THE EFFECT OF PRIMARY AND SECONDARY SLUDGE MIX RATIOS ON VFA PRODUCTION IN THERMOPHILIC AEROBIC DIGESTION USING PILOT SCALE ATAD UNITS

by

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ABSTRACT

Research was undertaken to determine if a mixture primary and secondary sludge could provide increased volatile fatty acid (VFA) production, as compared with primary sludge alone, in a thermophilic aerobic digestion process. In addition, pre-solubilization of the secondary sludge, with NaOH, was investigated for its effect on VFA production. Previous research has demonstrated that VFA production can be enhanced during the thermophilic digestion of primary sludge with reduction in both aeration and retention time. Secondary sludge was predicted to further enhance production by providing the required substrate for process micro-organisms 'pre-packages' in the correct ratios. Pre-solubilization of the secondary sludge was intended to make this substrate readily available to process micro-organisms, eliminating a potentially rate-limiting step. Pre-solubilization of feed sludge has been shown to enhance anaerobic digestion.

Experiments were carried out at UBC's Wastewater Treatment Pilot Plant. Primary and secondary (Bio-P) sludges were generated on-site, by a modified UCT process, and metered to feeding tanks daily for use in the autothermal thermophilic aerobic digestion (ATAD) reactors. Configured in parallel, the two, 125 L reactors were each operated as first stage reactors, in semi-continuous mode, with an average retention time of 3 days. Based on TS, primary/secondary mix sludge ratios of 100/0, 65/35, 35/65, and 0/100 were tested in parallel with primary sludge in the control reactor. The 35/65 and 0/100 streams were additionally pre-solubilized, with 15 meq/L of NaOH, and tested in parallel with non-solubilized mix ratios of 35/65 and 0/100, respectively, in the control reactor. Through all experimental runs: feed consistency was maintained around 1% TS; reactor temperatures stayed between 42°C to 50°C, ie. within the thermophilic range; and a "micro-aerobic" environment was sustained with a constant supply of air into the reactor contents (< 1 mg/L DO, and consistent ORP values between -200 mV and -450 mV).

The incorporation of secondary sludge, in mixed sludge feed, resulted in increased production and accumulation of VFA. The greatest production and accumulation of VFA was produced with the digestion of 100% secondary sludge. Although chemical pre-solubilization of sludge resulted in increases in VFA concentrations in the feed tanks, no conclusions could be made with respect to its effect on VFA production in ATAD. The addition of NaOH did produce large fluctuations in reactor pH. Based on this impact on digester stability, and the positive results obtained without chemical pre-solubilization of feed sludge, further investigations were not undertaken with NaOH. Analysis of nutrient species confirmed that, both the mixing of primary and secondary sludge, and further, the thermophilic aerobic digestion of mixed and secondary sludges, results in the release of stored phosphorus and increases in ammonia nitrogen. Post-treatment, of some type, would be required before recycle to nutrient removal processes.

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1.0 INTRODUCTION

Volatile fatty acids (VFA) are one of many carbon substrates utilized by micro-organisms in nutrient removal in wastewater treatment. Although naturally present in wastewater, levels are variable and result in inconsistent removal. The principle of producing additional VFA to supplement processes has been developed and widely applied using fermenters. Although VFA have been detected in thermophilic aerobic digestion units, the use of the effluent for this same purpose has not been as extensively investigated, nor applied.

Since its inital development in Germany in the 1960's, autothermal thermophilic aerobic digestion (ATAD) has been investigated for its suitability in numerous applications around the world. Research of thermophilic aerobic digestion has focused on process kinetics, stabilization and pasteurization capabilities, and pre-conditioning benefits for mesophilic anaerobic digestion. Researchers in Canada have investigated many of these aspects and additionally have initiated research into enhancing the accumulation of VFA, a by-product of the process, for the benefit of Bio-P wastewater treatment processes.

The produciton of VFA in thermophilic aerobic digestion is theorized to be the result of both oxidation and fermentation reactions which are co-established as a result of the oxygen restricted environment. The net accumulation of VFA has been theorized to be the result of inhibiton of their degradation, the uncoupling of oxidation and non-oxidation phases of metabolism, and the combination of these and other alterations to bio-chemical pathways.

This thesis investigated the effect of raw secondary sludge and pre-solubilization of secondary sludge on VFA production. Secondary sludge was predicted to potentially increase VFA concentrations as a result of improved treatment effeciency in thermophilic aerobic digestion. Specifically, by supplying biomass as substrate, process micro-organisms are provided with the necessary components for aerobic bio-oxidation "pre-packaged" in the correct ratios. In addition, fermentation mechanisms may also be enhanced with increases in treatment efficiency. Moreover, pre-solubilization of secondary sludge feed could make this "ideal" substrate directly available to process microorganism and assumedly further enhance treatment efficiency and VFA production. In the past, pre-solubilization has been demonstrated to enhance anaerobic digestion and the formation of by-products (Knezevic, 1993).

1.2 Project Objectives

Utilizing the pilot scale ATAD units and wastewater treatment facilities at UBC, experiments were designed to:

(a) determine if a mixture of primary and secondary sludge can provide increased VFA production in thermophilic aerobic digestion, as compared to primary sludge alone;

(b) determine if pre-solubilization of secondary sludge enhances VFA production in thermophilic aerobic digestion;

(c) evaluate the effects of secondary sludge addition and pre-solubilization on "nutrient fate" and treatment efficiency in thermophilic aerobic digestion.

2.0 LITERATURE REVIEW

The production of volatile fatty acids (VFA) in thermophilic aerobic digestion was detected in early development and application of the process. Investigations into the mechanisms of VFA production and dedicated generation is only more recent. Before presenting a detailed summary of this research, a brief description of the thermophilic aerobic digestion process is provided, along with an overview of VFA utility in wastewater treatment.

2.1 Thermophilic Aerobic Digestion

Autothermal thermophilic aerobic digestion, ATAD, is the name and acronym coined for the aerobic digestion of sewage sludges at elevated temperatures without the application of external heat sources. The energy generated in the bio-oxidation of substrate is conserved as heat within the system, elevating reactor temperatures to greater than 40°C. Interchangeably, TAD, thermophilic aerobic digestion, also refers to this same process; the use of "autothermal" in the process description is debatable based on the high energy inputs required for efficient mixing and aeration. In addition, some facilities use additional heat sources. In this paper, TAD will be used to refer generally to thermophilic aerobic digestion, while ATAD will more specifically refer to systems known to rely solely on biologically generated heat, mixing and aeration to attain desired temperatures, ie. the UBC pilot plant reactors. TAD, like other digestion processes, is designed to stabilize sludge through the reduction of volatile solids, but additionally provides the temperatures required for regulatory pasteurization.

Thermophilic aerobic digestion is also used as a pre-treatment step for mesophilic anaerobic digestion. The thermophilic temperatures during aerobic thermophilic pretreatment (ATP) provide the necessary environment for pasteurization that are absent with mesophilic anaerobic treatment, while at the same time supplementing volatile solids destruction to reduce overall treatment time (Hamer & Zwiefelhofer, 1985; Langeland et al., 1985). ATP has also been demonstrated to enhance anaerobic digester performance with respect to:

- improved stability of process due to consistent feed (Appleton &Venosa, 1986b)
- improved bio-gas production (Baier & Zwiefelhofer, 1991)
- reduced, to complete elimination, of heating requirements (Fuggle & Spensley, 1985)
- reduced requirements for buffering chemicals (Appleton & Venosa, 1986b)
- reduced foaming due to control of *Nocardia* (Pagilla et al., 1995),
- elimination of competitive micro-organisms (Sonneleitner & Fiechter, 1983),

Dual digestion, as this combined treatment is referred to, has been extensively employed in the expansion and upgrade of existing facilities equipped with mesophilic anaerobic digesters (Baier & Zwiefelhofer, 1991).

2.1.1 Process Description

Thermophilic aerobic digestion systems can be either single or multi-stage. As thermophilic organisms build-up spontaneously with an increase in temperature (Sonnleitner & Fiechter, 1985), systems operate without sludge recycle and can be operated in batch, semi-continuous or continuous mode. Multi-stage facilities, with batch or semi-continuous operations, are the most common as they ensure a minimum retention times for regulatory degree-day specification for pathogen elimination (Langeland et al., 1984; Strauch et al, 1985; Deeney et al., 1991).

Key components of the ATAD include adequate biodegradable matter for the aerobic micro-organisms to generate heat (> 2.5% VS), a well-insulated reactor to contain the heat and allow elevation of reactor temperature, and efficient aeration and mixing equipment to facilitate high oxygen transfer efficiency without excesses heat losses in off-gases (Fuggle & Spensley, 1985; Hamer & Zwiefelhofer, 1985; Vismara, 1985; Deeney et al, 1991). Both aspirating, and pump and venturi systems, using air or oxygen, have been successfully applied in ATAD. Retention time is also critical in ATAD, see Section 2.3.3.3.

The main advantages sited for the use of thermophilic aerobic digestion systems are reduced reactor volumes and/or retention times as a result of increased biological rates, and simultaneous production of a pasteurized sludge. Specifically, in comparison to a mesophilic anaerobic digestion reactor, volumes are approximately 1/4 the size (Kelly et al, 1995), and in comparison to composting, lime conditioning and extended aeration for pasteurization, treatment times are reduced from months to days (Murray et al., 1990). In addition, thermophilic aerobic digestion is a flexible and stable process which is simple to operate and maintain. The main draw-back of the ATAD system is the high energy inputs required for mixing and aeration (Bruce & Oliver, 1987).

Originally developed in Germany as an alternative digestion treatment to meet new land disposal regulations, the thermophilic aerobic digestion process has been adapted world wide for various applicatons. Burnett (1995) and Deeney et al. (1991) provide excellent overviews of ATAD systems in Europe and Canada. With respect to economics, ATAD is generally limited to small and medium sized facilities; in larger facilities, anaerobic digestion is still favoured for energy recovery through methane production (Wolf, 1982).

2.1.2 Facilities in North America

In 1990, the ATAD process was introduced to North America in Banff, Alberta, while at the same time pilot scale reactors were added to the wastewater treatment plant on UBC's campus for research. Since this initial introduction, other research facilities and full scale plants have been constructed across North America. Figure 2.1 illustrates the location of the 6 Western Canada plants, and those plants operating or under construction with the Fuchs™ aeration system (other facilities exist). Salmon Arm, Gibsons and Ladysmith were the first three, full-scale ATAD facilities in BC and their successful operations provided the design specification for the facility in Whistler (Kelly et al., 1993). As an added measure of ATAD's success and suitability in winter climates, ATAD has again been selected in the upgrade and expansion of the Whistler facility. The facility is being expanded to accommodate a population equivalent to 52, 500 bed units (Kelly, 1996).

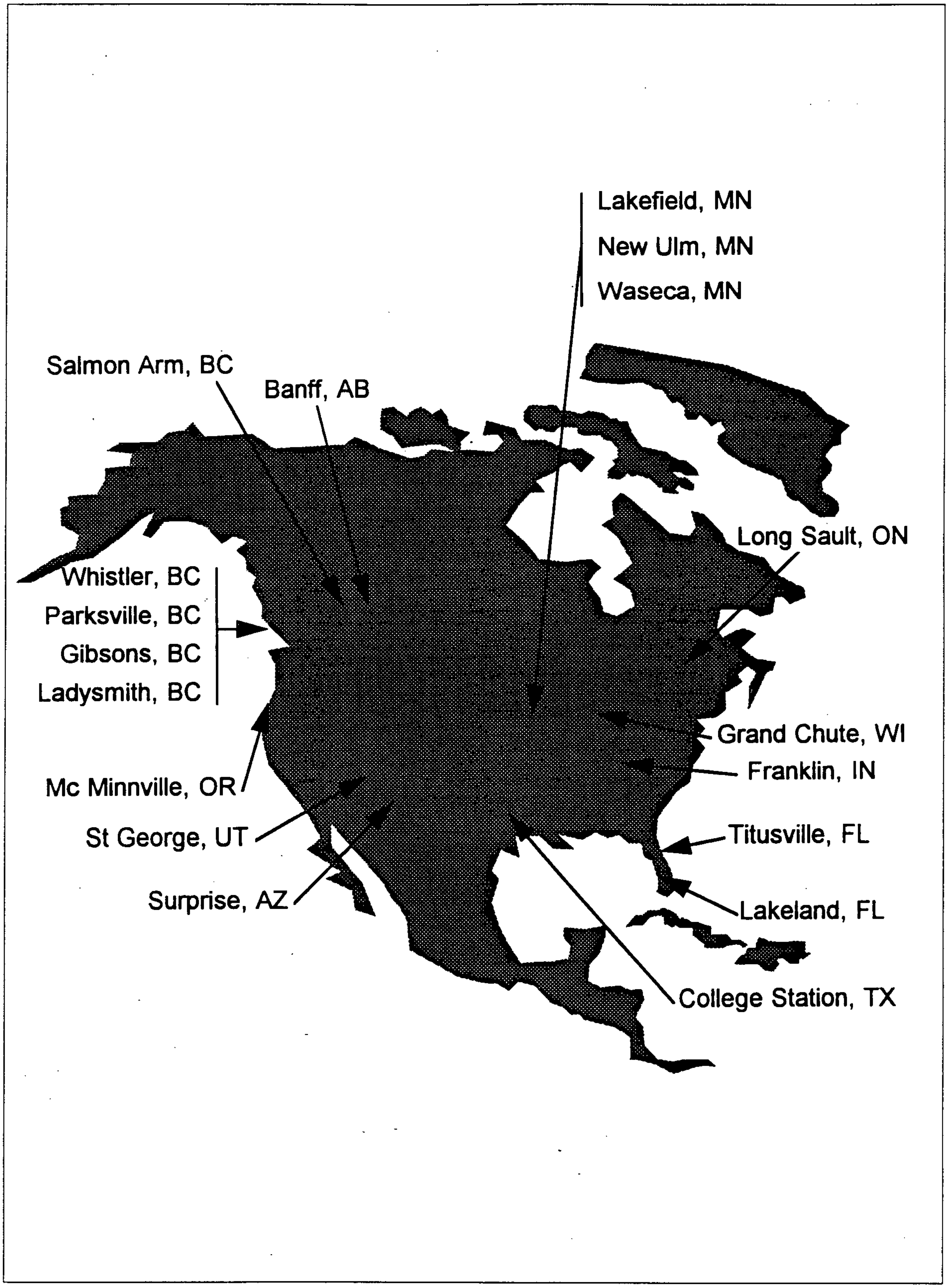


FIGURE 2.1: Location of ATAD Facilities in North America

(adapted from Kelly, 1996 & Smyth, 1996)

2.2 Volatile Fatty Acids

Fatty acids are defined as mono basic acids containing only carbon, hydrogen and oxygen, consisting of an alkyl radical, CH_3, C_2H_5, etc, attached to a carboxyl group, -COOH (Sharp, 1990). The lower weight species of fatty acids, loosely classified as short chain compounds, are referred to as volatile fatty acids (VFA). Table 2.1 list these species and their chemical structure. Terminology is used interchangeably, acetate and ethanoic acid also referring to acetic acid, propionate and propanoic acid to propionic acid. Similarly, VFA are also referred to as carboxylic acids.

TABLE 2.1: VOLATILE FATTY ACID SPECIES

Compound	Structure
acetic acid	CH_3COOH
propionic acid	CH_3CH_2COOH
iso-butyric acid	$(CH_3)_2CHCOOH$
butyric acid	$CH_3(CH_2)_2COOH$
valeric acid	$CH_3(CH_2)_3COOH$
iso-valeric	$(CH_3)_2CHCH_2COOH$
2-methylbutyric	$CH_3CH_2\ CH_3CHCOOH$

VFA are one of numerous biodegradable materials utilized by micro-organisms as substrate in wastewater treatment. Most importantly for this research, acetate and propionate have been identified as one of the most effective substrates in the enhanced biological removal of phosphorus (Rabinowitz, 1985). The model in Figure 2.2 illustrates the two phase process; bacteria are conditioned to take up greater amounts of phosphorus in an aerobic environment through initial stimulated release of phosphorus in a preceeding anaerobic zone.

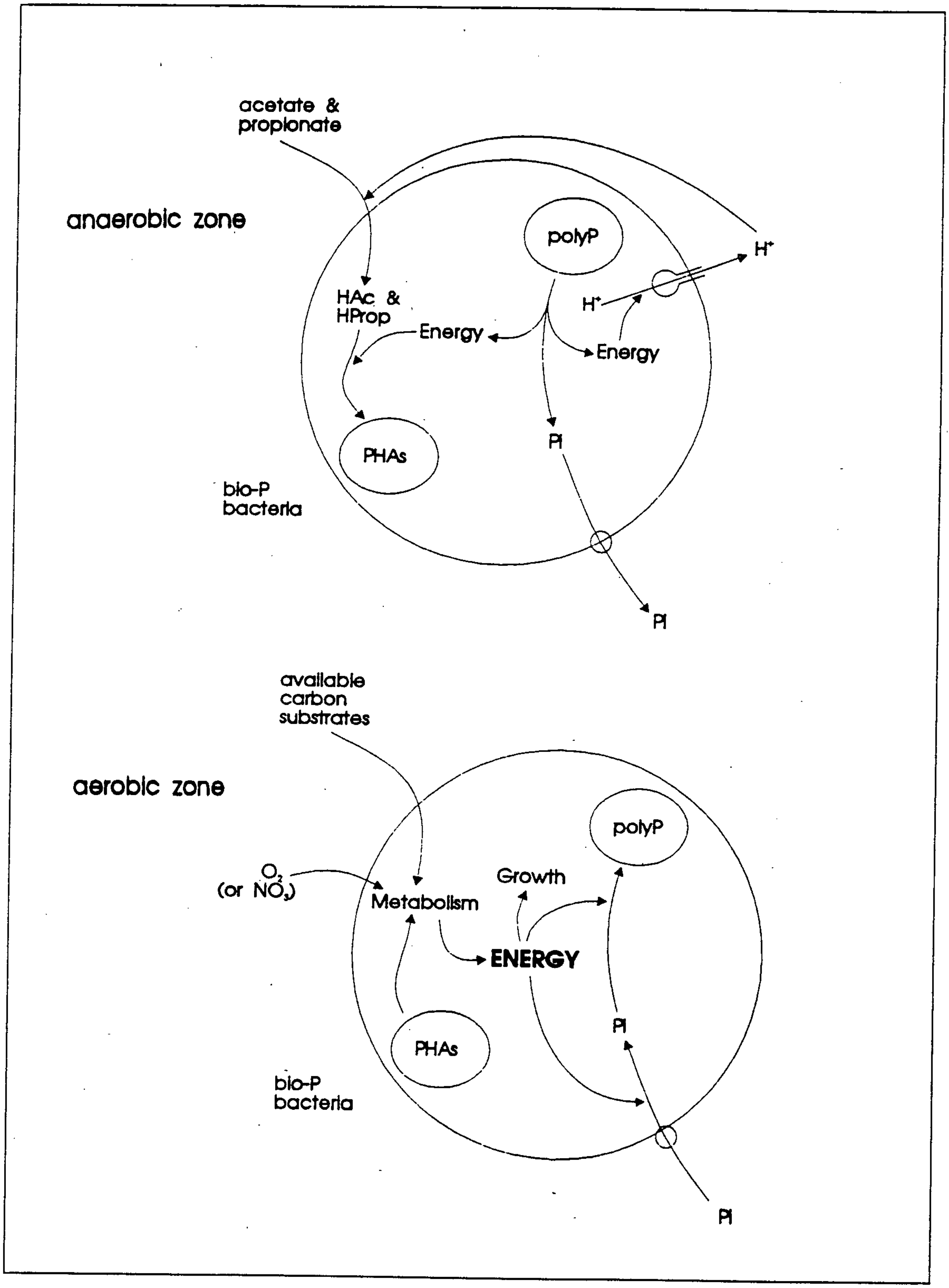


FIGURE 2.2: Model of Enhanced Biological Phosphorus Removal (taken from Chu, 1995)

Natural levels of volatile fatty acids found in wastewaters are principally the result of fermentation, due to extended retention times in the sewage collection systems. At the same time, as detailed in reviews by Chu (1995) and Atherton (1995), it is the fermentative pathway that has been adapted in the dedicated production of VFA from primary sludge for biological phosphorus removal. Similarly, McIntosh & Oleszkiewicz (1996) highlight "VFA produced through fermentation processes" as one of the prinicple sources of carbon substrate for denitrification treatment.

Fermentation can be promoted within a primary clarifier, or provided in a dedicated side-stream fermenter. Atherton (1995) provides an excellent review of both of these options for VFA production in comparison to her investigations with a main-stream fermenter. The use of either side-stream or main-stream fermenters is preferrable as it allows for the direct input of the VFA rich effluent to the desired zone in BNR processes .

2.3 Volatile Fatty Acids in Therophilic Aerobic Digestion

The concept that thermophilic aerobic digestion could also be used for the purpose of VFA production stems from both positive findings and the theory that the oxygen restricted environment in the reactors allows fermentation metabolism to occur.

2.3.1 Detection

At the first full scale thermophilic aerobic digestion facility in the UK, acidic odours were the first indication that VFA were being produced (Morgan et al., 1984). Associated with low DO levels, subsequent sampling of TAD reactor contents confirmed the presence of VFA. In discussion of these and other results, it was concluded that VFA production/accumulation was ideal for anaerobic digestion, which follow in dual digestion facilities (Casey, 1984). In specific assessment of a dual digestion process in Germany, Hamer & Zwiefelhofer (1985) also noted an increase in VFA concentrations from feed to the ATP reactor and additionally recorded complete elimination in the anaerobic digestion phase. A similar pattern was demonstrated by other dual digestion facilities in Europe. In an evaluation of a decade of opeating data from full scale facilities, VFA (acetate) concentrations increased from 2470 (1140) mg/L in raw sludge, to 6081 (3315) mg/L in the ATP reactor, down to 325 (320) mg/L after anaerobic digestion (Baier & Zwiefelhofer, 1991).

Since VFA in final effluent are considered an indication of incompletely stabilized material, this ultimate elimination is a positive result. For example, in the full scale facility in Palmersford, UK, although low aeration rates were found beneficial in improving temperature elevation in ATAD, it was discussed that air levels may need to be increased to reduce the production of VFA for a stabilized endproduct (Wolinski, 1985). It has subsequently been demonstrated that VFA can be eliminated in final TAD effluent.

2.3.2 Theory of Production

Isolating cultures in bench scale studies, Mason & Hamer were one of the first groups to propose a model for VFA production in thermophilic aerobic digestion (Mason et al., 1987a). Using yeast cells as substrate, initial results confirmed that VFA were only produced in an oxygen limited environment. Although the quantity of each species varied with retention time, acetate was the predominant species. At concentrations of 1400 mg/L to >2500 mg/L, acetate levels were 5 to 10 times greater than any other VFA (Mason et. al, 1987b). In further studies with oxygen limited conditions, VFA concentrations exceeded 6000 mg/L, again with acetate predominating (Hamer, 1987). Based on these results the model proposed that, in oxygen limited environment, acetate was produced simultaneously with the enzymatic degradation of substrate bacteria, as a result of fermentative metabolism. At the same time, the model predicts the sequential disappearance of VFA, starting with acetate, as "preferred" substrates reach exhaustion. The model does not predict accumulation (Hamer, 1987). More recent investigations by the same group of researchers continues to support this theory, and demonstrates simultaneous production and utilization of acids (Häner et al., 1994)

Bomio et al., (1989) attempted to expand on this model with similar studies using "natural substrate", primary and secondary sludge collected from a wastewater treatment plant. Under neither high, nor low, aeration rates was a substantial quantity of VFA produced. In comparison to influent VFA concentrations, the maximum increase attained was only 20%. It is interesting to note that both studies acheived maximum levels around 36 hours, followed by utilization of acids to basically zero concentration.

