296
Mar 23 (M)	0.022				2.636				2.258
Mar 24 (T)	0.026				3.603				3.621
Mar 28 (Sa)	0.069				2.878				3.108
Mar 30 (M)	0.082				3.811				3.468
Mar 31 (T)	0.098	0.130	0.102	4.064	3.484	0.147	0.151	4.012	2.769
Apr 2 (Th)	0.081				2.895				3.172
Apr 3 (F)	0.150	0.366	0.198	3.261	2.808	0.125	0.219	3.779	3.085
Apr 4 (Sa)	0.060				2.728				3.023
Apr 5 (Su)	0.209				2.746				2.993
Means	0.081	0.177	0.266	3.767	3.200	0.163	0.203	3.731	3.203
Std Dev.	0.060	0.086	0.224	0.524	0.435	0.028	0.055	0.504	0.508

RAW DATA - RUN #3B TOTAL KJELDAHL NITROGEN
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L Nitrogen

			Cntl Aerobic Zo		Exp Aerobic Zo		Cntl Effluent		Exp Effluent	
Date	ug	Prim Ef	ug	Aero-A	ug	Aero-B	ug	A- Efflu	ug	B-Efflue
Mar 2 (M)	181.01	36.20	124.82	249.64		252.00	18.74	0.94	85.59	4.28
Mar 4 (W)	191.04	38.21					12.84	0.64	35.77	1.79
Mar 5 (Th)	128.03	25.61						0.00		0.00
Mar 10 (T)	145.25	29.05					43.83	2.19	33.13	1.66
Mar 11 (W)	162.47	32.49	129.63	259.27		251.00		0.00	28.03	1.40
Mar 13 (F)	177.29	35.46	123.00	246.00		304.00	27.39	1.37	31.21	1.56
Mar 16 (M)	169.40	33.88					20.09	1.00	29.24	1.46
Mar 17 (T)	152.94	30.59	118.82	237.63		282.00	1.60	0.08	507.15	
Mar 18 (W)	135.81	27.16					25.19	1.26	39.11	1.96
Mar 23 (M)	181.20	36.24					22.10	1.11	65.08	3.25
Mar 24 (T)	197.00	39.40					13.01	0.65	33.45	1.67
Mar 28 (Sa)	186.19	37.24					17.67	0.88	30.94	1.55
Mar 30 (M)	130.62	26.12					20.08	1.00	26.54	1.33
Mar 31 (T)	176.39	35.28	128.40	256.80		259.00	37.15	1.86	26.52	1.33
Apr 2 (Th)	152.73	30.55					26.35	1.32	28.65	1.43
Apr 3 (F)	165.27	33.05					12.11	0.61	24.81	1.24
Apr 4 (Sa)	186.65	37.33					6.99	0.35	30.25	1.51
Apr 5 (Su)	160.31	32.06					16.40	0.82	37.65	1.88
Means		20.02		80.05		95.07		1.62		1.85
Std Dev.		16.35		114.58		129.06		1.46		1.31

RAW DATA - RUN #3B PHOSPHATES
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L Phosphorus

Date	Prim Eff	A side process - Control				B side process - Experiment			
		Anaerol	Anoxic	Aerobic	Effluent	Anaerol	Anoxic	Aerobic	Effluent
Mar 2 (M)	3.276	16.422	6.368	4.070	2.884	13.620	6.820	3.278	3.638
Mar 4 (W)	3.599				4.142				4.369
Mar 5 (Th)	2.957								
Mar 10 (T)	3.525				1.958				1.629
Mar 11 (W)	2.884	19.244	7.021	2.934	2.504	13.366	5.615	1.883	1.800
Mar 13 (F)	3.389	19.942	8.480	3.699	3.764	15.594	8.747	2.967	2.985
Mar 16 (M)	3.398				3.380				2.713
Mar 17 (T)	3.428	18.923	8.424	4.397	3.978	16.090	7.555	3.876	3.462
Mar 18 (W)	3.702				2.771				2.296
Mar 23 (M)	3.826				3.981				4.871
Mar 24 (T)	4.438				4.279				3.801
Mar 28 (Sa)	2.879				3.862				4.591
Mar 30 (M)	3.312				4.047				3.861
Mar 31 (T)	2.778	17.983	9.153	4.080	4.337	19.281	9.506	4.747	4.033
Apr 2 (Th)	2.889				4.420				4.564
Apr 3 (F)	3.328	20.276	9.243	5.514	5.312	13.354	8.990	5.694	5.609
Apr 4 (Sa)	3.344				4.517				4.982
Apr 5 (Su)	3.346				3.170				3.753
Means	3.350	18.798	8.115	4.116	3.724	15.218	7.872	3.741	3.703
Std Dev.	0.393	1.292	1.067	0.775	0.819	2.116	1.353	1.232	1.090