At the Salmon Arm facility in BC, unconfirmed acetate levels of 10, 000 mg/L were reported and thus stimulated investigation into VFA production at full-scale. Kelly (1990) holds that both oxidation and fermentation are occuring through the presence of facultative microorganisms, but agrees it is fermentation which accounts for much of the formation of VFA.

More recently, Chu (1995) highlights that although fermentation does produce VFA, typically propionate also represents a significant proportion of VFA; the sole dominance of acetate in ATAD was not observed although it represented 70-80% of VFA species.. Chu offers a number of alternative mechanisms, in addition to fermentation, that could be responsible for acetate accumulation:

• aerobic oxidation of VFA

• mutant *atp* behaviour

• accumulation of NADH switches carbon flow towards acetic acid

• inefficient coodination or uncoupling of the oxidative (TCA cycle and elctron transport chain) and non-oxidative (glycolysis) phases of glucose metabolism, resulting in acetyl-coA being diverted to acetate

From the results of his own investigations, Chu favours the later explanation referred to as the "overflow pheomenon", and a combination of all processes including fermentation. At the same time, 2,4-dinitrophenol was identified to inhibit acetate consumption, resulting in large accumulations of acetate in batch experiments, suggesting that other agents may exist that inhibit acetate consumption. Hamer (1987) also suggested inhibition of VFA degradation as an explanation for VFA accumulation, a contradiction to the predictions of his model.

More studies are required to accurately determine the bio-chemistry of VFA metabolism in thermophilic aerobic digestion, especially as the influent streams are so different and themselves variable. At the same time, not all operating parameters have been systematically investigated for their effect. The focus of this research is on assessment of VFA production in ATAD at the operations level.

2.3.3. Effects of Operating Conditions

Aerobic thermophilic digestion is used in both ATAD and ATP, dual digestion systems. All configurations are capable of attaining stabilization and pasteurization, if so designed. The simultaneous production of VFA has been established with adjustments to certain operating parameters. The following sections highlight the research that identified these parameters and the investigations that have assessed their impact on VFA production. This review should illustrate how the project objectives were established, and how operating parameters were set.

2.3.3.1 Temperature

As a product of biological activity, VFA production is a function of temperature. This is demonstrated in the seasonal decrease in influent wastewater concentrations during the winter (Atherton, 1995). Specifically, UBC's pilot plant influent demonstrated an increase from 8 - 25 mg/L between November and February, to 18 - 35 mg/L from April to September. Similarly, increases in temperature alone have shown to increase VFA production in anaerobic digestion (Rimkus et al., 1982). With respect to the overflow phenomenon, studies suggest that the coordination of oxidation and non-oxidation phases is less at elevated temperatures (Chu, 1995).

In ATAD systems, heat is generated in the system by biological oxidation of substrate and the energy input for mixing and aeration. At full-scale facilities, studies have shown that the majority of the heat is biologically produced; studies by one researcher have quantified it at 70 - 80% (Ponti et al., 1995b). This same "auto-heating" is not demonstrated with smaller scales systems or with short retention times (Gould & Drnevich, 1978, Kelly, 1990). At UBC's pilot plant, this inefficiency is compensated for through increased mechanical energy. As illustrated in Figure 2.3, increases in mixer speed of as little as 20 rpm resulted in changes in reactor temperature (Chu, 1995).

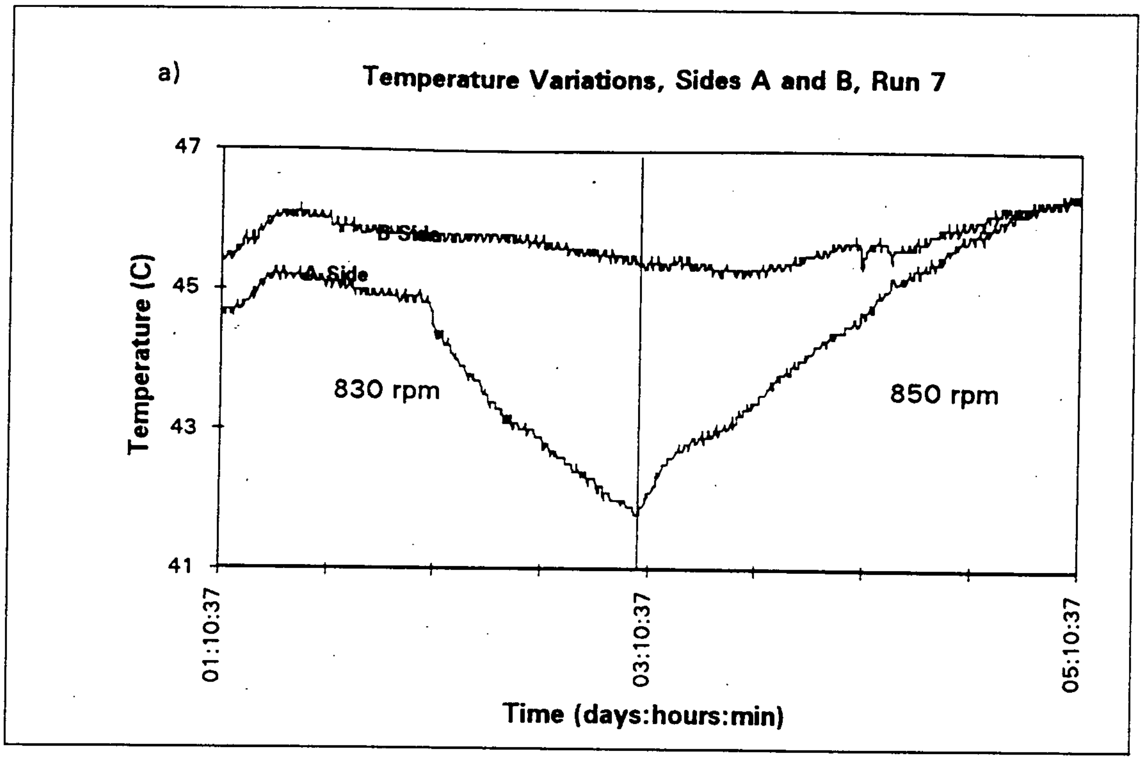


FIGURE 2.3: Temperature Effect of Changes in Turborator™ Speed (Chu, 1995)

Typical operating temperatures for thermophilic aerobic digestion systems are listed in Table 2.2. These temperatures should promote VFA production if other conditions are condusive.

TABLE 2.2: TYPICAL TAD OPERATING TEMPERATURES

First Cell	Subsequent Cells	Reference
35 - 50°C	50 - 65°C	(U.S.EPA, 1990)
50 - 55°C	55 - 70°C	(Kelly, 1991)
60 - 68°C	anaerobic digestion	(Baier & Zwiefelhofer, 1991)

2.3.3.2 Aeration

Originally, the ATAD system was designed with specifications to maintain a measurable level of dissolved oxygen (Gould & Drenevich, 1978, Vismara, 1984); however, the aeration rates required to produce such an environment cause cooling of the system and result in excessive consumption of energy (Appleton et al., 1986b; Edgington et. al, 1993). In addition, it has been demonstrated that aeration rates, set to provide an oxygen restricted environment within ATAD reactors, increase solids removal rates and result in overall higher solids destruction (Mason et al., 1987b; Kelly, 1990). The theory is that the resulting mixed culture of aerobic and facultative anaerobic bacteria functions more efficiently than a "mono-culture", as found with strictly aerobic processes, and is additionally more stable (Hamer, 1987).

Aeration levels are now established to produce environments described as oxygen deprived (Boulanger, 1995), micro-aerobic (Chu, 1995), anaerobic aerated (McIntosh & Oleszkiewicz, 1996).

As measurement of very low dissolved oxygen levels are often immeasurable , ORP has been found to be a more effective monitoring instrument (Morgan & Gunson, 1987; Kelly et al, 1993). Values at the facilities investigated in BC, detected redox values between 30 mV and -350 mV in the first reactor, with less negative readings in the second reactor (Kelly, 1990). In recent pilot scale studies investigating oxygen transfer efficiency, negative redox was registered during all studies (Ponti et al., 1995b).

Along with the original design to provide an aerobic environment, Gould & Drenevich (1978) also asserted that pure oxygen was required for aeration in ATAD for oxygen transfer efficiency and positive heat balances. Comparative studies in the UK were some of the first to demonstrate that air could be efficiently employed and additionally, was superior to pure oxygen with respect to oxygen utilization efficiency (Wolinski , 1985; Morgan & Gunson, 1987). At the same time, Booth & Tramontini (1984) suggested that the higher oxygen utilization with air was a result of carbon dioxide stripping. In contrast, Fuggle & Spensley (1985) argue that air results in greater heat losses and is thus, less desirable. Both air and pure oxygen are used in full-scale ATAD facilities, and both systems have demonstrated the ability to produce VFA.

Using air, pilot scale studies by Chu (1995) assessed the effect of aeration on VFA production from primary sludge in ATAD. Initially running 2 reactors in series results indicated that the highest accumulation of VFA occurred under the lowest aeration level in the first reactor. Switching to 2 single stage systems in parallel, to provide a control reactor through experimentation, air flow rates of 0 to 165 ml/min were assessed. Net VFA production increased with a decrease in aeration with 950 mg/L being the maximum recorded concentration.

At this same time, the effect of "air" aeration was assessed on a mixed sludge feed by Boulanger

(1995; Boulanger et al., 1984 and 1995). With the reactors configured in a two stage process, aeration was varied through redox levels of -300 mV to +100 mV, corresponding generally to dissolved oxygen levels of <1 mg/L to >1 mg/L . VFA concentrations increased from <10 mg/L to 724 mg/L in the first stage, and 225 mg/L in the second stage with the decrease in aeration.

Similar aeration studies have been carried out using pure oxygen and primary sludge at the University of Manitoba (McIntosh & Oleszkiewicz, 1996). Within an ORP range of -10 mV to -225 mV (0.14 V/V-hr), there was no net accumulation of VFA, whereas with ORP values consistently <300 mV (0.025 V/V-hr), net increases of approximately 1500 mg/L resulted in reactor concentrations around 3000 mg/L.

The aeration levels used in these studies are comparable to full scale facilities with respect to resulting ORP values. The low aeration rates in ATAD promote VFA production.

2.3.3.3 Retention Time

Since there is no recycle in TAD processes, retention time is synonymous with SRT and HRT. Based on feeding rates, a minimum retention time exists, before wash-out occurs, where energy generated by the bio-oxidation of substrate is not sufficient to provide autoheating (Jewell and Kabrick, 1980). This is illustrated in the requirement of many dual digestion system with retention times of less than 1 day to either pre-heat feed sludge, or heat the aerobic reactor itself (Bruce & Oliver, 1987). Similarly, above a maximum retention time, substrate is exhausted and again insufficient biologically generated heat is produced (Wolinski, 1985; Kelly et al., 1991). Typically, total ATAD retention time ranges between 6 and 10 days, with equal retention time in each stage (Burnett, 1995).

The relationship between retention time and VFA production was noticed early in studies. As described in section 2.3.2, in bench scale studies with isolated cultures, acids were shown to accumulate over the first 36 hours, then gradually disappear. (Mason et al., 1987b; Bomio et al., 1989). Although the actual time frame of these results may be incorrect, it illustrates that VFA can be degraded by thermophilic organisms with time.

In the studies mentioned above, Chu (1995) also investigated the effect of retention time on VFA production in ATAD. Initial results with reactors in series, indicated that the highest accumulation of VFA ocurred in the first stage reactor. This result was also confirmed by Boulanger (1995). In subsequent parallel studies, VFA production was shown to increase with a decrease in retention time from 6 days to 3 days.

Similarly, McIntosh & Oleszkiewicz (1996) also investigated the effect of varying retention time on VFA production using their pure oxygen system as described above. Although results indicate a decrease in net VFA production with a decrease in retention time from 24 to 12 hours, in contrast to findings by Chu, percent increases and gross concentrations in the TAD reactors did not demonstrate similar trends. In comparison of absolute values, the shorter retention times in McIntosh & Oleszkiewicz's studies produced 3 times the concentration of VFA. Similarly, comparison toVFA levels in ATP reators in dual digestion, shows higher concentrations have been realized with even shorter retention times: ATP retention times of 18 - 24 hours produced >6000 mg/L (Baier & Zwiefelhofer, 1991), while retention times of 3 days in TAD generate less than 600 mg/L. These general results support the relationship proposed by Chu (1995) that reduced retention time enhances VFA production.

At the same time, in a review by Ponti et al (1995a), studies have shown how retention times in TAD reactors, established with frequent feedings of smaller volumes, improved degradative efficiencies due to smaller fluctuations, while volume changes of more than 20% of the working volume resulted in adverse effects. As an example of ineffective processing, the bi-weekly feeding schedule and 16 day retention time in one UK plant resulted in poor destruction, and difficulty in attaining designed process temperatures of 50°C (Edgington et al., 1993). Frequent volume changes have also demonstrated to reduced electrical requirements due to increased microbial efficiency (Ponti et al., 1995b). VFA production could potentially also be enhanced by increased feeding frequency.

2.3.3.4 Feed Sludge

As discussed in previous sections, a sufficient quantity of substrate is critical in ATAD to attain sufficient heat energy from aerobic bioxidation. Typically, 4 - 6 % total solids provides adequate volatile content (U.S. EPA, 1990; Deeney et al., 1991; Kelly et al., 1995).

The quality of sludge is also an important facture. Primary sludge is theorized to require longer treatment, as it is initially less stabilized than secondary sludge (Smith Jr., et al., 1975). In addition, both the irregular composition and concentration of the primary sludge can result in fluctuating and unstable digestion (Ponti et al., 1995).

In contrast, secondary sludge is theorized to more suitable for ATAD as it is closer to the oxidative state of thermophilic culture (Mason et al., 1987). The other theory that proposes secondary sludge as a more effective substrate in ATAD is referred to as the "t.v. dinner theory": although primary sludge has a higher volatile content, secondary sludge, consisting of biomass, provides the required substrate pre-packaged in required ratios. In ATAD, this material is then made readily available to process biomass through lysis (Kelly et al., 1995). Both primary and secondry sludge, including mixtures, have been successfully treated in thermophilic aerobic digestion systems.

With respect to enhancement of VFA, secondary sludge is chemically the most suitable. Under oxygen limited conditions, aerobic bio-oxidation of the substrate biomass results in the production of carbon dioxide, process biomass and soluble by-products. In addition, as nitrification is inhibited at the high temperatures found in TAD reactors, by-products formation is limited. The conversion of substrate biomass can thus be represented by the following equation, which clearly illustrates how VFA production should be enhanced with the addition of secondary sludge (Hamer & Zwiefelhofer, 1985).

$$CH_{1.4}O_{0.4}N_{0.2} + a\,(O_2) \rightarrow b\,(CH_{1.8}O_{0.43}N_{0.23}) + c\,(CO_2) + d\,(H_2O) + e\,(NH_3) + f\,(\underbrace{C_nH_{2n+1}COOH}_{\text{VFA}})$$

The main concern in digesting secondary sludge is the release of nutrients previously removed in wastewater treatment and the additional load on plant capacity when recycled to the process. Most critically, phosphorus is readily released from secondary sludge when mixed with primary sludge and under aerobic digestion due to lysis (Anderson & Mavinic, 1993; Rabinowitz & Barnard, 1995). Studies have confirmed that digestion of mixed sludge feed in ATAD results in subsequent nutrient release (Boulanger, 1995). At the same time, anaerobic digeston of mixed sludge also results in phosphorus release, requiring treatment before recycle (Knezevic, 1993; Niedbala, 1995; Rabinowitz & Barnard, 1995).

Effluent from the ATAD process in Salmon Arm, BC where primary and secondary sludge are co-thickened before digestion, has been recycled without additional treatment. Although operational difficulties suspended the full scale trial before impact could be assessed, subsequent bench scale studies predicted only minimal increases in phosphorus release and uptake, and additional full scale studies were discontinued (Kelly, 1990). Further enhancement of the production of VFA in ATAD could potentially compensate for the release of nutrients.

2.3.3.5 Pre-Solubilization

Based on the theory that secondary sludge provides a pre-packaged substrate for micro-organisms in the digestion process, pre-solubilization of secondary sludge feed is intended to release this material for direct availability to process micro-organisms, eliminating a potentially rate-limiting step. Even in thermophilic digestion, where both high temperatures and increase enzyme production result in the lysis of cells and the expulsion of cell contents into solution (Hamer, 1987), lower initial reactor temperatures with cooler feed, lower osmotic pressure or more resilient bacteria could delay the release of this ideal substrate (Brock & Madigan, 1991). Chemical solubilization is a measured and controllable mechanism that can be optimized for a given feed stream.

The secondary sludge at UBC had previously been assessed for optimum chemical dose and mixing time for pre-solubilization, with both calcium hydroxide and sodium hydroxide (Knezevic, 1993). Based on the results of the application of the pre-solubilized sludge in anaerobic digestion, and the demonstrated enhancement of COD removal and methane gas produciton, it was hypothesized that VFA production could similarly be enhanced.

The application of thermophilic aerobic digestion in stabilization and pasteurization of municipal sludges has been widely demonstrated. Similarly, the benefits of ATP in dual digestion have also been well documented. The enhancement of volatile fatty acids production in both processes, to supplement nutrient removal and methane production respectively, has been proposed and partially evaluated. The goal of this thesis is to contribute additional findings to this area of research.

3.0 METHODS AND MATERIALS

3.1 Experimental Set-Up

All experiments were conducted at the University of British Columbia's Pilot Plant, located on South Campus. The wastewater treatment facility with two parallel BNR trains, configured as a modified UCT process, treats sewage from on-campus housing and residences. To achieve adequate solids loading to the process, sewage is pumped twice daily from a main sewage line into three equalizing tanks at the head of the plant. Raw sewage is buffered daily with the addition of approximately 500 g of sodium bicarbonate to each tank. All effluent and discharges are returned to the main sewage line for treatment at Annacis Island, Vancouver's wastewater treatment facility. A process flow diagram of the wastewater treatment plant is provided in Figure 3.1. Actual photos of the facility are provided in Appendix B.

The pilot scale ATAD system, consisting of 2 sealed and insulated reactors, built for previous research, was brought back on line with the plant's wastewater treatment process in June, 1995. Experiments were run between September and December of the same year, with samples being concurrently analyzed in UBC's Environmental Engineering Laboratory. Four experimental runs were designed to test the influence of secondary sludge on ATAD sludge digestion, and 2 supplemental runs investigated the influence of pre-solubilization of the secondary sludge. For all experiments, the 2 ATAD reactors were configured in parallel, to maintain a control throughout the test period: 100% primary sludge for Runs 1 to 4, and identical sludge mix ratio, unsolubilized for Runs 5 and 6. The sludge mix ratios were selected to cover the range from 100% primary to 100% secondary, as well as to facilitate camparison to previous research completed at UBC (Knezevic, 1993; Boulanger, 1995; Niedbala, 1995). Table 3.1 outlines the experimental design.

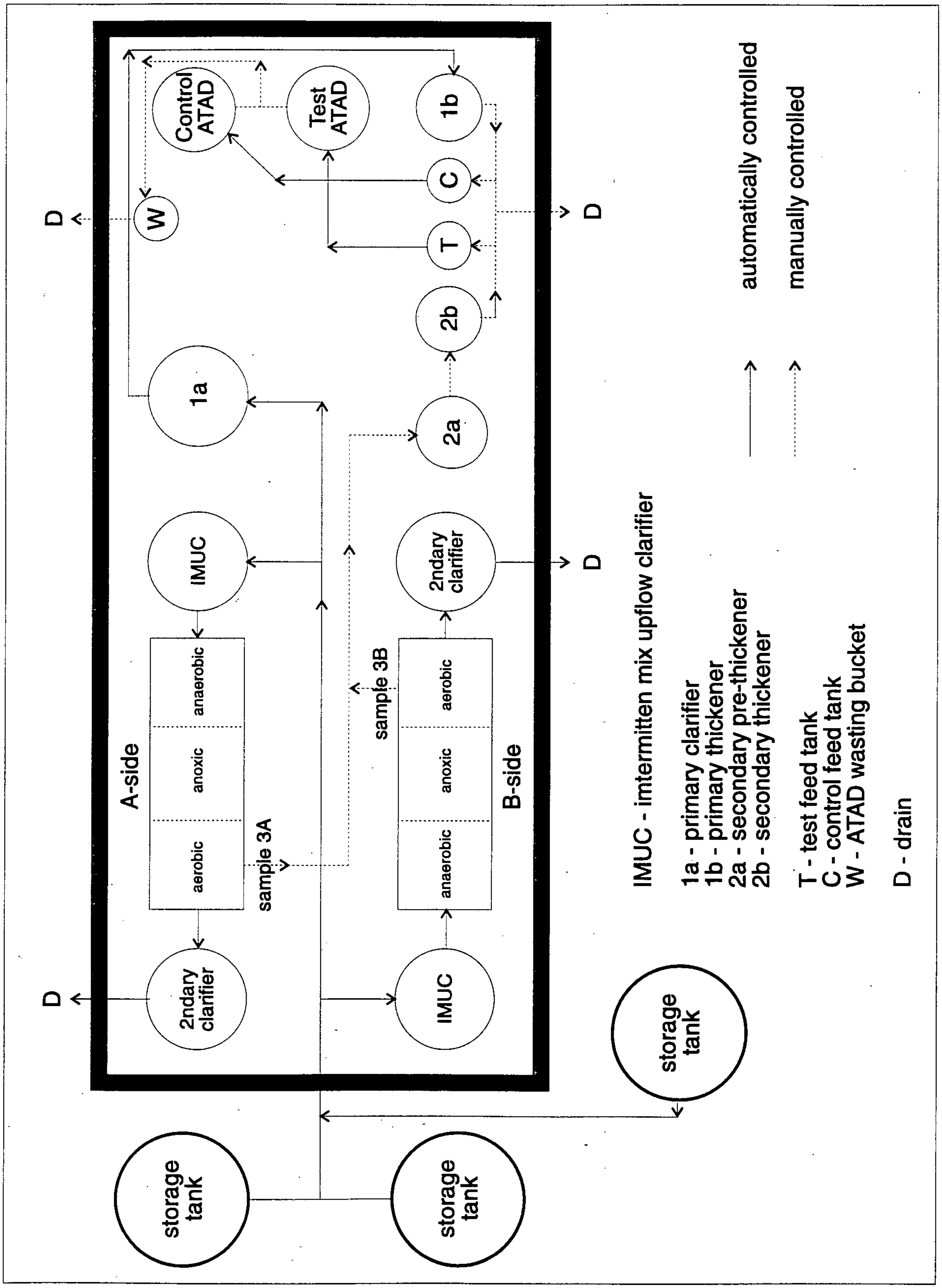


FIGURE 3.1: Process Flow Diagram of the UBC Pilot Plant

TABLE 3.1: EXPERIMENTAL DESIGN

Run	Primary/Secondary Sludge Ratio (based on TS) Test Reactor	Control Reactor	Timing (minimum)
1	100/0	100/0	2 SRT
	acclimitize to 65/35		2 SRT
2	65/35	100/0	2 SRT
	acclimitize to 35/65		2 SRT
3	35/65	100/0	2 SRT
	acclimitize to 0/100		2 SRT
4	0/100	100/0	2 SRT
	acclimitize to pre-solubilization	acclimitize to 0/100	2 SRT
5	0/100 pre-solubilized	0/100	2 SRT
	acclimitize to 35/65 & pre- solubilization	acclimitize to 35/65	2 SRT
6	35/65 pre-solubilized	35/65	2 SRT

3.1.1 Sludge Source

Primary sludge was generated from a side stream clarifier, as the clarifier serving the process train is an intermittent mix, upflow clarifier. To maintain consistent total solids (TS) the flow rate to the clarifier was initially estabished at 6.25 L/min, and gradually reduced with the decreased use of primary sludge to 5.4 L/min. Sludge was pumped from the bottom of the clarifier every 5 minutes for 30 seconds, to a second clarifier for further thickening and storage. Sludge was transfered to the feed tanks daily, with additional wasting to the drain, to maintain a consistent sludge age.

Secondary sludge was wasted from the last aerobic zone of the UCT process. Every 24 hours, 100L of sludge was transferred to a pre-thickener. The sludge was allowed to settle and free water was manually sucked off with the use of pump; the remaining material was pumped to the secondary thickener. Generally, the sludge condensed to 1/5 its original volume within the hour before transfer the thickener. To avoid anaerobic conditions during holding, the contents of the secondary thickener were periodically stirred up, and left to settle a minimum of an hour before transfer to the feed tanks.

Primary and secondary sludge was metered into the feed tanks once daily by gravity flow. Mix ratios were based on TS calculated every 24 hours, with dilution with distilled water to maintain a 1% sludge feed. Although this would be considered "thin feed" in ATAD, it is the maximum thickness of secondary sluge that can be readily produced from the process, at this scale, for the daily quanitities required. Both feed tanks were continuously stirred to keep solids suspended for homogenous consistency at the outlet at the bottom of the tank. A process flow schematic of the ATAD experimental set-up is provided in Figure 3.2, and photos in Appendix B show the actual equipment.

Pre-solubilization of feed sludge was carried out in the feed tanks with the addition of a measured quantity of sodium hydroxide (NaOH). Based on the results of previous research at UBC, 15 meq/L of secondary sludge was used (Knezevic, 1993). However, due to the semi-continuous operation of the ATAD reactors, the "optimum" 5 hours of mixing for the pre-solubilization of secondary sludge could not be provided. Instead, NaOH was dissolved in distilled water and added to the test feed tank immediately after a feeding to provide a minimum of 1 hour pre-solubilization. Consequently, only 4 litres of sludge did not receive the prescribed 5 hours of mixing.

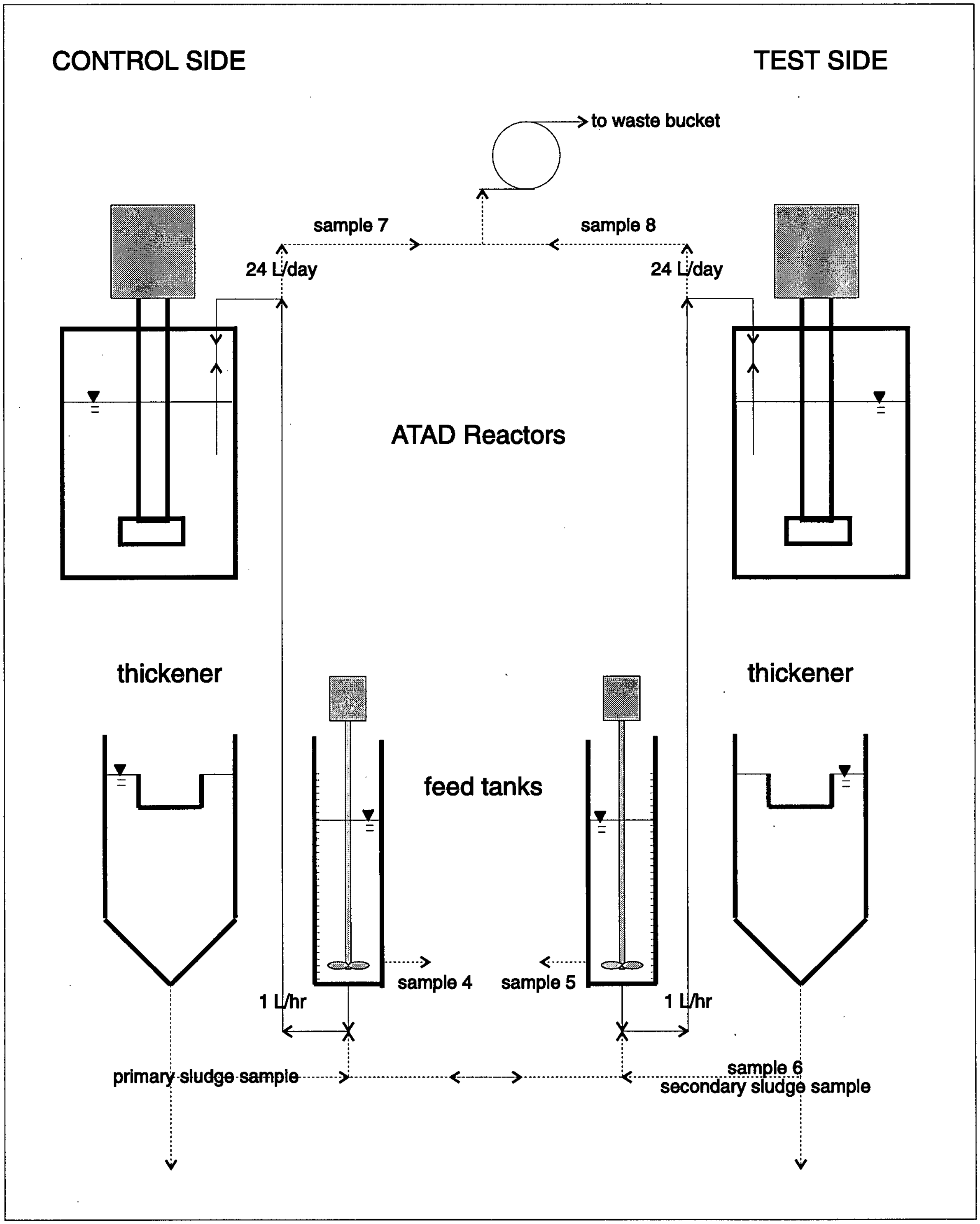


FIGURE 3.2: Process Flow Diagram of Experimental ATAD Set-up

3.1.2 ATAD Reactors

Two, 125 L stainless stell tanks, fitted within insultated tanks, served as the ATAD reactors. The tanks were sealed with a lid perforated for: the sludge inlet/outlet pipe, air exhaust port, temperature and ORP probes. The shaft of the mixing and aeration device also perforated the lid. All perforations were well-sealed to maintain high insulation proporties as well as to prevent escape of off-gases, or entry of outside air. Figures B5 (a) and (b), in Appendix B, illustrate the reactor lid detail.

The ATAD reactors were operated in semi-continuous mode through automatic feeding and manually wasting. Both feed pumps were Moyno progressive cavity pumps (model 33101). Each pump was equipped with a speed controller to deliver 1 L of sludge during a 30 second "on" period established by an electrical relay. The pump used to remove sludge from the reactors was a Masterflex peristaltic pump (model 7585-50), top mounted to suck sludge out throgh the same down pipe used for feeding. Manually operated, each reactor was wasted separately into a bucket to control the volume of digested sludge removed and to obtain ATAD sludge samples.

3.1.3 Retention Time

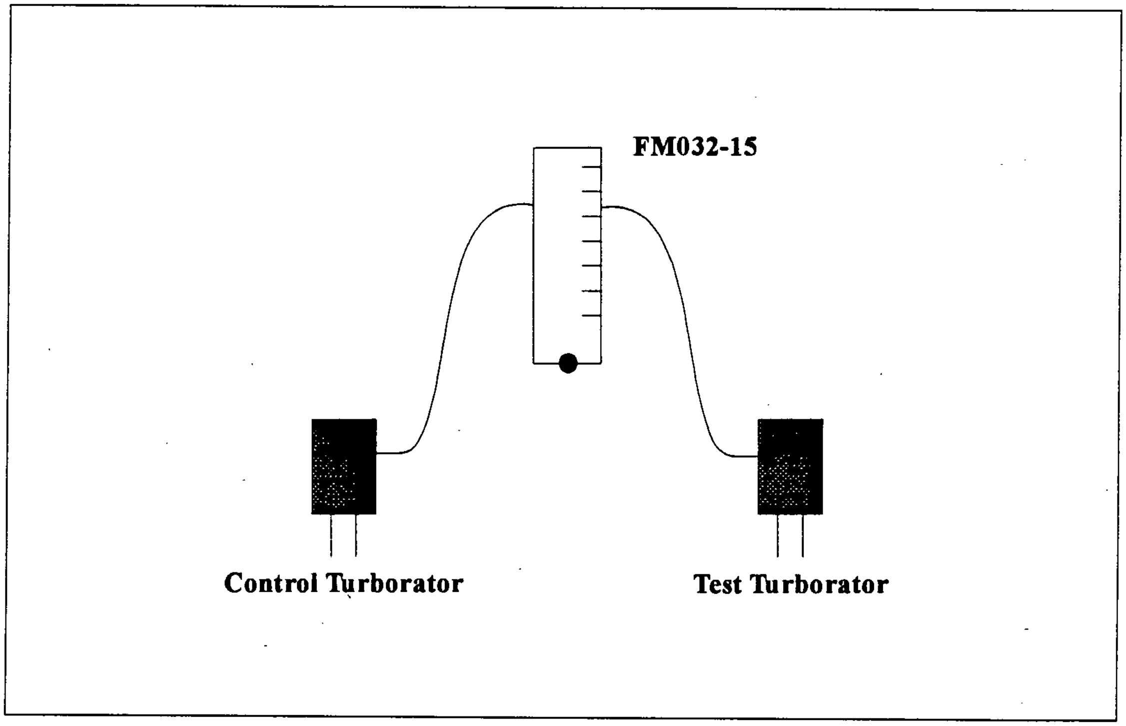
A retention time of 3 days was selected for experiments based on the results of previous work on VFA production in these same reactors (Boulanger, 1995; Chu, 1995). Based on a semi-continuous feed rate of 1 L/hr, an average volume of 72 L was required. During regular operations, 24 litres of sludge was wasted once a day and the sludge volume rose daily from 60 L to 84 L. During test runs, wasting occured twice a day in order to obtain samples. Therefore, to maintain an average volume of 72 L with only 12 L being removed at a time, oscillations were established between 66 L and 78 L.

For 10 days prior to acclimitization for Run 5, when it was required to build up the sufficient quantity of secondary sludge for the last two runs, the retention time in the reactors was extended beyond 3 days. Both reactors were filled with 30 L of partially digested secondary sludge and 30 L of fresh secondary sludge. Every second day, the contents of both reactors were interchanged and mixed, to ensure consistency between reactors.

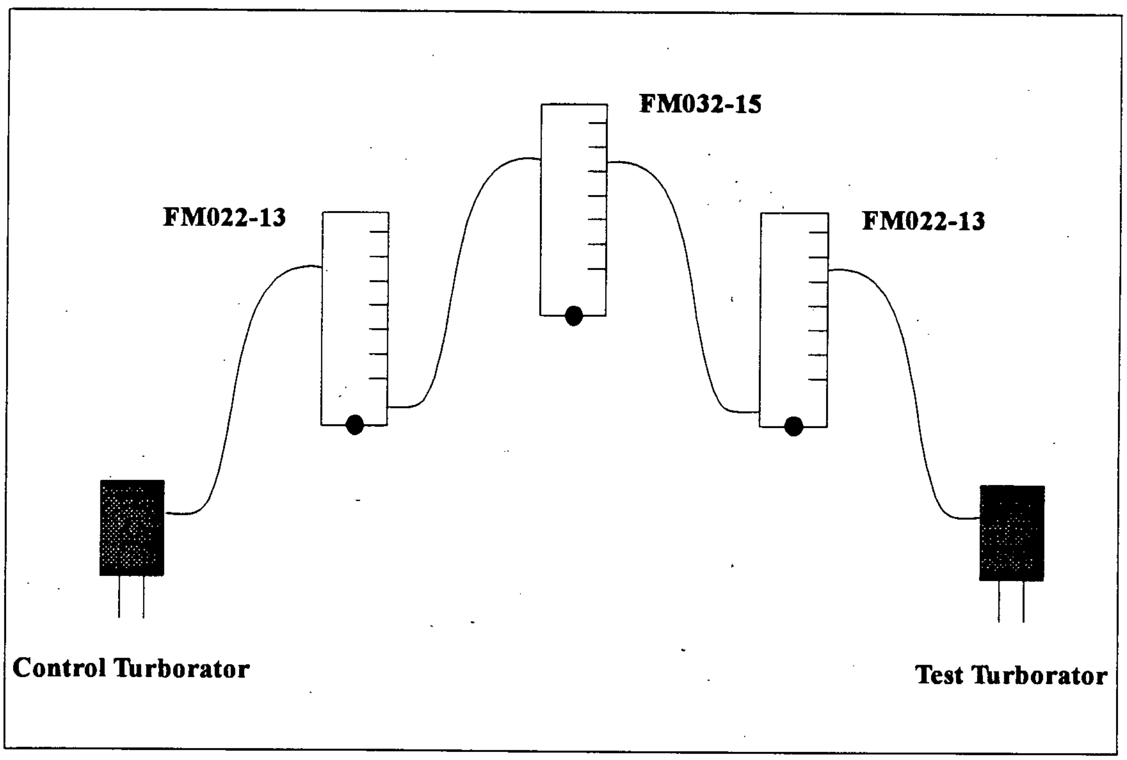
3.1.4 Mixing and Aeration

Mixing and aeration was supplied by an aspirating device, supplied and modified by Turborator Technology™ for the pilot plant system. Air is introduced through the hollow shaft of the device, and thoroughly mixed with contents of the reactor through a patented blade assembly. Turborator™ techonology is used in the ATAD facility in Salmon Arm, BC (Kelly et al., 1993).

The supply of compressed air to the device was controlled using both a regulator and air measuring devises. Air flow was metered at levels within the lower end of the 0 - 165 ml/min range shown to enhance VFA production in the ATAD reactors (Chu, 1995). During the first 4 runs, air was supplied equally to both reactors by splitting the flow after the meter. During Runs 5 & 6, two additional flow meters were installed on each of the split lines to more accurately measure flow to each reactor. To compensate for variability between the air flow devices, the meters were switched between the two reactors every 3 days. The set-up of air flow measuring devices in depicted in Figure 3.3.



(a) Runs 1 to 4



(b) Runs 5 & 6

FIGURE 3.3: Air Flow Meter Set-up

Exhaust gases were vented from the reactor. Initially, a 25 mm inside diameter hose had simply been connected to the outlet port on the reactor lid to vent off-gases out of the trailer. This system, which theoretically allowed outside air to enter the reactor headspace and thus supply additionally oxygen, was replace by 4 mm tygon tubing discharging through a water trap to the atmosphere.

3.2 Monitoring Variables

The following variables were monitored on-line or at regular intervals throughout the research period, as indicators of process performance and stability. Operating conditions were established to match EPA design requirements as closely as possible, as well as to correlate with previous research with the same system to facilitate comparison of results.

3.2.1 Temperature

The temperature of the reactor was maintained between 45°C and 55°C, typical for first stage reactors (Kelly, 1990; U.S. EPA, 1990). Heating of the reactors was provided by mixing, aeration and biological activity. Temperature was monitored on-line with a temperature probes connected to a data logger (Labtech Notebook/XE). Readings taken every 10 seconds were averaged every 5 minutes and plotted continuously on a dedicated monitor. Readings were verified with a thermometer on a bi-monthly basis.

3.2.2 Turborator™ Speed

Due to the surface area to volume ratio of pilot scale reactors, the heat balance is not the same as for full scale facilities; the mixing and aeration equipment provides a larger portion of the heat input as described in Section 2.3.3.1. For this reason, Turborator™ speeds were set to obtain the desired reactor temperature for the feed rate provided. As each Turborator™ has its own inherent efficiency (Boulanger, 1995), the mixers were controlled separately, although maintained within the same range.

Each Turborator™ was equipped with a high speed motor and speed controller. Maintenance required the Turborators™ to be stopped each day for cleaning. As the controllers were reset each time, speeds were measured and recorded every 12 hours to 24 hours with a tachometer.

3.2.3 ORP

Oxidation reduction potential (ORP) was not controlled, but monitored as an indicator of oxygen levels. ORP values of 0 to -300mV were considered positive indicators of an ATAD environment (Kelly et al., 1993), and consistency of a value during a run an indicator of stability and steady-state reactions. As with temperature, ORP was monitored on-line. Measurements were taken every 10 seconds and an average value was calculated, logged and plotted every 5 minutes.

Due to the high temperatures in the reactors, two probes were used in each reactor to ensure a higher degree of accuracy. Increases in the difference between the two probes also indicated the need for cleaning. ORP calibration tests were performed at the beginning of the experimental period, using Ag-Cl. Consequently, each reactor received one new probe.

3.2.4 Dissolved Oxygen

Dissolved oxygen levels were measured in the ATAD effluent immediately after wasting to provide a second parameter for assessment of the reactor environment, and again to facilitate comparison to previous research results. A YSI Model 54, DO Meter with model 5739 probe was immersed in the sample and allowed to stabilize for approximately 1 minute. The probe and meter were calibrated for each group of measurements.

3.2.5 Airflow

As detailed in Section 3.1.4, aeration was controlled with air flow measuring devices. For Runs 1 through 4 a single meter was used, Cole-Palmer FM032-15. For Runs 5 & 6 two meters were added, Cole-Palmer FM022-13. Due to the variability and sensitivity of the apparatus, flows were recorded every 12 hours to 24 hours and adjusted after shaft cleaning, as necessary.

Prior to Run 5, it was attempted to check the accuracy of the air flow meters, due to the discrepency in calibration information provided by Cole-Palmer. As illustrated in Figure 3.4, calibration rates for the same models varied by as much as 60 mL/min for different years. However, the low precision of the calibration tests did not allow for any better assessment and it was decided to use the more recent curves supplied by Cole-Palmer for evaluation of airflow rates. Since the airflow was split after the meter for Runs 1 - 4, even though the absolute flow rates can not be assured, the relative difference should be zero. On the other hand, flow rates from Runs 5 & 6 can not be accurately compared to previous runs; however, ORP was used to confirm aeration rates were similar.

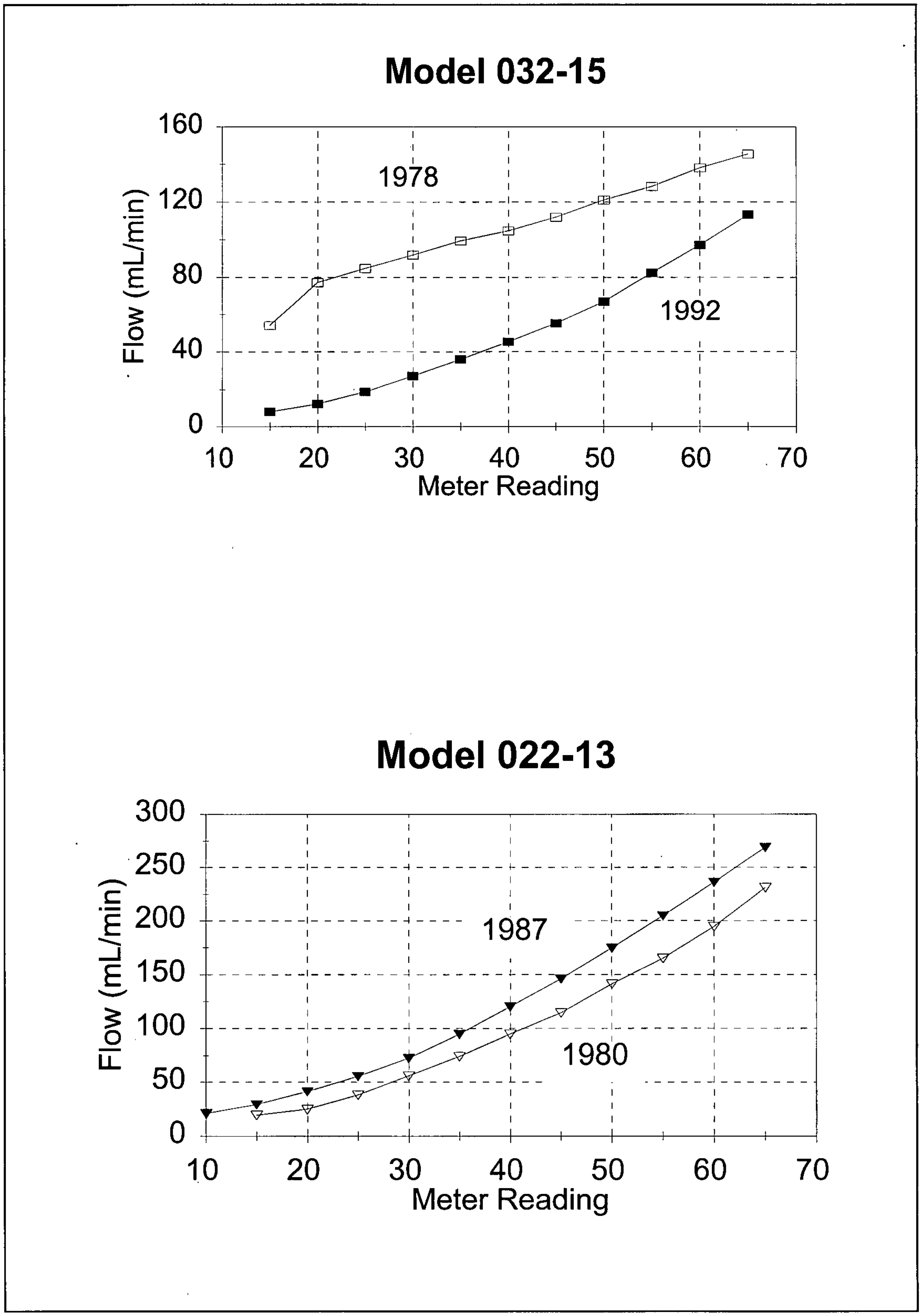


FIGURE 3.4: Air Flow Calibration Curves (adapted from Cole-Palmer, 1995)

3.2.6 Air Composition

Reactor headspace air composition was measure in Runs 4, 5 and 6, to assess whether anaerobic reactions were prevailing, as ORP levels potentially indicated as such. Using a flow through gas sampling vial, fitted with an adaptor for the exhaust gas outlet, a syringe was used to purge and fill the sample chamber. The tube was then sealed and removed from the port, and the exhaust venting system reconnected. The sampling vial is shown in Figure B5, photo (c).

The air samples were taken to the Environmental Engineering Laboratory for analysis within 2 hours of removal. A Fisher-Hamilton Gas Partitioner (model 29) with Spectra Physics Computing Integrator (model SP4290) was used to determine the % composition of oxygen, carbon dioxide, methane and nitrogen. An ambient air sample was taken in the trailer or in the laboratory for comparison.

3.2.7 pH

The pH of the feed and reactor contents was measured during test runs on samples removed from each feed tank and reactor. The pH meter utilized was a Fisher Scientific Accument pH Meter (model 25), calibrated daily with standard pH solutions of 4, 7 and 10, and a temperature probe. A magnetic stir bar was used to mix the sample during measurement.

3.2.8 Total Solids

Using between 60 and 75 mL of sample, total solids were determined daily by evaporating the measured volume of sample in a Fisher Isotemp (model 350) forced draft oven at 104°C. Analysis was performed as outlined in Standard Methods (A.P.H.A. et al., 1989). Since a consistent feed of 1 % TS was designed as an experimental control, drying times were restricted to around 23 hours to allow use of results for the preparation of sludge feed.

To assess solids destruction efficiencies of ATAD, both the feed and ATAD effluent streams were additionally sampled every 12 hours during experimental runs. Based on the semi-continuous operation and 3 day retention time of the reactors, TS destruction data was calculated by applying a 3 day moving average. Using the daily average TS measurements, destruction rates were calculated from the difference between ATAD output, and the average of the previous 3 days input. The level of stabilization acheived by the ATAD system was assessed based on destruction rates during experimental runs only. In between the 6 Runs, process feed was altered and reactors were acclimitizing; therefore, neither efficient operation, nor treatment, were expected. Examples of the calculations for total solids, feed metering and solids destruction are presented in Appendix J.

3.3 Experimental Variables

A 500 ml sample was removed from each of the sample streams for the following constituent analysis.