RAW DATA - RUN #3B TOTAL PHOSPORUS
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L Phosporus

Date	ug	Prim Eff	Cntl Aerobic Zor ug	Aero-A	Exp Aerobic Zor ug	Aero-B	Cntl Effluent ug	A- Efflu	Exp Effluent ug	B-Efflu
Mar 2 (M)	36.65	7.33	78.34	156.68		204.00	59.99	3.00	76.73	3.84
Mar 4 (W)	27.18	5.44					82.30	4.11	85.24	4.26
Mar 5 (Th)	24.29	4.86						0.00		0.00
Mar 10 (T)	23.79	4.76					42.56	2.13	39.15	1.96
Mar 11 (W)	23.28	4.66	93.94	187.88		184.00		0.00	41.65	2.08
Mar 13 (F)	29.45	5.89	89.00	178.00		173.00	86.32	4.32	67.86	3.39
Mar 16 (M)	21.83	4.37					83.44	4.17	68.98	3.45
Mar 17 (T)	24.08	4.82	84.13	168.25		174.00	8.09	0.40	158.21	7.91
Mar 18 (W)	27.07	5.41					81.15	4.06	72.40	3.62
Mar 23 (M)	29.08	5.82					79.23	3.96	88.03	4.40
Mar 24 (T)	34.44	6.89					80.06	4.00	60.44	3.02
Mar 28 (Sa)	30.18	6.04					80.31	4.02	96.96	4.85
Mar 30 (M)	22.77	4.55					82.91	4.15	79.88	3.99
Mar 31 (T)	29.10	5.82	95.77	191.54		173.00	88.47	4.42	78.31	3.92
Apr 2 (Th)	26.66	5.33					87.12	4.36	88.77	4.44
Apr 3 (F)	31.27	6.25	223.74	223.74		168.00	104.60	5.23	104.54	5.23
Apr 4 (Sa)	50.08	10.02					97.21	4.86	103.24	5.16
Apr 5 (Su)	52.38	10.48					67.08	3.35	76.91	3.85
Means		8.33		70.98		69.68		3.14		3.65
Std Dev.		6.38		88.78		81.50		1.70		1.76

RAW DATA - RUN #3B AMMONIA
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L Nitrogen

Date	Prim Eff	A side process - Control				B side process - Experiment			
		Anaerol	Anoxic	Aerobic	Effluent	Anaerol	Anoxic	Aerobic	Effluent
Mar 2 (M)	14.924	8.281	2.762	0.019	0.026	6.833	3.488	0.010	0.016
Mar 4 (W)	16.478				0.009				0.015
Mar 5 (Th)	13.943								
Mar 10 (T)	21.783				0.000				0.068
Mar 11 (W)	17.856	8.694	3.358	0.004	0.006	7.972	3.857	0.000	0.006
Mar 13 (F)	20.316	10.811	4.200	0.000	0.000	8.799	4.583	0.062	0.024
Mar 16 (M)	18.900				0.000				0.011
Mar 17 (T)	17.773	8.411	3.014	0.022	0.000	7.437	2.831	0.007	0.000
Mar 18 (W)	17.941				0.000				0.000
Mar 23 (M)	17.829				0.372				0.967
Mar 24 (T)	23.252				0.008				0.117
Mar 28 (Sa)	16.223				0.000				0.000
Mar 30 (M)	21.463				0.013				0.097
Mar 31 (T)	16.936	8.917	2.829	0.045	0.055	6.016	2.742	0.030	0.000
Apr 2 (Th)	15.440				0.107				0.126
Apr 3 (F)	15.573	7.061	3.553	0.027	0.028	6.570	3.703	0.127	0.028
Apr 4 (Sa)	15.086				0.077				0.088
Apr 5 (Su)	13.666				0.048				0.011
Means	17.521	8.696	3.286	0.020	0.044	7.271	3.534	0.039	0.093
Std Dev.	2.670	1.114	0.495	0.015	0.087	0.923	0.627	0.044	0.223