3.3.1 Volatile Fatty Acids

Samples for volatile fatty acids (VFA) analysis were prepared on-site. Sludge was centrifuged at high speed, approximately 12 000 rpm, for 10 minutes to separate solids that would interfer with the analytical instruments. The supernatant was then sampled with a dedicated dropper and transferred to 2 ml clear glass GC vials (HP model 5181-3375) containing the preservative, 2% phospheric acid. Vials were crimped capped (HP model 5181-1210) and frozen for the duration of each test period.

Each sample was prepared in triplicate.

VFA analysis was performed in the Environmental Engineering Laboratory. The vials were allowed to defrost at room temperature 24 hours before analysis. A Gas Chromatograph (HP model 5880a) with Automated Sampler (HP model 7672A) was used for sample injection and analysis. The column used and instrument settings are as specified in GC Bulletin 751G, Supelco Bulletin 751E:

oven temperature	120°C
injection port temperature	180°C
detector temperature	200°C
detector type	FID
carrier gas	helium
gas flow	20 mL/min
column length	4ft, 2 mm ID
column material	glass
column packing	60/80 Carbopack C/0.3% Carbowax®20M/0.1% H_3PO_4

Samples were analysed for acetic acid, propionic acid, iso-butyric acid and butyric acid, the 4 lower weight species of VFA. Previous research has indicated that these species predominate and additionally, acetate is the species of most interest for supplement to both Bio-P and anaerobic digestion (Atherton, 1995; Chu, 1995). Distilled water was analysed to test for contamination during preparation, and lab blanks were run to check instrument contamination.

During analysis of results, it was noted that samples that had been rerun the following day to double check anomalies, consistently registered lower concentrations of VFA. Two explanations are provided for this difference: either degradation of acids occurred once defrosted or volatilization of acids resulted with an increase in headspace in the vials, after some of the sample was removed for analysis. In addition, heat generated by normal GC operations would have heated the samples during analysis, enhancing both degradation and volatilization. Subsequently, no rerun data was used although trends were confirmed. Studies by Bomio et al. (1989) detail the fate of VFA in samples during preparation and storage, and reported lower VFA concentrations even at temperatures as low as -2°C. The period between sampling and analysis was kept consistent for all runs.

Analysis of samples also resulted in obvious carry over between samples, specifically when analyzed sequentially by date rather than by sample stream. Higher weight VFA have longer detention times in the GC apparatus than was provided in the analysis of only the 4 lower weight species. As a result, peaks of valeric and methyl butyric acid from the previous samples were detected and registered in the first sample of a triplicate that otherwise registered little or no presence of VFA. Analysis of samples was subsequently performed in order of increasing VFA concentrations. This problem could be further alleviated with blanks set between different sample sets and analysis of all VFA species.

3.3.2 Nitrogen and Phosphorus

Samples for ortho-phosphate (PO_4), nitrates (NO_x), and ammonia (NH_4) were also prepared on-site. Sludge was centrifuged, as described for VFA samples, and using Whatman No. 4 fitlered into plastic sample tubes. Samples requiring dilution for the analysis within the instrument's range, 0.05 to 20 mg/L, were diluted 1 in 10 using distilled water. Ortho-phosphate and nitrate samples were preserved with a drop of 2% methyl mecuric acetate, later diluted to 1% as column degradation was evident. Ammonia samples were acidified to pH <3 using sulphuric acid, H_2SO_4. Again, all samples were frozen for the duration of the test period and defrosted only for analysis in the Environmental Engineering Laboratory. For nutrients in particular, samples were defrosted under refrigeration to avoid rapid warming and potential volatilization of sample constituents.

Total phosphorus (TP) and Total Keidjal Nitrogen (TKN) samples required digestion before analysis and samples were frozen to be prepared in the lab. For soluble TP and TKN, sludge samples were additionally centrifuged, filtered and acidified to pH<2 using sulphuric acid before freezing, as described above. Upon defrosting, before an aliquot of sample was transferred to a digestion tube, soluble samples were tip mixed while the unaltered sludge samples were each blended for 1 minute using a Braun Hand Mixer® to ensure a representative sample was removed. Along with the samples, a blank, known test solutions and standards were prepared according to Standard Methods (A.P.H.A. et al., 1989). Boiling chips and 10 mL of digestion solution were added to all tubes in final preparation for digestion. Samples were digested for 7 hours, allowed to cool and then diluted to 75mL with distilled water for analysis.

Analysis of samples was performed in the Environmental Engineering Labortatory using a Quick Chem AE System Unit, Automated Ion Analyzer by Lachat Instruments, with XYZ Sampler. Calibration checks were performed every 20 samples, with >10% deviation being unacceptable for continuation without recalibration.

3.3.3 Total Organic Carbon

Total organic carbon (TOC) is an indicator of solubilization; as such it was assessed most specifically in Runs 5 & 6. Runs 1 to 4 were also sampled, but only on every other day.TOC samples were centrifuged and filtered, as described above, in preparation for analysis. For Runs 1 through 4, preparations were carried out in the lab on defrosted, blended samples. For Runs 5 & 6, samples were prepared and frozen on-site, then defrosted and tip mixed in the lab prior to analysis. A Shimdzu Total Organic Carbon Analyzer (TOC-500) with ASI-502 Automatic Sample Injector was used for analysis.

3.4 Sampling Points

The samples for the experimental parameters and total solids were taken from 6 sampling points in the process:

3 - mixed liquor (unsettled secondary sludge)
4 - Control feed
5 - Test feed
6 - secondary sludge
7 - Control ATAD effluent
8 - Test ATAD effluent

Mixed liquor was sampled directly from the process during wasting, sample 3A from A-side and sample 3B from B-side. Feed sludge samples were removed from the feed tanks from a valve located on the tank wall approximately 2 cm from the bottom. Feed tank contents were continually stirred and the valve was flushed with material before a sample was taken. During Runs 1 through 4, control feed samples also represented primary sludge; only during Run 6 was a separate sample taken from the transfer line to the feed tanks. Similarly, secondary sludge samples were represented by the test feed in Run 6, and control feed in Run 5 and were otherwise removed from the transfer line to the feed tanks. ATAD samples were taken from the volume pumped into the wasting bucket. Mixing of the ATAD reactor contents continued during wasting; however, mixer speeds were reduce to 250 rpm. Sampling points are indicated by numbers in the process flow diagrams pesented earlier in Figures 3.1 and 3.2.

The 4 principle streams that were sampled every 12 hours during experimental runs are in bold face. Comparison between corresponding feed and ATAD samples will illustrate the effect of TAD treatment on a given feed stream, while comparisons between test and control samples should demonstrate the effects of secondary sludge addition and pre-solubilization of feed. Samples of the mixed liquor will provide an indication of wastewater treatment variability and, in comparison to the resulting "secondary sludge", effects of dewatering, thickening and storage should be evident.

3.5 Interpretation of Results

Since a control reactor was maintained through all runs, the inherent variability of sewage sludge can be eliminated; the effect of the test variable can be evaluated from the difference between the test and control reactors (T - C). Relationships and trends are then based on the difference between the (T-C) values for each run. Differences between the control and test reactor in Run 1, when feed streams are both 100% primary sludge, should be minimal, although the reactors have demonstrated inherent differences in previous research (Boulanger, 1995; Chu, 1995).

Comparisons are made based on the average, minimum, maximum, median, and standard deviation values calculated for each set of data. For VFA samples, triplicate data was averaged first before statistical analysis, and total VFA values are simply the sum of these average values for each of the 4 species measured. The paired t-test for sample means was used to establish if differences were statistically significant. Formulas for the calculations performed by Quattro Pro 4.0 for Windows are given in Appendix J.

Analytical results below instrument detection limits are labelled or highlighted in appendix tables, and detection limits are given. Negative values and "not detected" values are taken as zero. For statistical calculations and comparisons, if a number is given in the data tables it has been used in calculations, blank cells were ignored. This potentially results in values that are biased low.

4.0 RESULTS AND DISCUSSION

4.1 Experimental Set-up

Experimental runs were scheduled to be 6 days, with a minimum of 6 days acclimatization also, to provide 2 full retention time cycles in each case. Due to equipment repair and maintenance, to reduce the potential for process upsets during experimental runs, the acclimatization period was usually longer. The following table outlines the actual timing of the 6 runs.

TABLE 4.1: EXPERIMENTAL TIMETABLE

Run	Dates	Test	Control
1	September 11 - September 16	100/0	100/0
2	September 27 - October 2	65/35	100/0
3	October 12 - October 17	35/65	100/0
4	October 27 - November 1	0/100	100/0
5	November 20 - November 26	0/100 pre-solubilized	0/100
6	December 2 - December 7	35/65 pre-solubilized	35/65

Some of the delays encountered, included clogging and failure of the control feed pump (due to the consistency of primary sludge) and power failures, which shut down all processes and computers at the pilot plant. As the plant was visited at least once every 12 to 24 hours, repairs were done immediately resulting in minimal upset to the ATAD process. Similarly, as all equipment self-started with the return of power, the processes were able to recover immediately. At the same time, the data logger also self-started so the time and duration of these events, their effect on ATAD and recovery of the process were all recorded. The longest power outage was 8 hours long, occurring on the last day of Run 5, and resulted in run 5 being extended a extra half day. Other than this event, no major process upsets occurred during the 6 experimental runs.

4.2 Operating Conditions

The following parameters were measured to control and monitor the consistency of the feed stream and the ATAD process. Variations between test runs was expected due to the variation in feed characteristics with the introduction of secondary sludge and pre-solubilization. Variations between control runs, 1 to 4, was hoped to be minimal but inherent variability in sewage composition can not be eliminated. Similarly, variations between the reactors in Run 1, when feed streams were both 100% primary sludge, should also be minimal.

Tables summarizing the results are provided in Appendix C. For each of the 6 runs, data is provided as measured every 12 hours during the 6 days of testing. The average, range and standard deviation is calculated for each set of data for each run. Values will be highlighted in the following sub-sections.

4.2.1 Source Sludge

To provide an indication of the quality of sludge that was used for the experiments, settled primary and secondary sludge were sampled during all experimental runs as the feed tanks were being fed. In addition, unsettled mixed liquor (secondary sludge prior to decanting and thickening) was also sampled from the process at the time of wasting. As two separate process trains supplied mixed liquor for digestion, each was sampled separately before combined in thickener. Table 4.2 provides the overall mean, and range of the various parameters analyzed. The variability of sewage sludge is evident.

TABLE 4.2: CHARACTERISTICS OF SOURCE SLUDGE

Parameter	Primary Sludge		Mixed Liquor		Secondary Sludge	
	avg	range	avg	range	avg	range
TP (mg-P/L)	40	22 - 57	129 A 93 B	93 - 175 A 49 - 131 B	299	235 - 484
PO4 (mg-P/L)	4.6	3.0 - 8.2	0.06 A 0.05 B	0.01 - 0.15 A 0.03 - 0.08 B	111	55 - 136
NH4 (mg-N/L)	24	16 - 34	0.08 A 7.40 B	0.01 - 0.27 A 0.04 - 13.05 B	26.5	7.3 - 37.1
TS (g/L)	11.5	1.3 - 18.9	4.2 A 3.5 B	0.8 - 5.8 A 1.9 - 5.0 B	11.6	1.3 - 18.9
Total VFA (mg/L)	198	62 - 291	4 A 1 B	0 - 12 A 0 - 3 B	48.3	1 - 97

Note: A and B denote the two separate process trains supplying mixed liquor

This summary, with its large range of concentrations, presents an unstable picture of operations. On the other hand, as illustrated in Figures 4.1 to 4.4, this variability is largely between runs; consistency during each run was generally high (see Appendices C, E & G). Variability was introduced, however, when mixed liquor was introduced from side B of the wastewater treatment process. Specifically, ammonia levels were noticeably different between A and B mixed liquor samples when B-side was initially brought on-line. Fortunately, no significant impact was recorded in resulting secondary sludge. Ortho-phosphate shows the same trend, but as values were at or below detection limit, no conclusions can be drawn. On the other hand, the decrease in ortho-phosphate and ammonia concentrations in the secondary sludge in Run 5 was the result of the reduced retention time in the thickener, a consequence of the increased demand for secondary sludge as the mix ratio increased. Although secondary sludge was wasted from the thickener in addition to the volume used for feeding to try to stabilize sludge age, Run 5 was the peak of demand and the effects of this were evident: mixed liquor was visibly thinner, indicating process capacity was being exceeded.

Similarly, the reduced retention time also reduced VFA concentrations, dropping from >90 mg/L to <10 mg/L between Runs 3 and 4. Conversely, the decrease in VFA in primary sludge is mostly likely a reflection of decreasing seasonal temperatures and consequently reduced activity in the sewage collection system. This trend has been noted at the pilot plant during other research and generally in northern climates (Atherton, 1995).

The graphs also illustrate the effect of decanting and thickening of the mixed liquor. As phosphorus is initially tied up in the biomass of the mixed liquor, decanting of supernatant concentrates the residual, resulting in total phosphorus concentrations in the secondary sludge which are more than the sum of the contributions from the mixed liquor from A and B side. Retention in the thickener additionally results in the release of some of this stored phosphorus, indicated by the high levels of ortho-phosphate in secondary sludge. The apparent decreased release in Run 5 corresponds to a reduction in retention time in the thickener at peak demand. Similarly, the subsequent increased release in Run 6 is a consequence of an increase in retention time due to a decrease in demand.

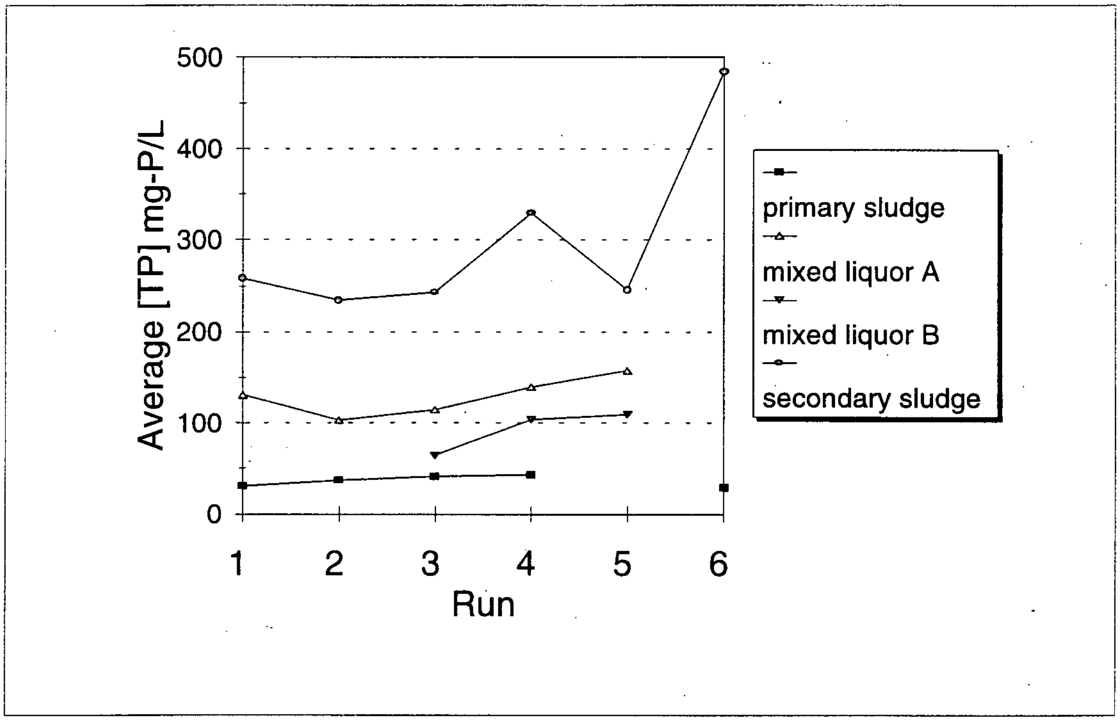


FIGURE 4.1: Source Sludge TP

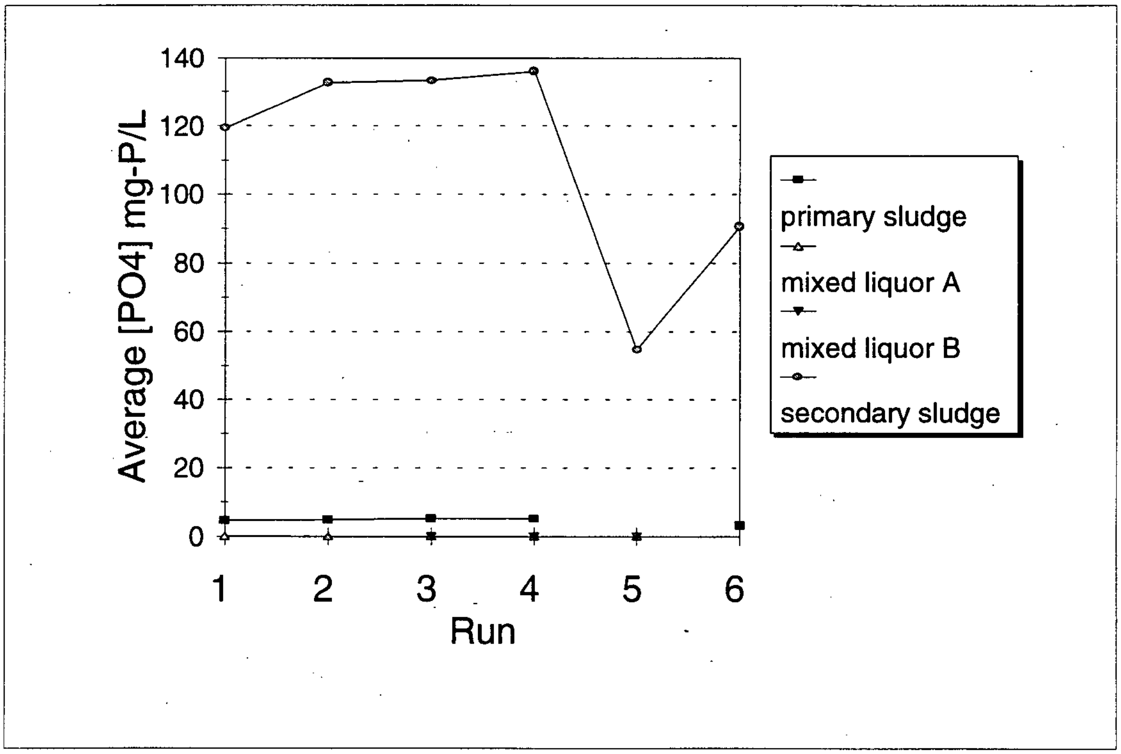


FIGURE 4.2: Source Sludge PO_4

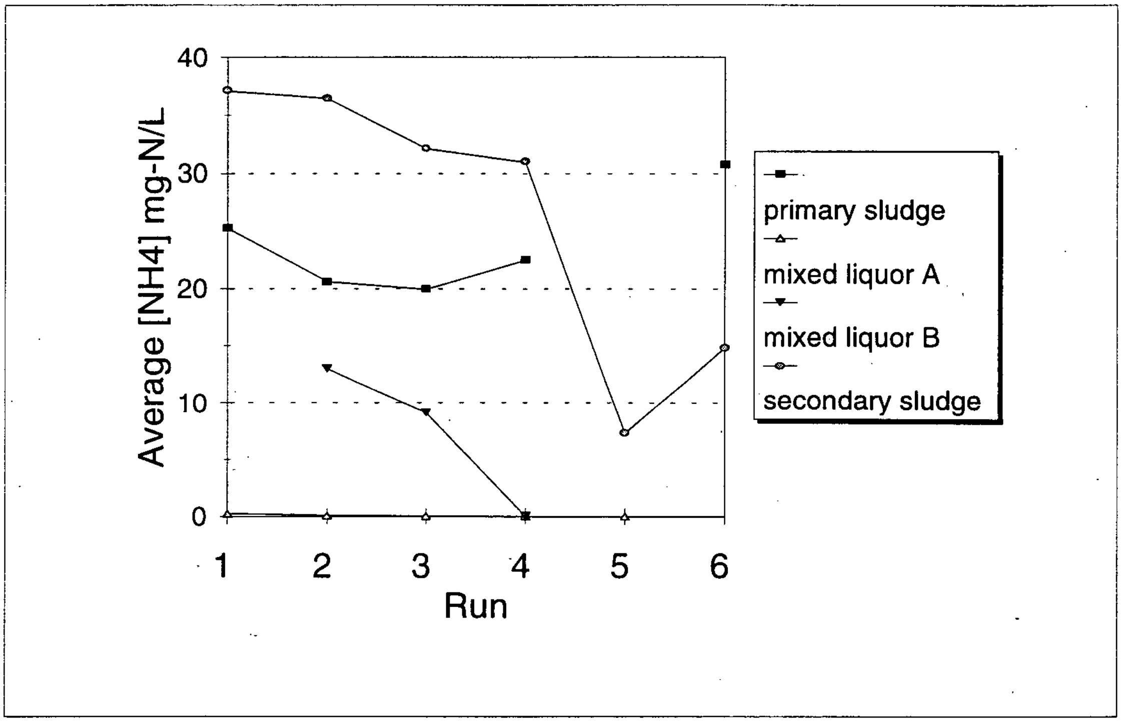


FIGURE 4.3: Source Sludge NH_4

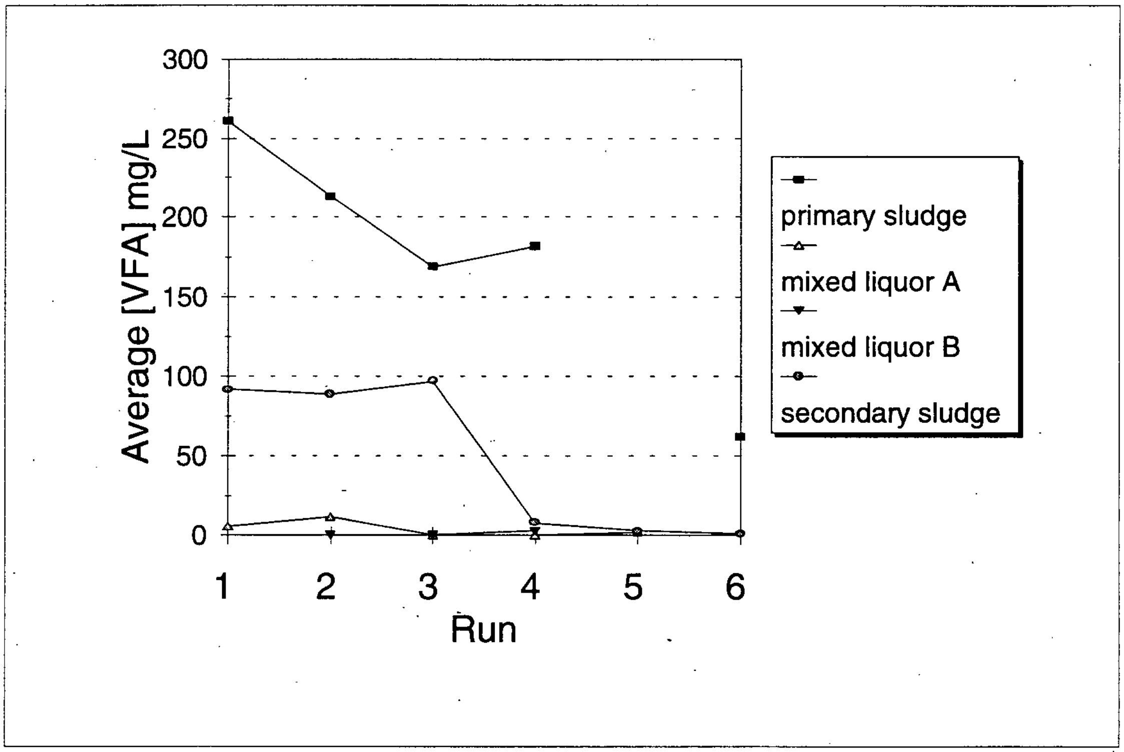


FIGURE 4.4: Source Sludge VFA

4.2.2 Temperature

The temperature of the ATAD reactors was maintained between 40°C and 52°C during all runs. Figures 4.5 to 4.10 illustrate the recorded on-line temperature of each reactor. The control reactor was always warmer than the test reactor, even during Run 1 when the feed was 100% primary sludge for both. Although this difference was found to be statistically significant, no correction factors have been applied in subsequent runs as neither mixer speed or aeration rates were consistent between runs and both parameters influence ATAD temperatures. In addition, the resulting VFA concentrations were higher in the test reactor, opposite to the predicted influence of temperature on VFA production and accumulation. Correction of the data would result in even greater differences between the test and control reactor with respect to VFA production.

All runs demonstrated an oscillating pattern through 24 hours, paralleling the rise in temperature during the day, and a decrease at night, indicating less than perfect insulation of the tanks. This same pattern was observed by Chu (1995). This pattern is less evident in later runs (Runs 5 & 6) as trailer heating was turned on for the winter. The sudden drop in the temperature profile in Run 5 is the result of a 8 hour power failure and a collapsed hole in the data.

From the continuously logged data the average temperature from midnight to noon, and noon to midnight was calculated and listed in the tables in Appendix C, although the statistical calculations were performed on the entire data set. Table 4.3 summarizes these values for each run for the ATAD reactors.

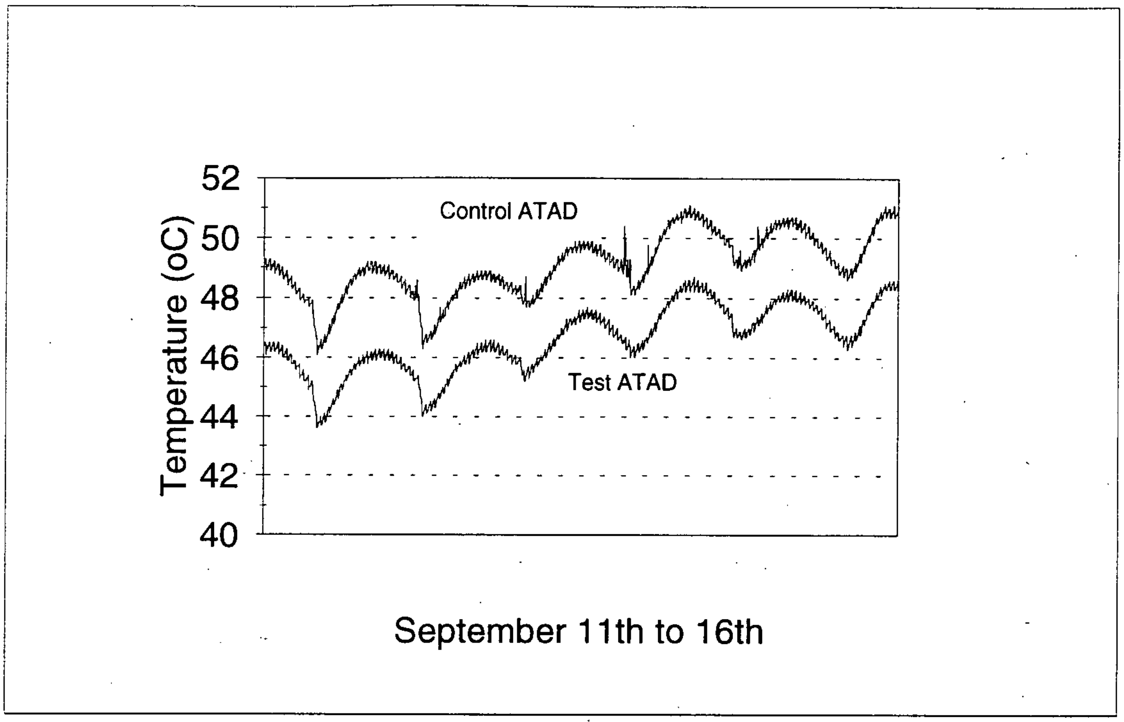


FIGURE 4.5: ATAD Temperature Profile, Run 1

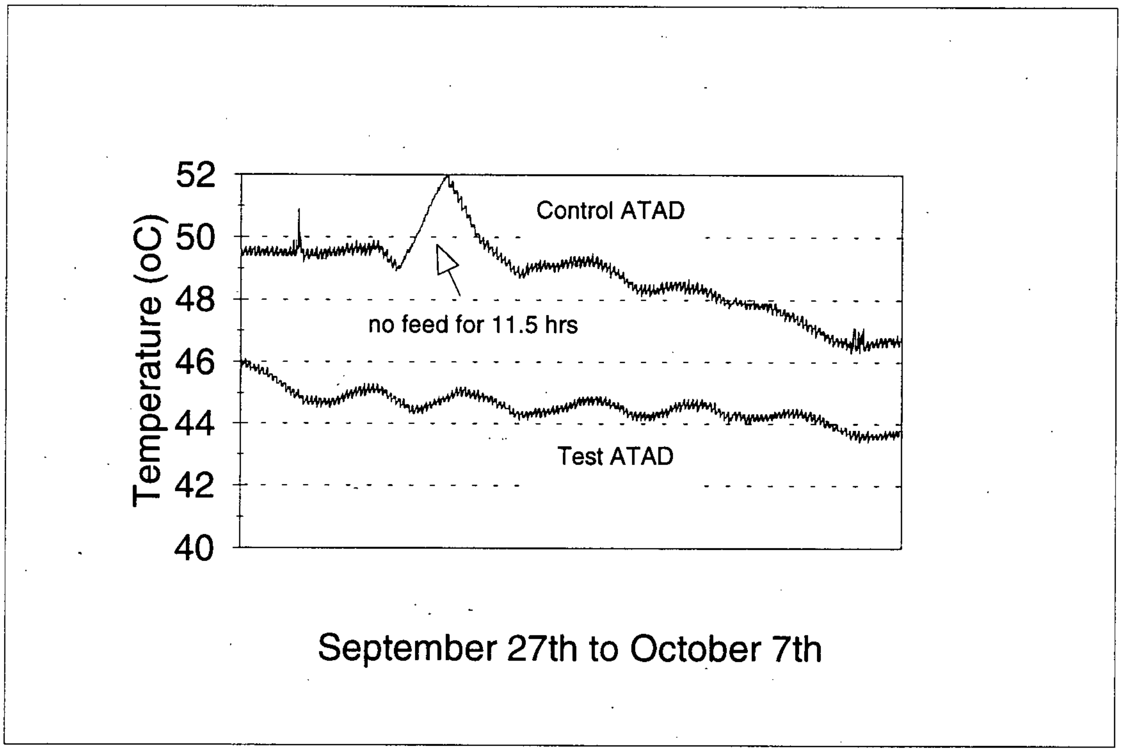


FIGURE 4.6: ATAD Temperature Profile, Run 2

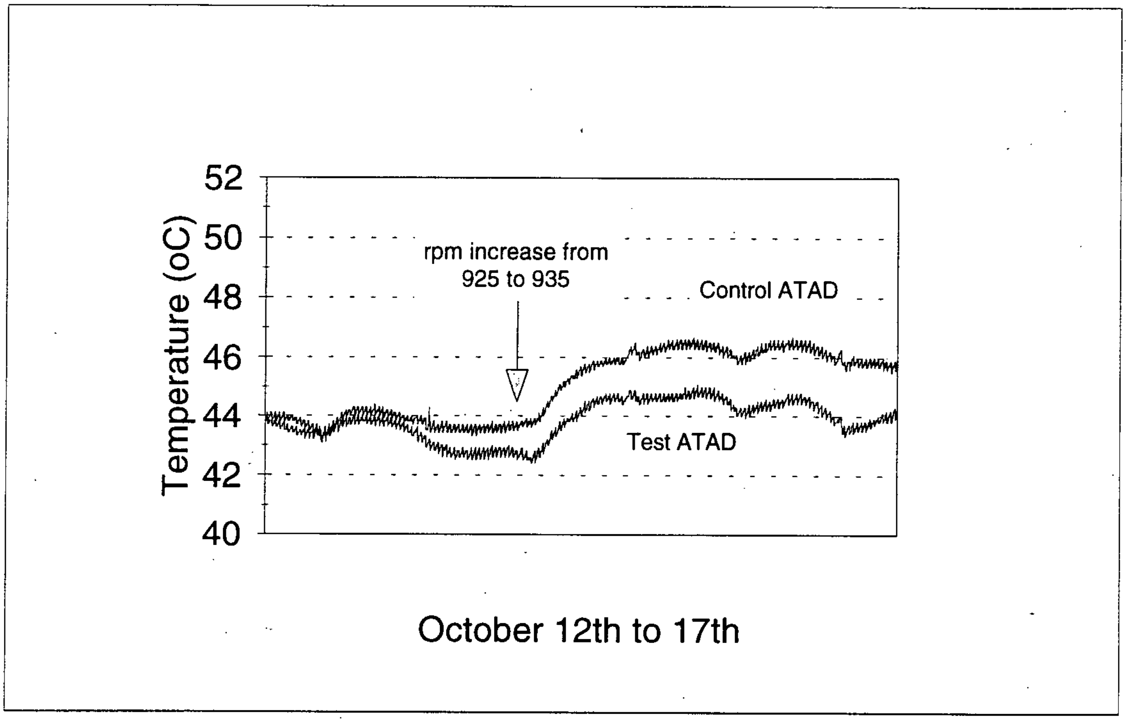


FIGURE 4.7: ATAD Temperature Profile, Run 3

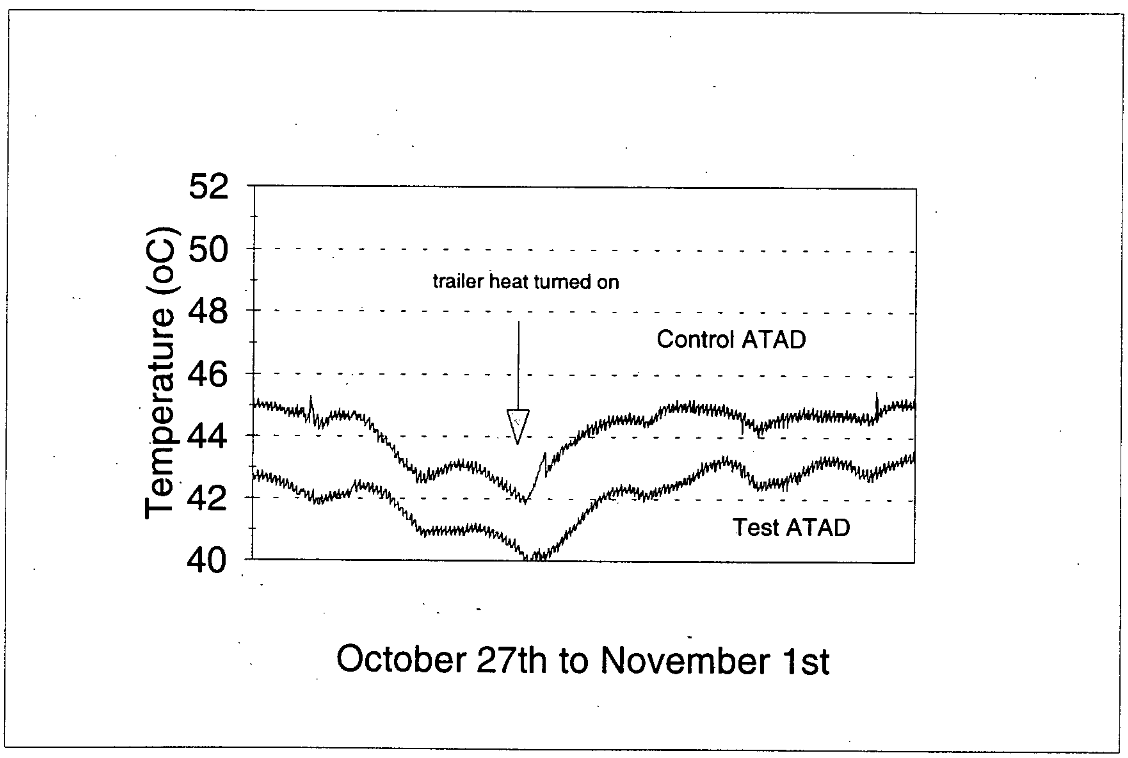


FIGURE 4.8: ATAD Temperature Profile, Run 4

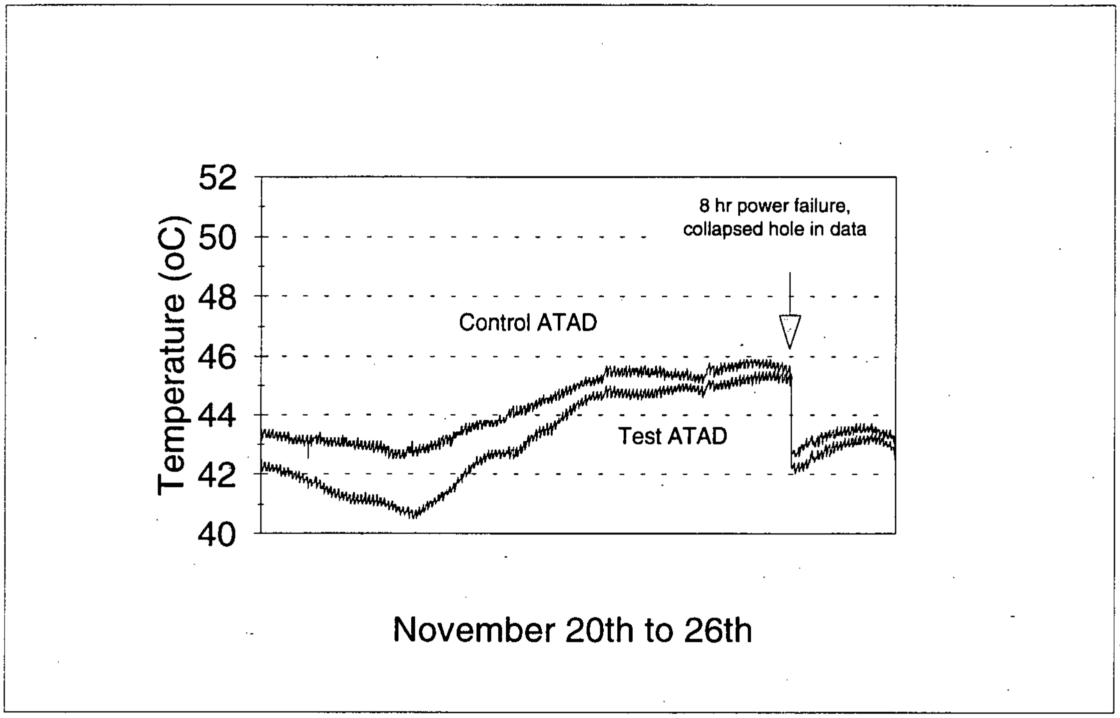


FIGURE 4.9: ATAD Temperature Profile, Run 5

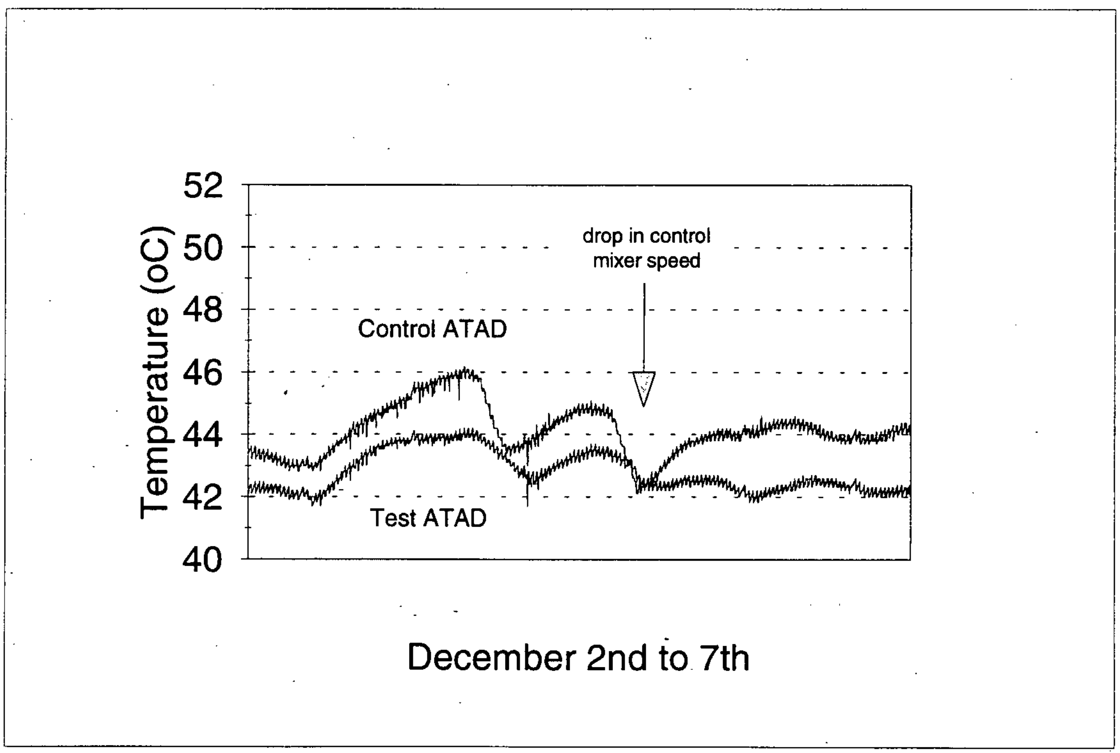


FIGURE 4.10: ATAD Temperature Profile, Run 6

TABLE 4.3: AVERAGE ATAD TEMPERATURE

Run	Date	Control	Test
1	09/11 - 09/16	49.1°C	46.6°C
2	09/27 - 10/02	48.8°C	44.5°C
3	10/12 - 10/17	45.0°C	43.9°C
4	10/27 - 11/01	44.2°C	42.1°C
5	11/20 - 11/26	44.1°C	43.1°C
6	12/02 - 12/07	44.1°C	42.8°C

Although the temperature did decrease from Run 1 through 4, paralleling the increased addition of secondary sludge, the decrease can not be attributed solely to this variable. Other pilot scale studies have shown that lower temperatures are attained with secondary sludge versus a mixture of primary and secondary (Trim & McGlashan, 1984); however, it is the difference between the test and control reactor which must be assessed, and it is inconsistent.. As discussed above, poor insulation resulted in temperature fluctuations, and the decrease in temperature from September to November can equally be attributed to overall temperature decreases associated with autumn. This is confirmed by the parallelled decrease in the control reactor's temperature, and the subsequent temperature increase in both reactors after October 29th when trailer heat was turned on.

Although only recorded in Runs 5 & 6, the temperature of the feed sludge was measured during pH measurements. During these runs, temperatures ranged between 13°C and 16°C. However, pre-solubilization resulted in immediate temperature increases in the test feed streams of as much as 0.7°C (test feed - control feed). Feed sludge temperatures remained elevated during feeding, and were further increased 12 hours after addition of NaOH in most cases. Temperature changes were more pronounced in Run 5 with 100% secondary sludge feed; the maximum recorded difference between control and test feed was 1.2°C. During both runs, the trailer was being heated, although not to room temperature.

The contribution of the mixing and aeration unit to heat generation is obvious from the temperature drop in Run 5, when an electrical outage occurred. Although it can be argued that because no air was being supplied to the reactor during this same period, that aerobic oxidation of substrate was also inhibited (and thus biological contribution to heat energy was also eliminated), in this case, the scale of the system favors mechanical energy as the predominant contributor of heat energy as presented in the literature review and illustrated in the next section.

4.2.3 Turborator™ Speed

Turborator™ speeds were maintained fairly consistent between reactors throughout the entire research period. Both the control and test reactor recorded a median of 934 rpm. Speed setting were established at 925 rpm, and increased to 935 rpm on October 14th. The average daily speed, calculated from 2 to 3 readings taken over each 24 hour period, is plotted in Figure 4.11. The variability of the apparatus is evident.

The two lowest readings were the result of increased resistance on the Turborator™ shaft. Constant vibration of the frame, upon which the Turborators™ are mounted, results in slight movement of the ATAD reactors and misalignment of the Turborator™ shaft with the opening in the reactor lid. The reading of >950 rpm were the result of resetting speed controllers too high after having being stopped for daily cleaning. Turborator™ speeds were allowed a minimum of half an hour to stabilize before a reading was recorded; this was obviously not always sufficient.

In support of the discussion of the predominance of mechanical energy at pilot scale to reactor temperature, the increase in Turborator™ speeds on October 14th is clearly registered as a temperature increase in Run 3 (see Figure 4.7). Similarly, one of the two periods of low speed occurred on December 5th in the control reactor and is registered as a temperature decrease unmatched by the test reactor in Run 6 (see Figure 4.10). The temperature decrease on December 4th in Run 6, paralleled more closely by the test reactor appears to have been caused by another variable. As Turborator™ speeds were averaged for a 24 hour period, not all fluctuations are recorded.

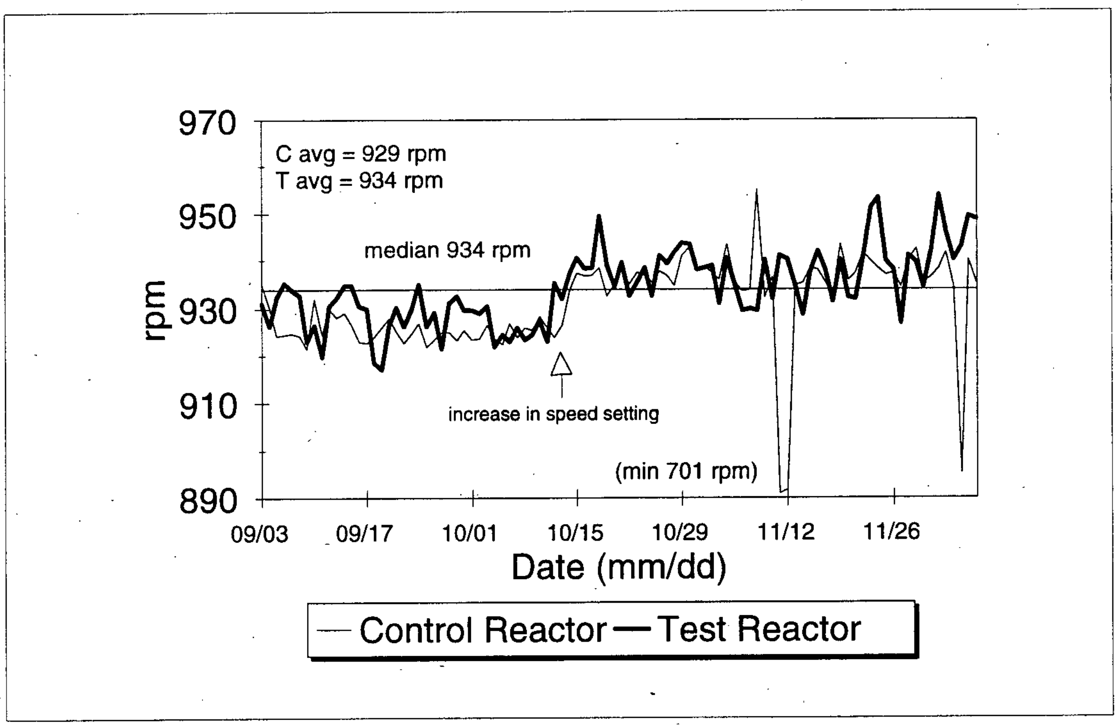


FIGURE 4.11: Turborator™ Speed

4.2.4 ORP

The redox potential of the ATAD reactors was also monitored on-line. The readings from the two probes per reactor were averaged and plotted for each of the 6 runs in Figures 4.12 to 4.17. Except for Run 5, where the ORP was very unstable in the test reactor, ORP was consistent during experimental runs. Values range between -200 mV and -500 mV, with the test reactor always being more negative. Based on traditional definitions this would indicate an anaerobic environment within the ATAD reactors; however, as supported by other monitoring variables and the fact that air is constantly being supplied, these values simply indicate a more reduced environment. Chu (1995) also recorded low ORP values in his ATAD studies at UBC.