RAW DATA - RUN #3B TOTAL CARBON
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L

*Soluable Organic Carbon - Fermenters

Date	Prim Ef	B side process - Experiment			
		B-1	B-2	B-3	B-4
Mar 2 (M)	58	63	59	57	61
Mar 4 (W)	53				
Mar 5 (Th)	59				
Mar 10 (T)	57				
Mar 11 (W)	53	61	53	57	54
Mar 13 (F)	63	78	61	69	66
Mar 16 (M)	62				
Mar 17 (T)	61	60	74	75	63
Mar 18 (W)	60				
Mar 23 (M)	58				
Mar 24 (T)	57				
Mar 28 (Sa)	53				
Mar 30 (M)	47				
Mar 31 (T)	44		51		43
Apr 2 (Th)	67				
Apr 3 (F)	43		50		41
Apr 4 (Sa)	46				
Apr 5 (Su)	47				
Means	54.7	65.5	58.2	64.6	54.7
Std Dev.	6.8	7.0	8.3	8.1	9.6

*Total Organic Carbon - Process

Date	Prim Ef	Cntrl	Exper
		A-Eff	B-Eff
Mar 2 (M	64	9	9
Mar 4 (W	65	8	9
Mar 5 (T	64		
Mar 10	80	9	8
Mar 11	61	10	8
Mar 13	69	9	9
Mar 16		9	9
Mar 17	73	12	10
Mar 18	68	10	9
Mar 23	65	7	7
Mar 24	68	8	7
Mar 28	67	9	7
Mar 30	67	9	7
Mar 31	68	9	6
Apr 2 (T	73		
Apr 3 (F	65	7	6
Apr 4 (S		8	8
Apr 5 (S	68	9	9
Means	67.7	8.8	7.9
Std Dev	4.3	1.1	1.0

RUN #3B
RAW DATA - SUSPENDED SOLIDS (TSS) IN SIDESTREAM FERMENTERS
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in mg/L

Suspended Growth Fermenter Solids (mg/L)

Date	Raw TSS mg/L	Primary E fermenter mg/L	mg/L
Mar 13 (F)		102.00	72.00
		94.00	69.00
Mar 16 (M)	207.00	116.00	137.00
	207.00	100.00	135.00
Mar 17 (T)		102.00	117.00
		106.00	136.00
Mar 18 (W)		96.00	388.00
		108.00	272.00
Mar 19 (T)	177.00	102.00	324.00
	147.00	108.00	356.00
Mar 20 (F)		80.00	324.00
		100.00	344.00
Mar 23 (M)	160.00	106.00	98.00
	173.00	108.00	120.00
Mar 24 (T)		124.00	104.00
		140.00	98.00
Mar 25 (W)		96.00	142.00
		98.00	162.00
Mar 26 (Th)	147.00	76.00	114.00
	167.00	96.00	116.00
Mar 27 (F)		74.00	184.00
		82.00	176.00
Mar 30 (M)	163.00	88.00	433.00
	183.00	110.00	424.00

Date	Raw TSS mg/L	Primary E fermenter mg/L	mg/L
Mar 31 (T)		92.00	152.00
		106.00	158.00
Apr 1 (W)		80.00	158.00
		70.00	154.00
Apr 2 (Th)	153.00	92.00	210.00
	203.00	94.00	210.00
Apr 3 (F)		80.00	86.00
		88.00	92.00
Apr 8 (W)		126.00	122.00
		134.00	128.00

RUN #1 & #2 & 3A & 3B

RAW DATA - Process SVI (Settling test after 30 minutes)
Effect of Fixed Film Prefermentation on BNR Process Performance