As was done for temperature data, ORP was averaged over 12 hour periods for the data tables in Appendix C, while the statistical calculations were performed on the complete data set. Table 4.4 provides a summary of run averages. Run 5 is highlighted, as the sample average does not reflect the oscillating pattern of the data. Values are within the range of full scale facilities and other pilot scale studies (see Section 2.3.3.2)

The increased addition of secondary sludge had a definite impact on ORP values; ORP became more negative with higher proportions of secondary sludge. Figure 4.18 illustrates the reationship. As ORP is most strongly effected by oxygen levels, the secondary sludge can be assumed to be exerting a higher demand than primary sludge. At the same time, the more reduced state of secondary sludge could lower the ORP of the system. Chu (1995) observed ORP to be more sensitive to substrate addition within each run, than to changes in aeration between 0 - 165 ml/min

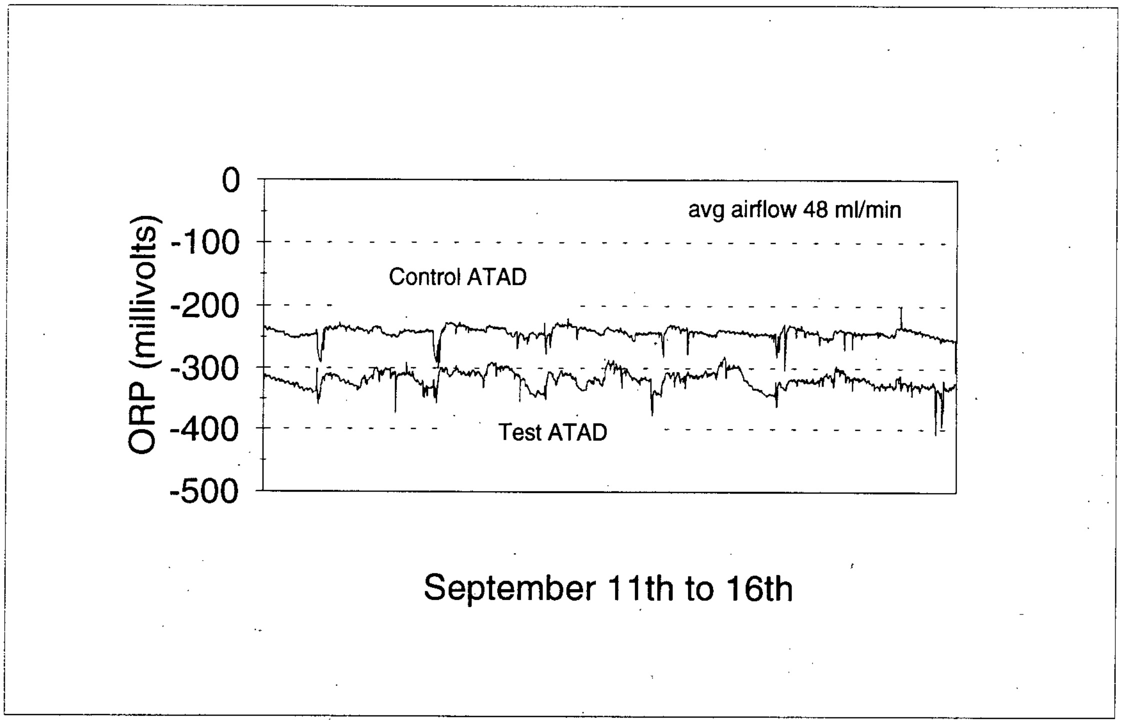


FIGURE 4.12: ATAD ORP Profile, Run 1

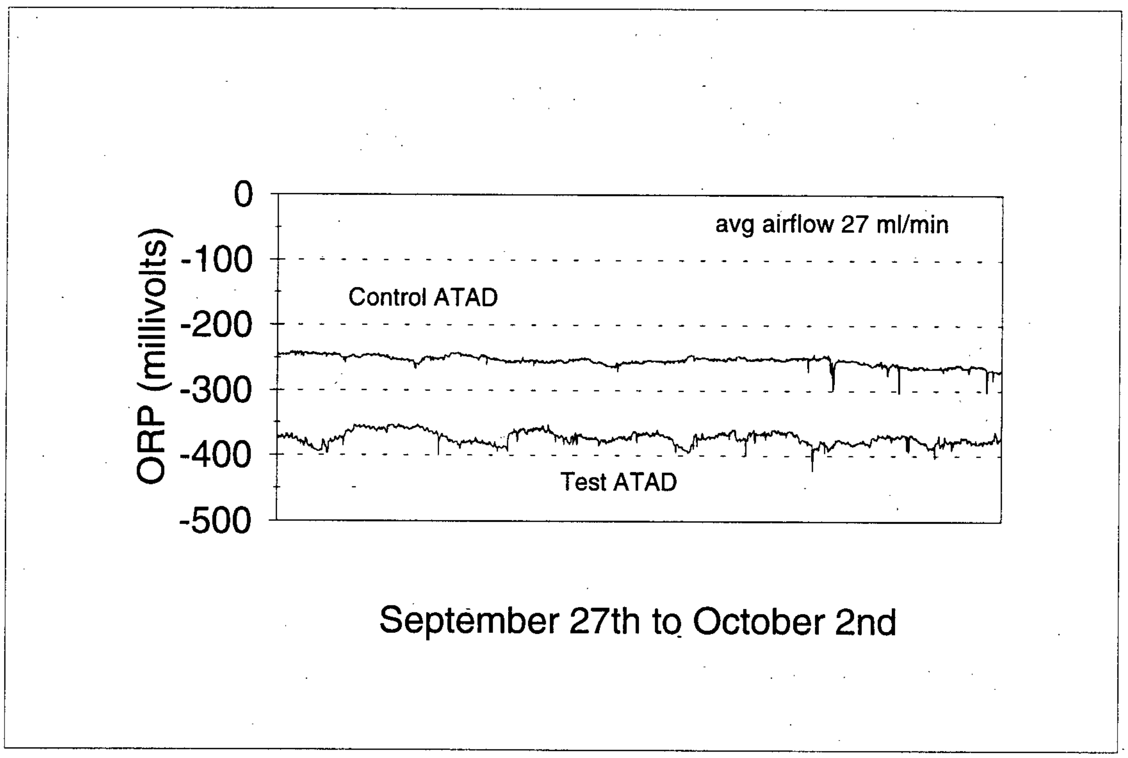


FIGURE 4.13: ATAD ORP Profile, Run 2

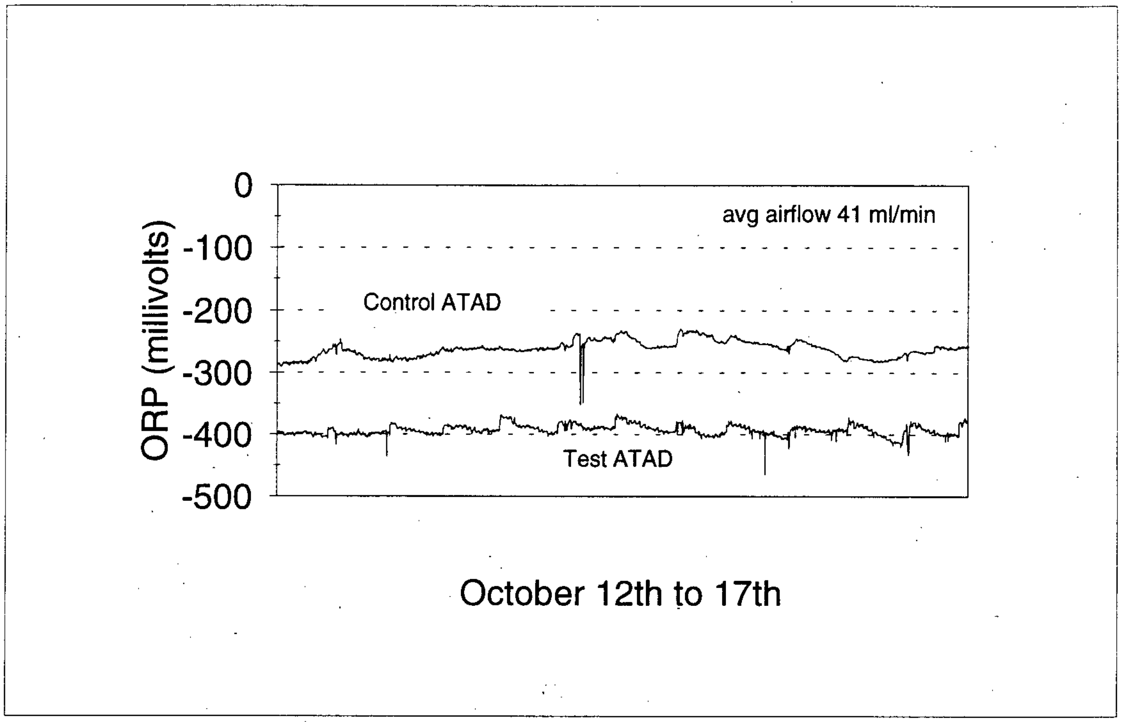


FIGURE 4.14: ATAD ORP Profile, Run 3

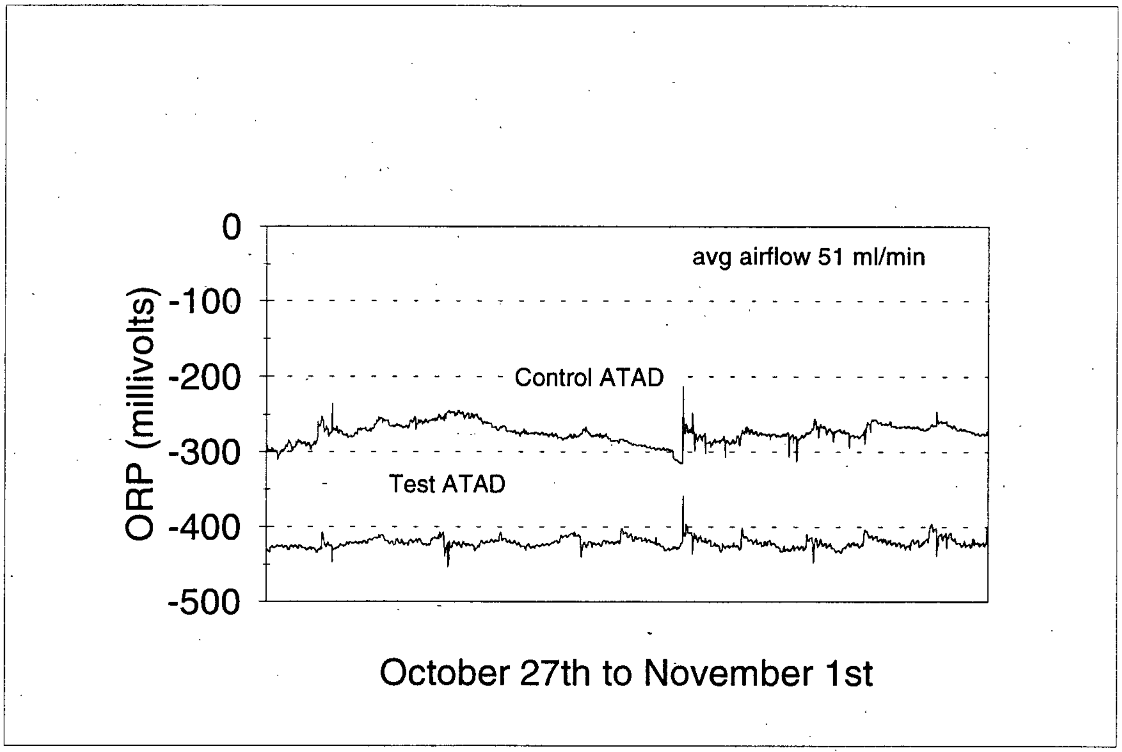


FIGURE 4.15: ATAD ORP Profile, Run 4

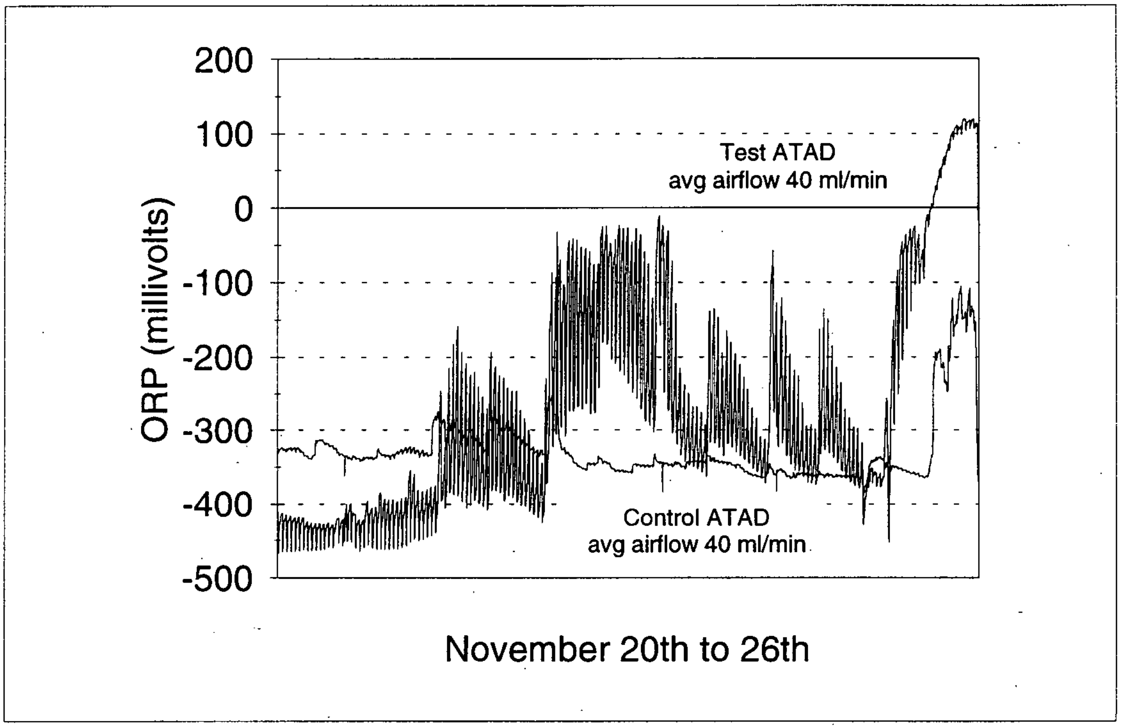


FIGURE 4.16: ATAD ORP Profile, Run 5

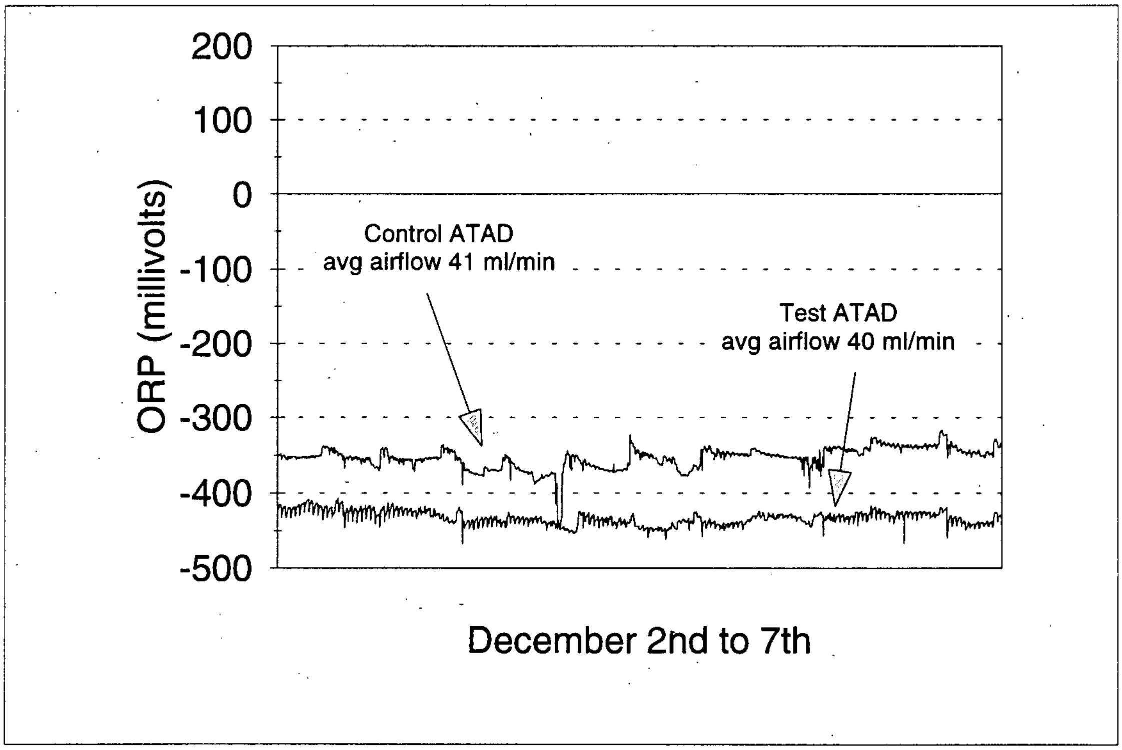


FIGURE 4.17: ATAD ORP Profile, Run 6

TABLE 4.4: AVERAGED ATAD ORP

Run	Test Sludge Ratio (primary/secondary)	Control (mV) avg	Control (mV) std dev	Test (mV) avg	Test (mV) std dev	Difference
1	100/0	-243	9	-319	14	76
2	65/35	-255	7	-374	9	119
3	35/65	-262	14	-393	9	131
4	0/100	-275	3	-421	7	146
5	0/100 solubilized	-327	48	-269	152	58
6	35/65 solubilized	-354	15	-433	9	79

On-line ORP monitoring was also done by Chu (1995) in his ATAD studies with primary sludge. A characteristic shark-tooth pattern was noticed to coincide with substrate addition to the reactors; at each hourly feeding, an abrupt decrease in ORP was registered, followed by a gradual recovery over the hour in between. Figure 4.19 illustrates the pattern. This same pattern is illustrated in all runs, although not consistently throughout and less pronounced with the scale used in the figures. The test reactor traces in Run 5 and 6 provide the most obvious examples. McIntosh & Oleszkiewicz (1996) also recorded this pattern with 3 hour feedings, values dropping to -225 mV and recovery to -10 mV. These responses indicate the utility of ORP for monitoring substrate addition.

The extreme oscillations in ORP values in the Test reactor in Run 5 may also be a result of process changes that occurred prior to the test period. In order to provide enough secondary sludge during the last two runs, feeding was stopped for a period of 10 days, to allow reserves to build-up. Thus, the retention time of the material in the reactor was significantly increased. It has been demonstrated that an increase in retention time increases oxygen demand and, as nitrification is inhibited at elevated

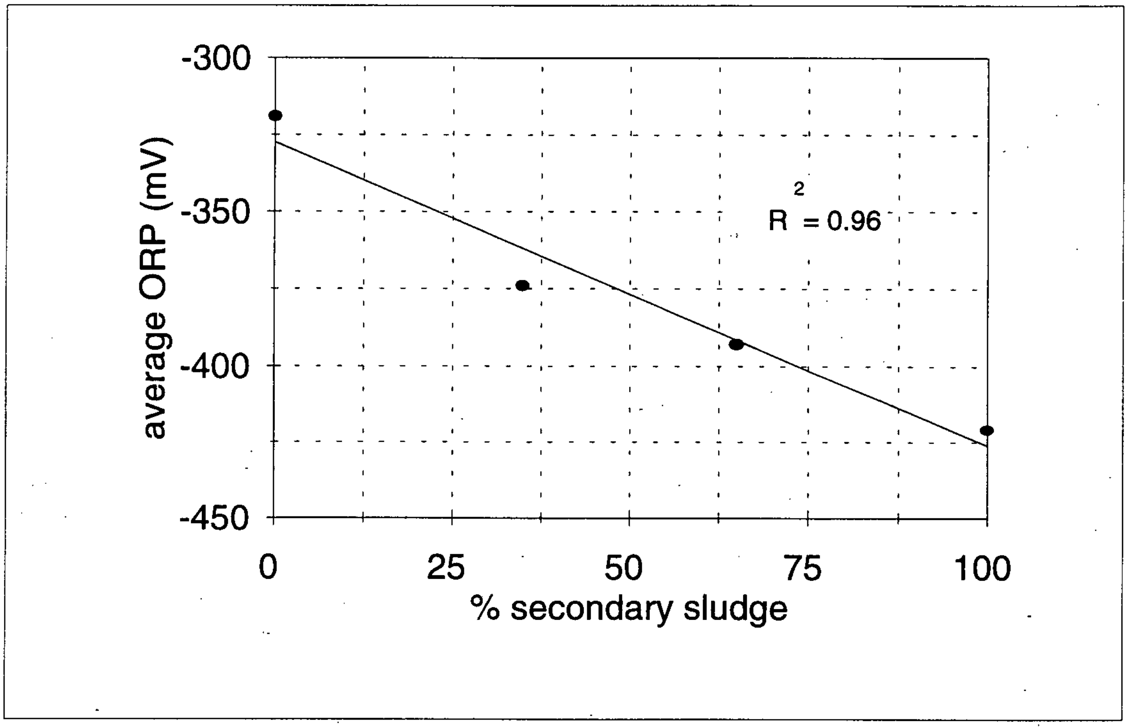


FIGURE 4.18: Effect of Increased Additions of Secondary Sludge on ORP

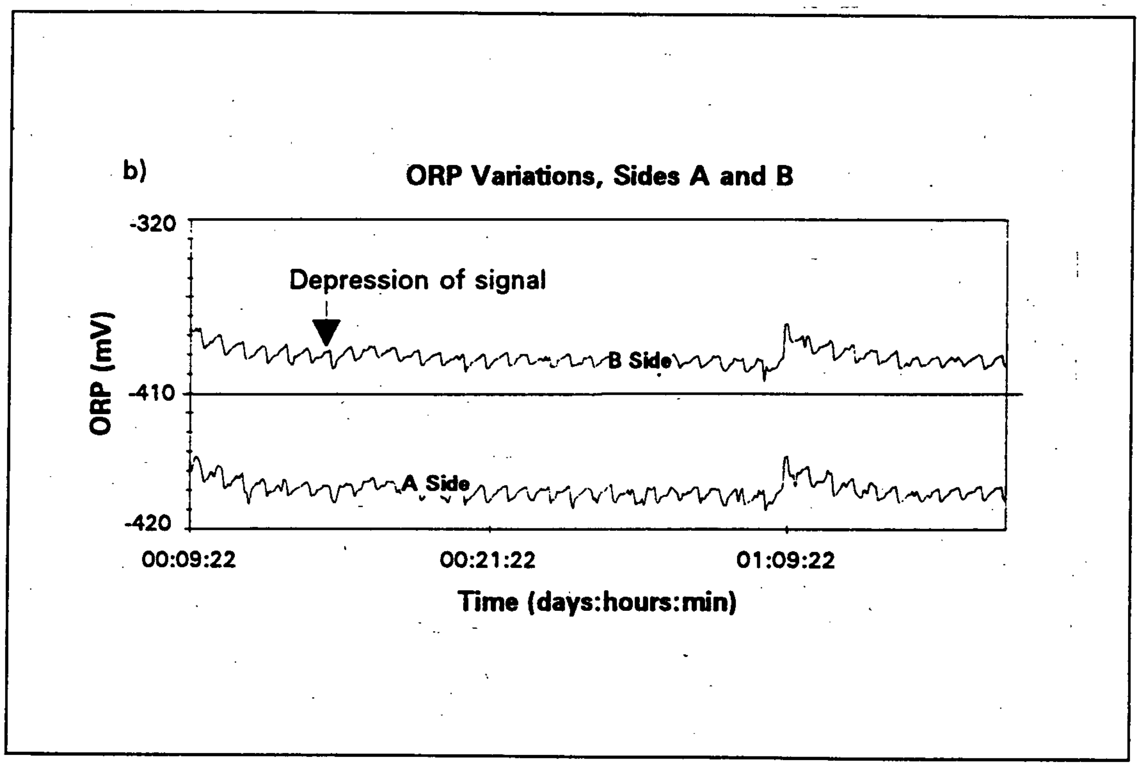


FIGURE 4.19: Shark Tooth Pattern of ORP in Response to Substrate Addition in ATAD

temperatures in TAD, the increased demand is assumed to be the result of increased endogenous respiration (Sucuru et al, 1986). Although the reactors were given 6 days to recover and acclimatize, the additional demand of pre-solubilized feed may not have allowed the test reactor to fully recover. The control reactor was fairly stable, although fluctuations were also recorded. By Run 6, both reactors appear to have stabilized.

4.2.5 Dissolved Oxygen

Dissolved oxygen (DO) levels were below 1 mg/L in all runs. This corresponds to the "oxygen deprived" classification defined by Boulanger (1995). As the accuracy of readings below 1 mg/L are assumed inaccurate, the results will simply be taken as indicating that an oxygen limited state was established in the reactors, and an anaerobic environment was avoided.

4.2.6 Airflow

Air flow rates calculated for the meter readings recorded throughout the process period are presented in Appendix D, along with calculated average, range and standard deviation. As these averages include a period of airflow adjustment where air flow was 800 ml/min, airflow rates were additionally averaged for each run for discussion. Run averages are given in Table 4.21, daily readings for each run are summarized in Appendix C. Since airflow was split after the meter for Runs 1 through 4, the flow rates per reactor are simply half of the total recorded flow.

Due to the discrepancy in calibration curves, highlighted in Section 3.2.5, values can not be accurately compared between Runs 1 to 4, and Runs 5 & 6. Relative comparisons to other variables in this study can be made within these two groupings. Similarly, any established trends can be compared with trends from other research. No comparison of absolute values is possible.

TABLE 4.5: AVERAGE AIRFLOWS

Run	Date	Control (ml/min)	Test (ml/min)
1	09/11 - 09/16	48	48
12	09/27 - 10/02	27	27
3	10/12 - 10/17	41	41
4	10/27 - 11/01	51	51
5	11/20 - 11/26	40	40
6	12/02 - 12/07	41	40

As an indicator that airflow rates were not excessive, no foaming problems were experienced during experimental runs (and installed foam cutters were never operated). The only period when foam production was noted was during the aeration studies between Runs 4 and 5, when dissolved oxygen was measured as high as 4 mg/L. One incident of a "foam overflow" occurred during this time, when feeding was reinitiated after the one week build-up period. In ATAD, maintenance of a foam layer is desirable to improve oxygen utilization, enhance bioactivity and provide insulation (Deeney et al., 1991). Excessive foam production is undesirable and has been shown to indicate excessive aeration, thin feed, process upset and changes in the characteristic of the process microorganism, specifically between mesophilic and thermophilic cultures (Kelly et al., 1995). All these factors would account for the foaming events.

4.2.7 Air Composition

As compared with ambient air composition at 20% oxygen and 80% nitrogen, headspace gases registered a small percentage of carbon dioxide and corresponding decrease in % oxygen. As illustrated in Figure 4.20, the control reactor tended to have a higher percentage of carbon dioxide than the test reactor, with a maximum of 2.7%. Methane was not detected in the headspace gases in either of the reactors. These results further indicate that an anaerobic environment was not established in the reactors.

In experiments by Boulanger (1995), elevated levels of nitrogen in the off-gases under oxygen deprived conditions was assumed to indicate that nitrification was occurring. This condition was not noticed under similar conditions .

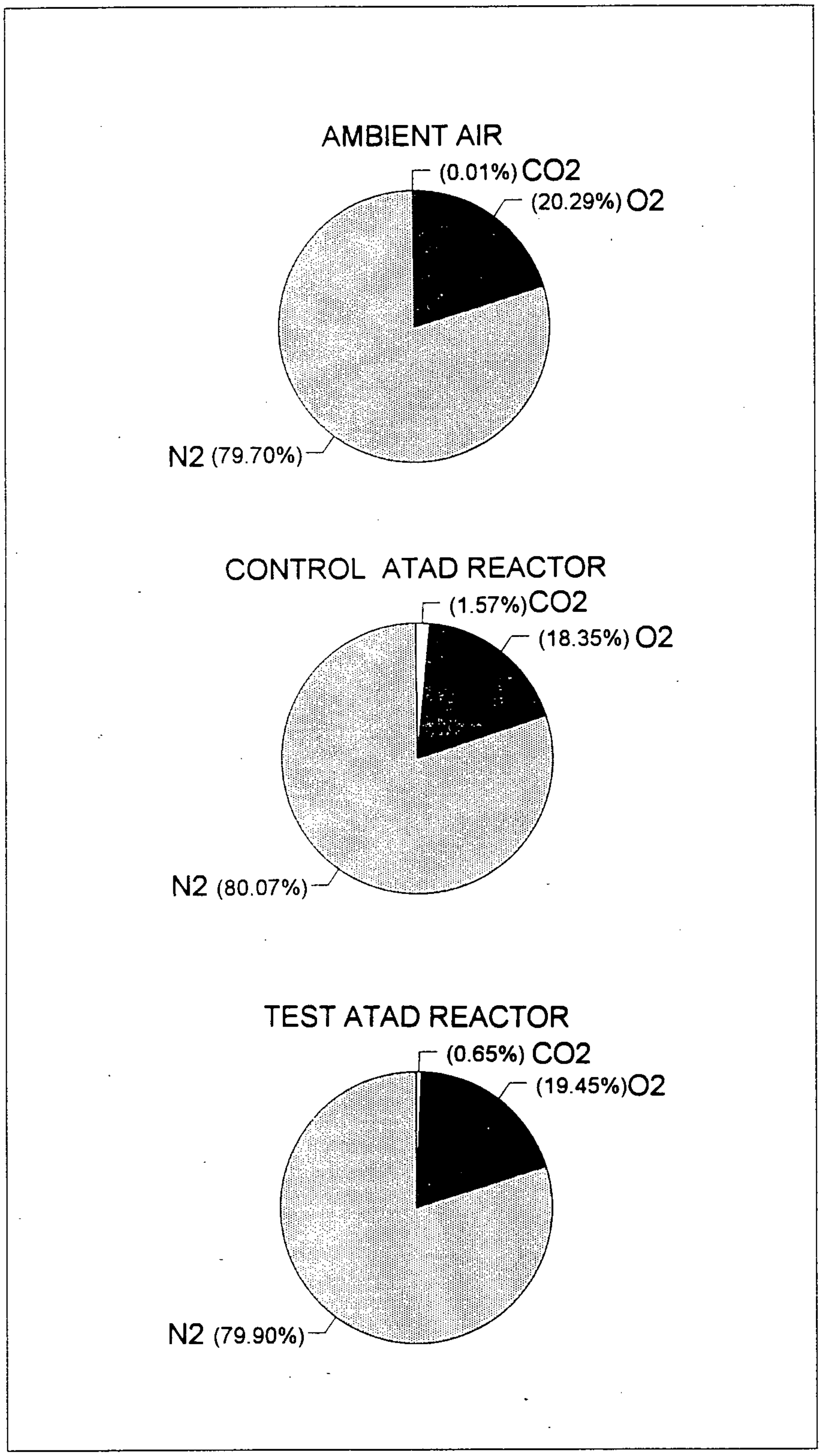


FIGURE 4.20: ATAD Air Composition

4.2.8 pH

The contents of the ATAD reactors remained between neutral and slightly acidic pH during non-solubilized runs, indicating stable operations. Pre-solubilization of sludge feed with 15 meq/L of NaOH resulted in an increase in the pH of the feed. As pH was consumed by the portion of sludge remaining in the feed tanks over the 24 hour semi-continuous feed cycle, and TAD produces alkalinity, the pH of the reactors was less effected. The average pH of the reactor contents during each run is summarized in Table 4.6. The complete data sets are given in Appendix C.

TABLE 4.6: AVERAGE ATAD pH

Run	Test Sludge Ratio (primary/secondary)	Control pH	Test pH
1	100/0	6.5	6.7
2	65/35	6.6	6.7
3	35/65	7.0	7.0
4	0/100	7.0	6.9
5	0/100 solubilized	7.2 (feed 6.5)	7.8 (feed 9.7)
6	35/65 solubilized	6.9 (feed 6.4)	7.4 (feed 8.4)

In comparison to previous research, under similar aeration rates and 3 days retention time, Chu (1995) recorded pH readings between 5.5 and 7.5 with primary sludge, and Boulanger (1995) recorded an average pH of 7.0 with 44/56 mix. In Chu's studies, a decrease in pH was noted with decreases in aeration and retention time. His results also suggested that there is a point at which available oxygen is limited and a drop in pH is attributed to VFA accumulation. In studies by McIntosh & Oleszkiewicz (1996) with primary sludge, no depression of pH was noted with decreases in retention time or the accumulation of VFA. Similarly, in these studies there is no trend of increasing pH with increasing VFA accumulation. In a review of full scale operating facilities, Deeney et al. (1991) reports typical pH values for feed and ATAD sludge of 6.5 and 7.2, respectively.

TAD is inherently stable with respect to pH, primarily as a result of inhibition of nitrification. At the same time, ammonia is a principle buffer (Kelly, 1990). In addition, the production of CO_2 increases alkalinity in TAD and provides additional buffering capacity for the anaerobic digester in dual digestion systems (Appleton & Venosa, 1986b; McIntosh & Oleszkiewicz, 1996). The effect of pre-solubilization with NaOH deteriorates this stability as indicated by the increase in pH in the test reactor in Run 5 & 6, and more clearly in the daily oscillation of pH as illustrated in Figure 4.21. Knezevic (1993) also noted pH increases with pre-solubilization of secondary sludge; however, in subsequent anaerobic digestion, this increase was beneficial, resulting in less frequent buffering requirements.

As pH was only measured every 12 hours, the rate of increase of pH in the feed tanks is not known, nor the time or rate of decrease. Based on the results by Knezevic (1993) on mixing time and pre-solubilization with this same chemical dose, it is assumed pH rose rapidly during the first 3 to 5 hours, followed by a slow decrease over the remaining holding time in the feed tanks. Therefore, it is assumed the maximum feed pH was not recorded and is slightly greater than the "am" measurement taken 1 hour after the addition of NaOH.

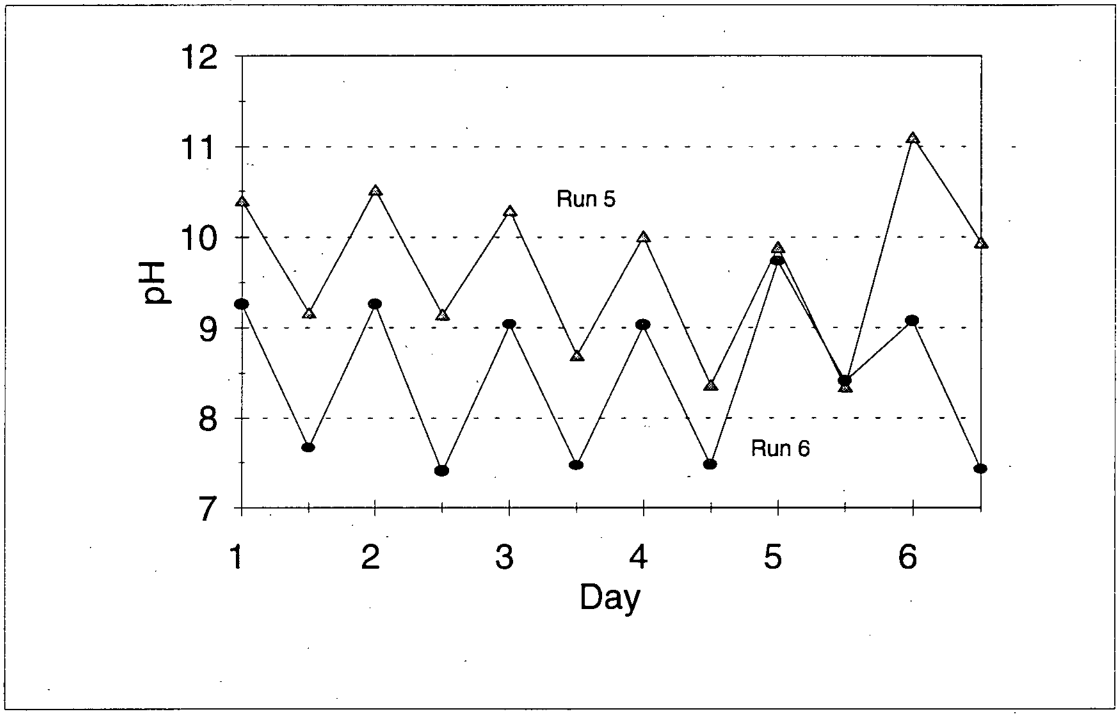


FIGURE 4.21: pH Instability with Pre-solubilization of Feed Sludge

4.2.9 Feed Total Solids

Total solids data for the entire experimental period is reported in Appendix E. Overall, average feed to the control reactor was 11.6 g/L (1.2%), slightly higher than the test reactor feed at 11.4 g/L (1.1%). The daily variability between feed streams is illustrated in Figure 4.22. The largest difference between the test and control feed was 13.5 g/L (1.4%), although the majority of the variability is closer to zero. At the same time, it is noted that large differences are usually followed by a negative difference of similar magnitude. This is due to the fact that mix ratios were based on the TS value of the sample taken 24 hours previously resulting in a 24 hour lag in compensation. As can be seen from the run averages summarized in Table 4.7, TS is basically consistent in all but Run 5.

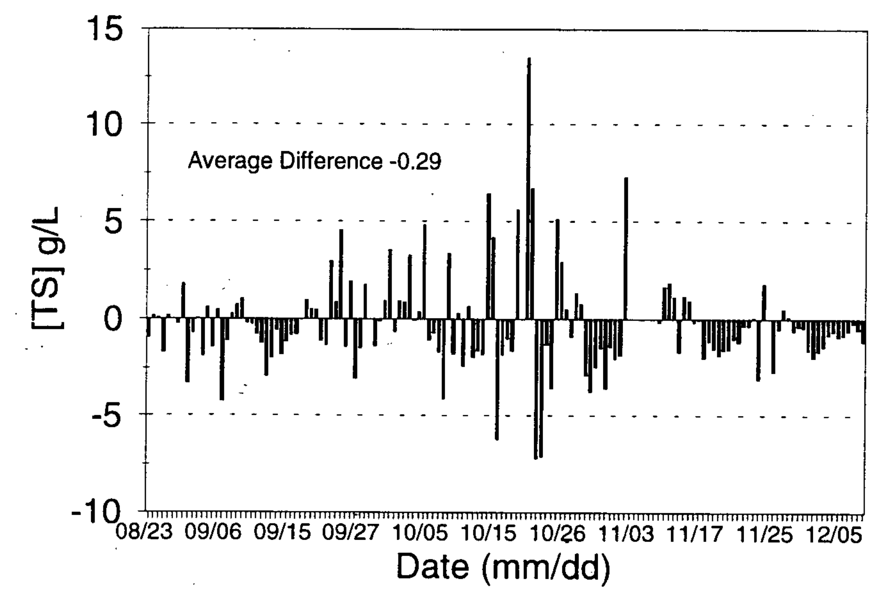


FIGURE 4.22: Total Solids Feed Variability

TABLE 4.7: AVERAGE FEED TOTAL SOLIDS

Run	Test Sludge Ratio (primary/secondary)	Control (%)	Test (%)
1	100/0	1.3	1.3
2	65/35	1.2	1.3
3	35/65	1.3	1.2
4	0/100	1.2	1.1
5	0/100 solubilized	0.8	0.7
6	35/65 solubilized	1.3	1.2

Total solids variability is normal in full scale operating facilities, but was designed as a control for these experiments as it effects digester performance and destruction efficiency (Kelly et al., 1993), and thus could influence VFA. At the same time, it needs to be remembered that TS is not a measure of the biodegradable portion of sludge. Although it has been assumed that 55%, of 80% of TS is biodegradable (Gould & Drnevich, 1978), the proportions are not consistent between processes or within processes due to the variability of sewage. Specifically, as there is no grit removal or screening at the pilot plant, it is likely that the primary sludge has a lower biodegradable content than the secondary sludge. Since the mix ratios used in assessment of the effect of secondary sludge are based on the mix ratio of TS, there is the potential that the distinction between the 65/35 and 35/65 mix ratios is not definitive or significant. The ratios could be closer to 50/50 with respect to VS. This point will be referred to in discussions of ATAD performance and VFA enhancement in the following sections.

4.3 Total Solids Destruction

ATAD destruction efficiencies are presented in Table 4.8 for all 6 runs. The control reactor was maintained at 100% primary for Runs 1 to 4; however destruction efficiencies range from a high of 40% in Run 1, to a low of 25% in Run 3. At the same time, there is a 7% difference between the control and test reactor in Run 1, when both reactors received the same feed. This apparent inherent difference in reactor performance was also recorded by Chu (1995) in parallel experiments with primary sludge. Still, a difference greater than 7% potentially indicates that the addition of secondary sludge reduced destruction efficiencies in Runs 2 and 4, and differences less than 7% with pre-solubilization indicates enhanced destruction. Comparison of the results to full scale operations and other studies precedes any further discussion of these points.

TABLE 4.8: TOTAL SOLIDS DESTRUCTION EFFICIENCY

Run	Test Sludge Ratio (primary/secondary)	Control (%)	Test (%)
1	100/0	40	33
2	65/35	29	18
3	35/65	25	19
4	0/100	26	12
5	0/100 solubilized	12	8
6	35/65 solubilized	16	16

As highlighted earlier, TS represent both biodegradable and non-biodegradable solids and thus the values presented above represent a higher % removal in terms of VS and VSS, by as much as 60%.

In comparison to the full scale facilities, as reviewed by Deeney et al. (1991), for systems treating a mixture of primary and secondary sludge, it is expected that VS destruction range between 35 and 45% with 6 days retention time. From actual reported values, a range of 35 - 66% VSS has been demonstrated for mixed sludge feed, and 25 - 40% for 100% secondary sludge feed. Since the reactors in this thesis represent the first stage of a minimum two stage system, comparisons to the first stage is more appropriate. Deeney et al. (1991) generalizes that 60%of VS destruction occurs in the first reactor, which would reduce the above reported efficiencies to 21 - 40% TSS for mixed feed, and 15 - 24 % for 100 % secondary sludge within the 3 days retention time in the first reactor. Overall, mixed sludge destruction efficiencies are still low.

In comparison to ATP units in dual digestion (generally single stage with retention times less than 3 days), Appleton & Venosa (1986b) summarize that operating systems generally achieve from 10 to 20% VS destruction, prior to anaerobic digestion. This range correlates much more closely to calculated results obtain in this research. In addition, the demonstrated improvement in destruction efficiency from 12 % VS at pilot scale to 27% VS at full scale in ATP studies by Fuggle & Spensley (1985) illustrates the effect of scale on TAD performance, and indicates that destruction efficiencies reported for the pilot scale reactors should be lower than reported full scale values.

In comparison to other pilot scale ATAD studies, where low initial feed solids tend to additionally reduce ATAD efficiency, destruction efficiencies are similar. Under the same operating conditions and the same reactors, Chu (1995) achieved 8 - 20% TS (10 - 23% VS) destruction with 100% primary sludge, and Boulanger (1995) achieved 20% VS reduction with a 44/56 sludge mix. Boulanger (1995) also demonstrated that aeration rates, increased to oxygen excess levels, did not effect destruction effeciency. Trim & McGlashan (1984) achieved 23% VSS reduction with 100% secondary sludge versus 27% with 50/50 mix; again, in terms of TS, these destructions are within the range of this work.

The results by Trim & McGlashan (1984) also support the relationship of reduced destruction with increased proportion of secondary sludge. On the other hand, Smith et al. (1975) reported conflicting trends. In initial studies, to achieve the same destruction efficiencies as with 40/60 mixed feed, retention time in the ATAD reactor had to be extended by 5 days when 100% secondary sludge was used. However, when retention time was controlled at 4 days, 33% TSS (40% VSS) reduction was achieved with 100% secondary sludge, while only 26 % TSS (30% VSS) was attained with a 60/40 sludge mix. Similarly, direct comparison of results by Chu and Boulanger indicates that mixed sludge feed gave a higher overall average destruction than primary sludge.

Based on the apparent discrepancies of other researchers and the results of this work, for accurate conclusions to be drawn with respect to the effect of secondary sludge addition on solid destruction efficiency, parallel experiments should be run for each mix ratio in the pilot plant ATAD reactors to eliminate any inherent differences between the reactors. Additionally, measurement of TS, VS and biodegradable VS on both feed and effluent is necessary for accurate assessment of solids destruction and comparison to other research.

With respect to pre-solubilization, Knezevic (1993) noted that, although it did not significantly improve VSS destruction in anaerobic digestion, overall VSS reduction was improved due to the destruction of solids during pre-solubilization itself. No consistent reduction between am and pm samples was recorded in Runs 5 & 6 as a result of pre-solubilization to draw the same conclusion from this work. Again, the apparent difference between the two reactors must be eliminated, or accurately quantified, before further conclusions can be made with respect to the effect of pre-solubilization on reactor destruction efficiencies.

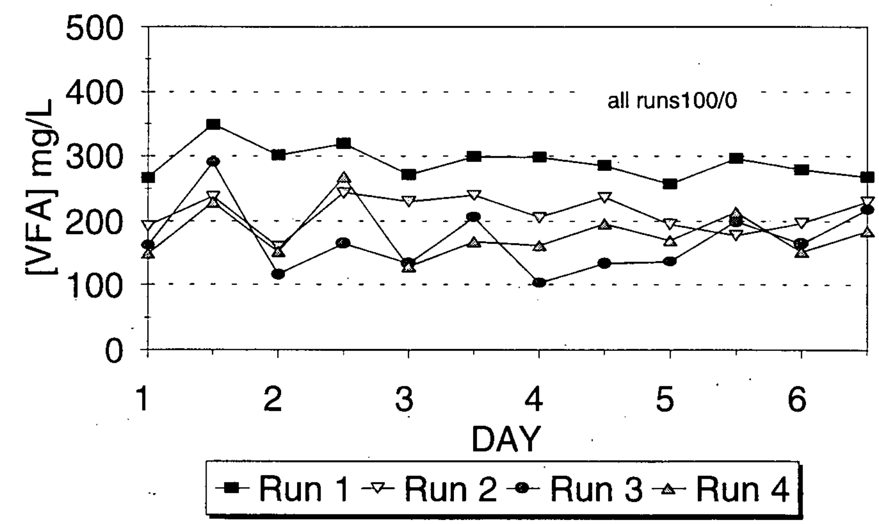
4.4 VFA Production - Mixed Sludge Ratio Runs

VFA were detected in all feed streams and ATAD reactor contents for all runs; however, concentrations did not always increase with digestion. Secondary sludge appears to dilute the concentration of VFA in the feed, but overall, it enhanced VFA production in ATAD. Appendix F contains the data presented in the subsequent figures illustrating these trends.