Date	A-side interfac ml/L		SVI mL/g	B-side interfac ml/L		SVI mL/g
Aug 8 (F)	945	55	12	915	85	21
Aug 11 (M)	950	50	11	935	65	17
Aug 14 (Th)	890	110	29	880	120	34
Aug 19 (T)	955	45	10	860	140	39
Aug 21 (Th)	950	50	11	885	115	35
Aug 25 (M)	950	50	12	895	105	33
Aug 28 (Th)	910	90	24	890	110	34
Sept 8 (M)	140	860	579	160	840	627
Sept 11(Th)	180	820	477	175	825	532
Sept 15 (M)	205	795	443	220	780	437
Sept 18(Th)	300	700	323	240	760	389
Sept 22 (M)	300	700	350	730	270	96
Sept 25(Th)	180	820	653	800	200	59
Sept 29 (M)	200	800	567	910	90	25
Sept 30(Th)	760	240	71	920	80	21
Oct 2 (M)	730	270	91	800	200	62
Oct 6 (Th)	470	530	226	860	140	49
Oct 9 (M)	315	685	335	780	220	75
Oct. 14 (T)	220	780	422	840	160	58
Oct. 16 (Th)	240	760	685	850	150	54
Oct. 20 (M)	190	810	611	830	170	61
Oct. 23 (Th)	250	750	423	730	270	101
Oct. 27 (M)	370	630	345	800	200	71
Oct. 30 (Th)	420	580	249	610	390	147
Nov. 3 (M)	780	220	81	810	190	68
Nov. 6 (Th)	820	180	62	690	310	112
Nov. 10 (M)	850	150	50	650	350	134
Nov. 13 (Th)	830	170	55	880	120	41
Nov. 17 (M)	910	90	23	760	240	81
Nov. 20 (Th)	910	90	25	490	510	192
Nov. 24(M)	870	130	36	380	620	274
Nov. 27(Th)	800	200	66	290	710	328
Dec. 2 (T)	730	270	85	280	720	335
Dec. 4 (Th)	740	260	87	260	740	366
Dec. 9 (T)	590	410	134	270	730	340
Dec. 11 (Th)	440	560	190	260	740	346
Dec. 15 (M)	580	420	139	300	700	304
Dec. 18 (Th)	450	550	188	280	720	326
Jan. 8 (Th)	260	740	429	300	700	270
Jan 12(M)	210	790	366	325	675	243
Jan 15 (Th)	210	790	367	320	680	247
Jan. 19 (M)	220	780	347	350	650	226
Jan. 22(Th)	250	750	310	340	660	250
Jan 28(W)	330	670	211	360	640	224
Jan 29 (Th)	370	630	204	380	620	216
Feb 2 (M)	650	350	101	440	560	181
Feb 5 (Th)	690	310	95	500	500	160
Feb 9 (M)	760	240	64	610	390	127
Feb 12 (Th)	710	290	80	440	560	175
Feb 16 (M)	670	330	90	475	525	169
Feb 19 (Th)	700	300	83	640	360	115
Feb 23 (M)	630	370	101	380	620	189
Feb 27 (F)	800	200	56	670	330	102
Mar 2 (M)	780	220	60	640	360	108
Mar 3 (T)	720	280	78	670	330	102
Mar 9 (M)	780	220	61	840	160	48
Mar 12 (Th)	810	190	53	855	145	42
Mar 16 (M)	810	190	52	830	170	49
Mar 19 (Th)	760	240	68	870	130	38
Mar 23 (M)	810	190	52	890	110	31
Mar 26 (Th)	850	150	41	895	105	29
Mar 30 (M)	840	160	42	895	105	29
Apr 2 (Th)	830	170	44	890	110	30

RUN #1 & #2 & 3A & 3B

RAW DATA - MLSS
Effect of Fixed Film Prefermentation on BNR Process Performance
Results in mg/L

Date	A-side Aerobic	B-side Aerobic
Jul 24 (Th)	4440	3080
	4590	3120
Aug 8 (F)	4790	4050
	4660	3910
Aug 11 (M	4690	3810
	4700	3850
Aug 14 (T	3830	3350
	3880	3780
Aug 19 (T	4630	3300
	4490	3830
Aug 21 (T	4420	3320
	4510	3210
Aug 25 (M	4020	3160
	4160	3220
Aug 28 (T	3650	3180
	3720	3320
Sept 8 (M	1460	1350
	1510	1330
Sept 11(T	1720	1600
	1720	1500
Sept 15 (N	1780	1700
	1810	1870
Sept 18(T	2120	1910
	2210	2000
Sept 22 (N	1960	2750
	2040	2860
Sept 25(T	1270	3370
	1240	3450
Sept 29 (N	1370	3480
	1450	3590
Sept 30(T	3320	3790
	3400	3790
Oct 2 (M)	2850	3250
	3070	3210

Date	A-side	B-side
Oct 6 (Th)	2310	2810
	2380	2850
Oct 9 (M)	2050	2920
	2040	2940
Oct. 14 (T	2130	2710
	1570	2850
Oct. 16 (T	1090	2780
	1130	2780
Oct. 20 (M	1320	2740
	1330	2840
Oct. 23 (T	1790	2640
	1760	2690
Oct. 27 (M	1490	3020
	2160	2640
Oct. 30 (T	2300	2590
	2360	2700
Nov. 3 (M)	2690	2520
	2720	3090
Nov. 6 (Th	2870	2720
	2940	2800
Nov. 10 (N	2960	2610
	3010	2620
Nov. 13 (T	3020	2900
	3110	3020
Nov. 17 (N	3730	2910
	3990	3020
Nov. 20 (T	3520	2850
	3750	2470
Nov. 24(M	3760	2250
	3400	2270
Nov. 27(T	3010	2140
Dec. 2 (T)	3060	2190
	3170	2100
Dec. 4 (Th	3160	2200
	2910	2050
	3100	1990

Date	A-side	B-side
Dec. 9 (T)	2960	2140
	3180	2160
Dec. 11 (T	3030	2050
	2880	2230
Dec. 15 (N	2990	2290
	3040	2310
Dec. 18 (T	2940	2240
	2900	2180
Dec. 29 (N	3080	1690
	3000	1880
Jan. 1 (T)	3000	1842
	3100	2050
Jan. 5 (S)	2470	2350
	2610	2570
Jan. 8 (Th	1720	2590
	1730	2600
Jan 12(M)	2150	2780
	2170	2780
Jan 15 (Th	2160	2750
	2150	2760
Jan. 19 (M	2230	2860
	2270	2900
Jan. 22(Th	2460	2600
	2380	2670
Jan 28(W)	3220	2780
	3140	2930
Jan 29 (Th	3010	2830
	3160	2910
Feb 2 (M)	3420	3120
	3490	3070
Feb 5 (Th)	3240	3030
Feb 9 (M)	3300	3210
	3740	2910
Feb 12 (T	3760	3250
	3590	3180
	3680	3220

Date	A-side	B-side
Feb 16 (M	3640	3100
	3720	3130
Feb 19 (T	3580	3090
	3690	3170
Feb 23 (M	3590	3270
	3740	3300
Feb 27 (F)	3500	3150
	3700	3290
Mar 2 (M)	3610	3310
	3730	3350
Mar 3 (T)	3600	3210
	3580	3260
Mar 9 (M)	3540	3290
	3620	3330
Mar 12 (T	3560	3430
	3670	3420
Mar 16 (M	3560	3350
	3680	3550
Mar 19 (T	3510	3420
	3530	3380
Mar 23 (M	3560	3520
	3690	3620
Mar 26 (T	3620	3620
	3750	3700
Mar 30 (M	3740	3590
	3920	3670
Apr 2 (Th)	3770	3540
	3910	3680
Apr 8 (W)	3660	3270
	3830	3300
Apr 13 (M	3220	3040
Apr 16 (Th	3370	3200
	3330	3090
	3360	3190

RUN #1 & #2 & 3A & 3B

RAW DATA - Process Sludge Wasting
Effect of Fixed Film Prefermentation on BNR Process Performance

Results in L/d

Date	MLSS control	MLSS exp'ment	TSS control	TSS exp'ment	Wasting control	Wasting exp'ment
Jul 24 (Th)	4515	3100	36	33	67	59
Aug 8 (F)	4725	3980	19	47	78	56
Aug 11 (M)	4695	3830	14	43	81	58
Aug 14 (Th)	3855	3565	25	28	71	67
Aug 19 (T)	4560	3565	18	30	79	66
Aug 21 (Th)	4465	3265	4	26	87	67
Aug 25 (M)	4090	3190	9	42	84	52
Aug 28 (Th)	3685	3250	26	43	70	52
Sept 8 (M)	1485	1340	29	30	34	26
Sept 11(Th)	1720	1550	31	30	38	34
Sept 15 (M)	1795	1785	38	44	29	19
Sept 18(Th)	2165	1955	18	32	66	43
Sept 22 (M)	2000	2805	13	48	71	41
Sept 25(Th)	1255	3410	18	36	49	60
Sept 29 (M)	1410	3535	16	35	57	61
Sept 30(Th)	3360	3790	31		63	90
Oct 2 (M)	2960	3230	23	28	68	65
Oct 6 (Th)	2345	2830	23	36	62	53
Oct 9 (M)	2045	2930	30	37	48	54
Oct 14 (T)	1850	2780	17	34	64	55
Oct 16 (Th)	1110	2780	16	31	48	58
Oct 20 (M)	1325	2790	18	43	51	46
Oct 23 (Th)	1775	2665	25	81	49	50
Oct 27 (M)	1825	2830	21	33	57	56
Oct 30 (Th)	2330	2645	23	29	62	58
Nov. 3 (M)	2705	2805	20	35	69	54
Nov. 6 (Th)	2905	2760	20	38	70	50
Nov. 10 (M)	2985	2615	27	14	64	75
Nov. 13 (Th)	3065	2960	24	41	67	50
Nov. 17 (M)	3860	2965	23	26	73	65

Date	MLSS control	MLSS exp'ment	TSS control	TSS exp'ment	Wasting control	Wasting exp'ment
Nov. 20 (Th)	3635	2660	12	12	80	77
Nov. 24(M)	3580	2260	26	19	69	66
Nov. 27(Th)	3035	2165	15	19	76	65
Dec. 2 (T)	3165	2150	19	20	73	63
Dec. 4 (Th)	3005	2020	21	28	70	50
Dec. 9 (T)	3070	2150	37	27	55	54
Dec. 11 (Th)	2955	2140	26	16	65	68
Dec. 15 (M)	3015	2300	23	19	68	66
Dec. 18 (M)	2920	2210	19	11	71	76
Dec. 29 (M)	3040	1785	25	61	66	60
Jan. 1 (T)	3050	1946	21	11	70	74
Jan. 5 (S)	2540	2460	23	53	64	28
Jan. 8 (Th)	1725	2595	23	31	52	56
Jan 12(M)	2160	2780	52	60	21	28
Jan 15 (Th)	2155	2755	25	27	57	62
Jan. 19 (M)	2250	2880	18	46	67	44
Jan. 22(Th)	2420	2635	18	25	69	63
Jan 28(W)	3180	2855	37	20	56	70
Jan 29 (Th)	3085	2870	13	23	78	67
Feb 2 (M)	3455	3095	18	31	75	61
Feb 5 (Th)	3270	3120	24	24	69	68
Feb 9 (M)	3750	3080	23	32	72	60
Feb 12 (Th)	3635	3200	30	51	66	44
Feb 16 (M)	3680	3115	57	153	45	
Feb 19 (Th)	3635	3130	34	51	63	43
Feb 23 (M)	3665	3285	25	23	70	70
Feb 27 (F)	3600	3220	63	63	40	34
Mar 2 (M)	3670	3330	23	22	72	71
Mar 3 (T)	3590	3235	20	74	74	24
Mar 9 (M)	3580	3310	26	47	69	49
Mar 12 (Th)	3615	3425	19	20	75	73
Mar 16 (M)	3620	3450	15	23	78	71
Mar 19 (Th)	3520	3400	9	19	83	74
Mar 23 (M)	3625	3570	17	50	76	50
Mar 26 (Th)	3685	3660	15	43	78	56
Mar 30 (M)	3830	3630	15	19	79	75
Apr 2 (Th)	3840	3610	18	59	77	43