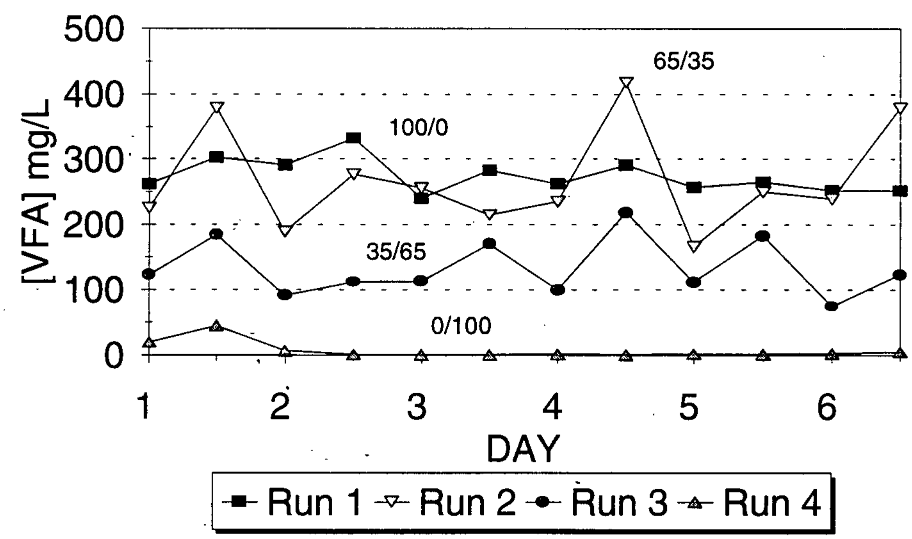
4.4.1 Feed Streams

Figures 4.23 (a) and (b) illustrate the differences in total VFA concentrations of the feed streams through the first 4 experimental runs. The feed to the control reactor was maintained with 100% primary sludge for all 4 runs and yet, not only did the concentrations vary during the 6 day runs by as much as 188 mg/L, the average concentrations ranged from a high of 291 mg/L in Run 1, to a low of 169 mg/L in Run 3. This illustrates the natural variability of VFA concentrations in primary sewage sludge and reinforces the need to maintain a control reactor through experimental work.

In comparison, the feed to the test reactor was changed in each run and differences between runs is expected. Figures 4.23 (b) shows a trend of decreasing VFA concentrations with increasing proportions of secondary sludge. Average VFA concentration dropped from a high of 274 mg/L with 0% secondary sludge, to 269 mg/L when 35% was added, to 134 mg/L with 65%, and finally to 8 mg/L with 100% secondary sludge. Daily fluctuations in the VFA concentrations in the mixed sludge feed streams parallels the fluctuations recorded with 100% primary sludge in the control reactor, again illustrating the variability of primary sewage sludge. The mixing of primary and secondary sludge appears to enhance fluctuations, as both primary and secondary sludge alone show relatively consistent levels.



(a) Control

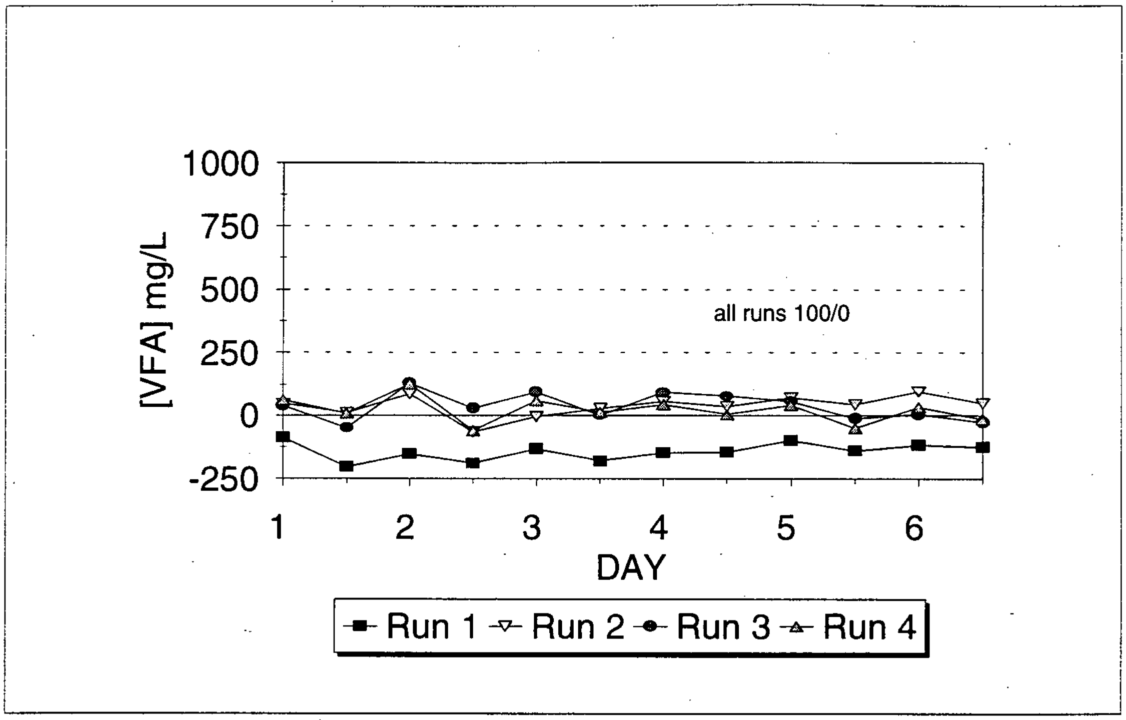


(b) Test

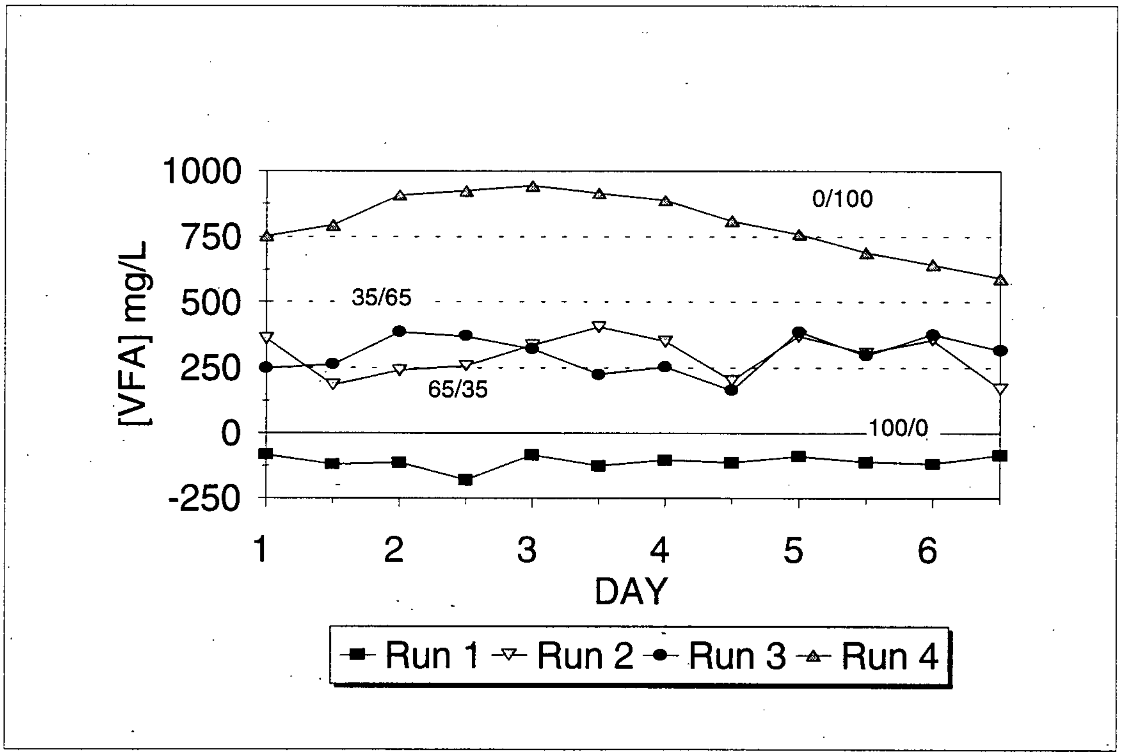
FIGURE 4.23: VFA in Feed, Runs 1 to 4

4.4.2 ATAD VFA Production

In the digestion of sludge, VFA are both produced and consumed. The difference between influent and effluent concentrations provides an indication of the net production of VFA. As illustrated in Figure 4.24, 100% primary sludge resulted in less than 125 mg/L net production, and in some cases, net consumption of VFA. In contrast, increases in the proportion of secondary sludge resulted in increased net production of VFA. The highest net production of VFA, close to 1000 mg/L, was obtained with 100% secondary sludge. The same scale is used in both figures to highlight the differences.



(a) Control



(b) Test

FIGURE 4.24: Net VFA Production in ATAD, Runs 1 to 4

However, due to the variability of VFA levels between runs in the control streams, assessment of the effect of secondary sludge on VFA production must be done using the differences produced specifically, between the test and control reactor for each run. For this comparison, the concentration of VFA that accumulated in the reactor whether introduced in the feed, or generated as a by-product of ATAD, are used. The differences between the test and control are plotted in Figure 4.25, and secondary sludge still demonstrates enhancement of VFA production in ATAD, with 100% secondary sludge resulting in up to 757 mg/L greater accumulation of VFA.

Although the test reactor exhibited enhanced VFA production in Run 1, when the same feed stream was being introduced to both reactors, subsequent runs exhibited significantly larger differences, eliminating the need to "correct" the data. However, further review of the results of experiments run by Chu (1995) using this same apparatus, indicates that the reactor used for the test experiments in the first 4 runs does possess some inherent mechanical or physical difference which enhances VFA production over that of the reactor designated the control.

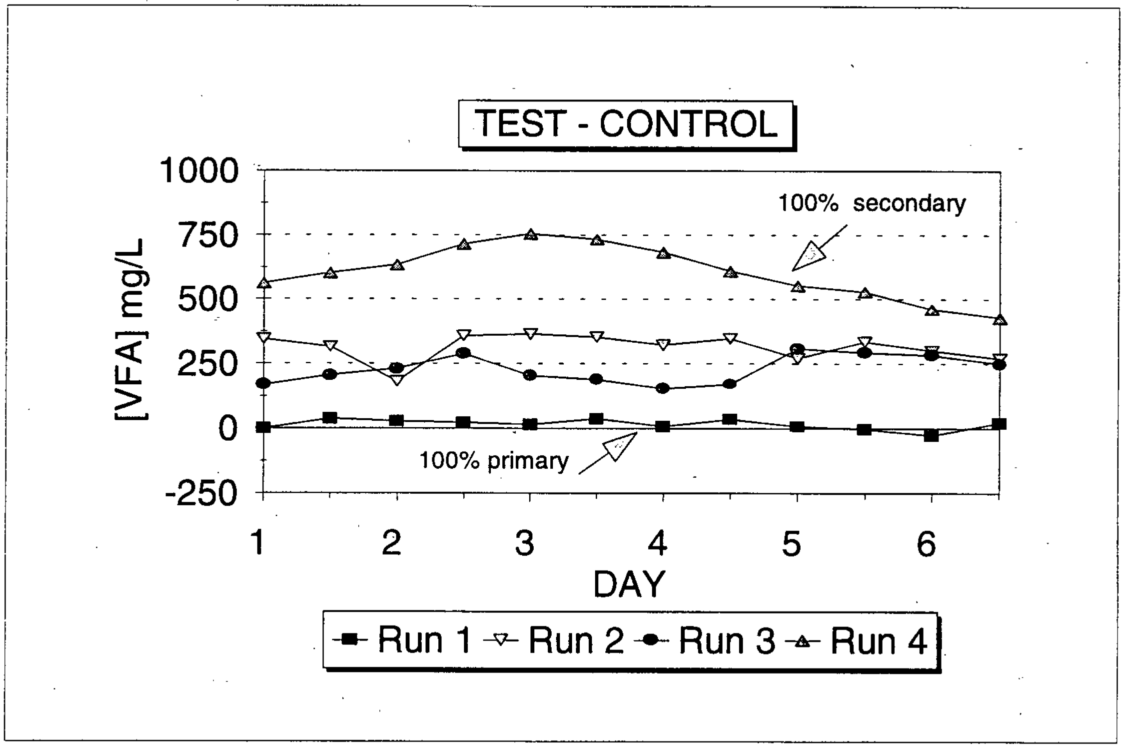


FIGURE 4.25: ATAD VFA Accumulation as a result of Mixed Sludge Feed

Considering other trends and inconsistencies in the results, Run 4 has a relatively large range of VFA concentrations over the 6 day test period. Initially, levels between 600 and 800 mg/L total VFA, drop off to less than 400 mg/L by the end of day 6. Since the use of secondary sludge was highest during this last run, the consistency of the feed to the test reactor had been generally declining from the beginning of the run and was visibly thin at the end. ATAD is strongly effected by solids feed consistency, and this decrease could have resulted in depressed performance of the test reactor and consequently, reduced VFA production in the last days of Run 4.

At the same time, from the figures presented, it can be seen that the distinction between the 65/35 and 35/65 mix ratios is not definitive. As discussed earlier, this is potentially the result of indistinct differences in mix ratios, with respect to VS and biodegradable material, as calculations are based on TS only. This factor restricts the development of a mathematical relationship between % secondary sludge and enhancement of VFA production, although in reality, one may exist.

Furthermore, the non-distinct relationship between the 65/35 and 35/65 mix ratios may also be a result of differences in aeration levels, since decreases in aeration have been demonstrated to increase VFA production (Chu, 1995). Considering the control reactor, where only 100% primary sludge was used, total VFA concentrations are lower for runs with higher recorded airflow rates. Table 4.9 ranks the data and illustrates the inverse relationship. Therefore, the similarity in VFA concentrations in the test reactor in Runs 2 and 3, even though the mix ratio was adjusted from 65/35 to 35/65, may be a result of the relatively lower aeration rates in Run 2 enhancing VFA production to levels of Run 3; conversely, Run 3 VFA accumulations may have been inhibited by the higher aeration levels.

Additionally, in support of previous results that indicated 100% secondary sludge resulted in the highest levels of VFA production and accumulation, it is noted that these concentration maximums occurred under one of the second highest aeration rates. Thus, predictions could be made that VFA production in ATAD with 100% secondary sludge would have be even greater if all runs had been maintained at the same aeration level.

TABLE 4.9: AIRFLOW EFFECTS ON VFA ACCUMULATION

Control ATAD, 100% Primary Sludge					
Median Total VFA Accumulation (mg/L)			Median Airflow Rate (mL/min)		
Highest	57	Run 2	Run 2	26	Lowest
↑	44	Run 3	Run 3	41	↓
↑	34	Run 4	Run 4	50	↓
Lowest	- 144	Run 1	Run 1	51	Highest

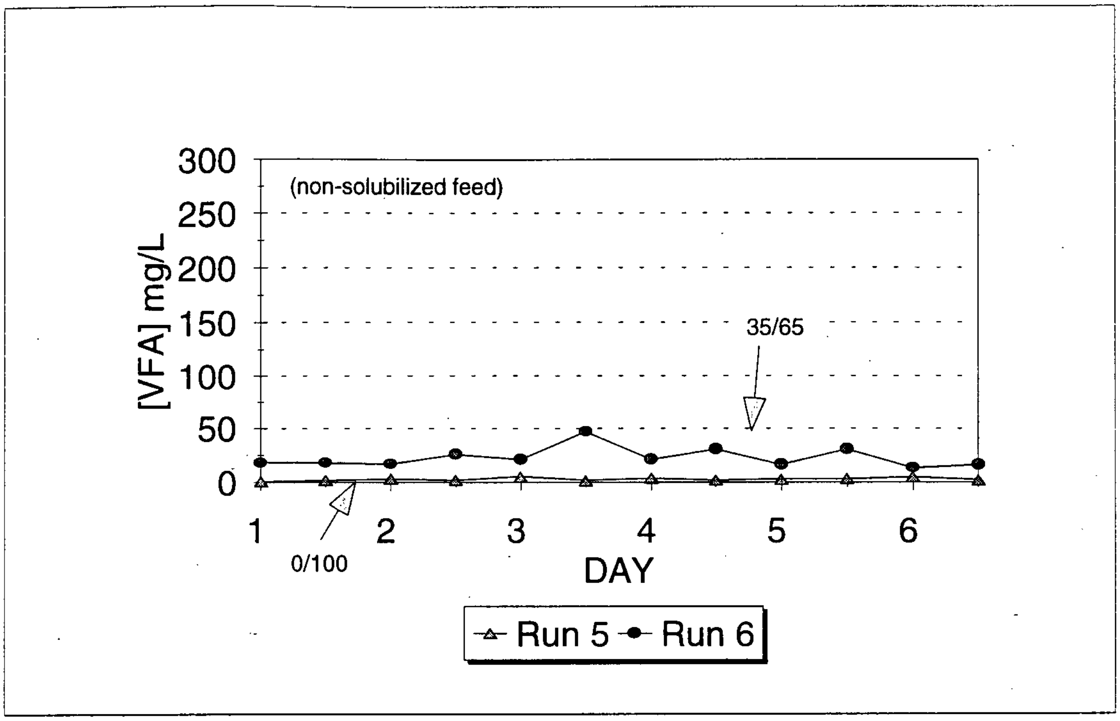
4.5 VFA Production - Pre-solubilization Runs

VFA were detected in all feed streams and ATAD reactor contents for both runs; however, concentrations did not always increase with digestion. Pre-solubilization appears to "inhibit" the benefit derived from the addition of secondary sludge.

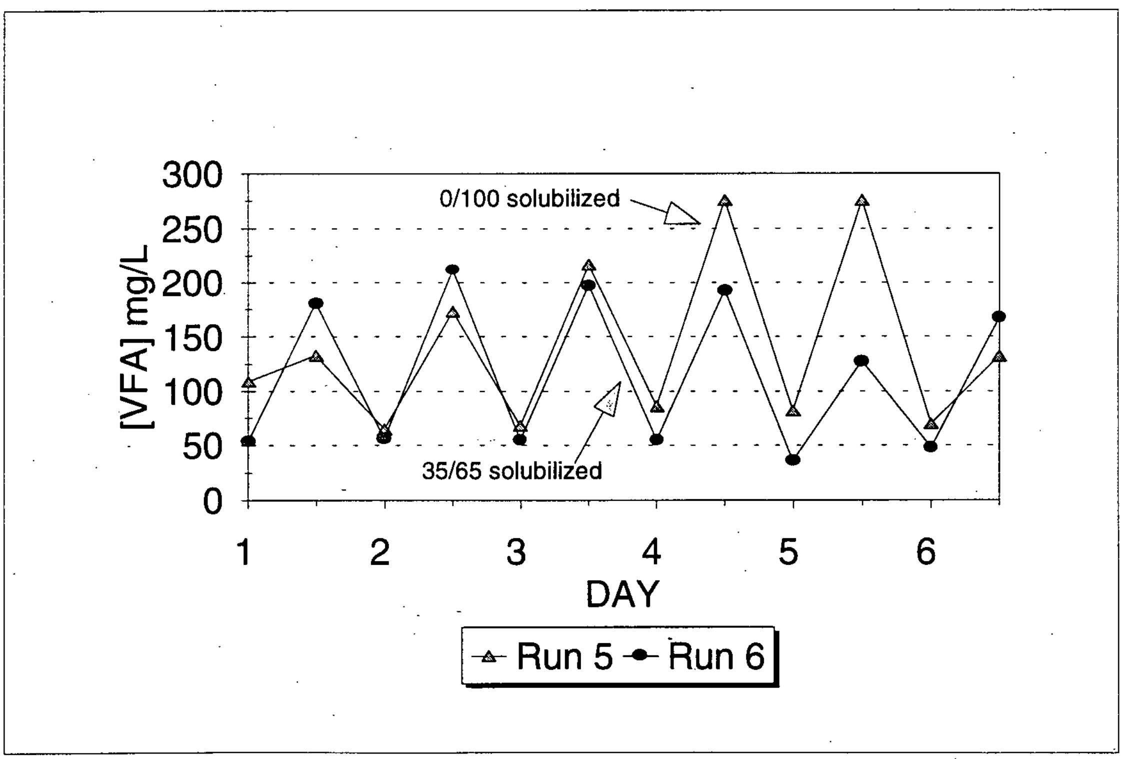
4.5.1 Feed Streams

In non-solubilized feed streams (control feed), the variability of VFA is similar to patterns in the first 4 runs. Fluctuations appear to be the consequence of variability in primary sludge VFA concentrations, enhanced in mix ratios with secondary sludge, and secondary sludge exhibits relatively, consistent levels of VFA. Overall however, absolute concentrations were lower as compared to the same mix ratios in earlier runs. This run variability is discussed in a later section. Figure 4.26 (a) is a plot of feed concentrations for the control reactor in Runs 5 & 6.

In contrast, Figure 4.26 (b) illustrates the extreme variability in solubilized feed streams (test feed). As a result of pre-solubilization with NaOH, VFA levels increased immediately within the first hour and continued to increase over the holding period in the feed tank. Data points are from samples removed and preserved 1 hour and 12 hours after chemical addition. As the analysis of these samples was not completed until after experiments had been completed, no samples of the feed sludge were taken after 24 hours (before addition of fresh feed and solubilization chemicals) to determine if VFA levels continued to increase, level-off or decrease between 12 and 24 hours mixing time.



(a) Control



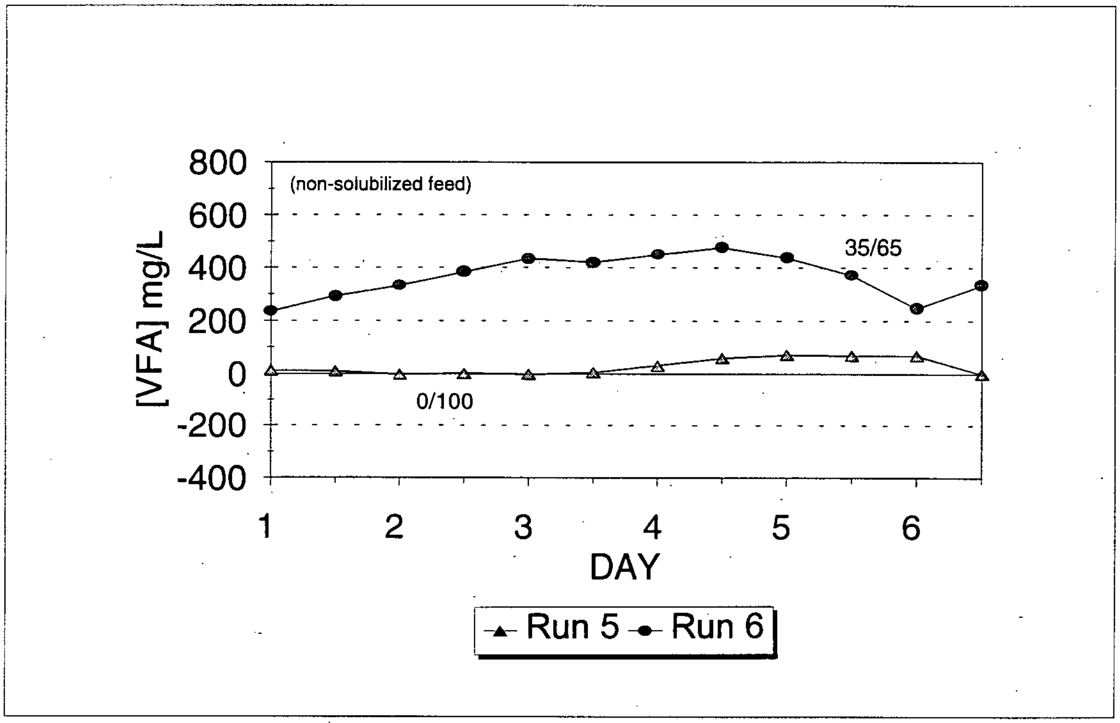
(b) Test

FIGURE 4.26: VFA Feed Variability, Runs 5 & 6

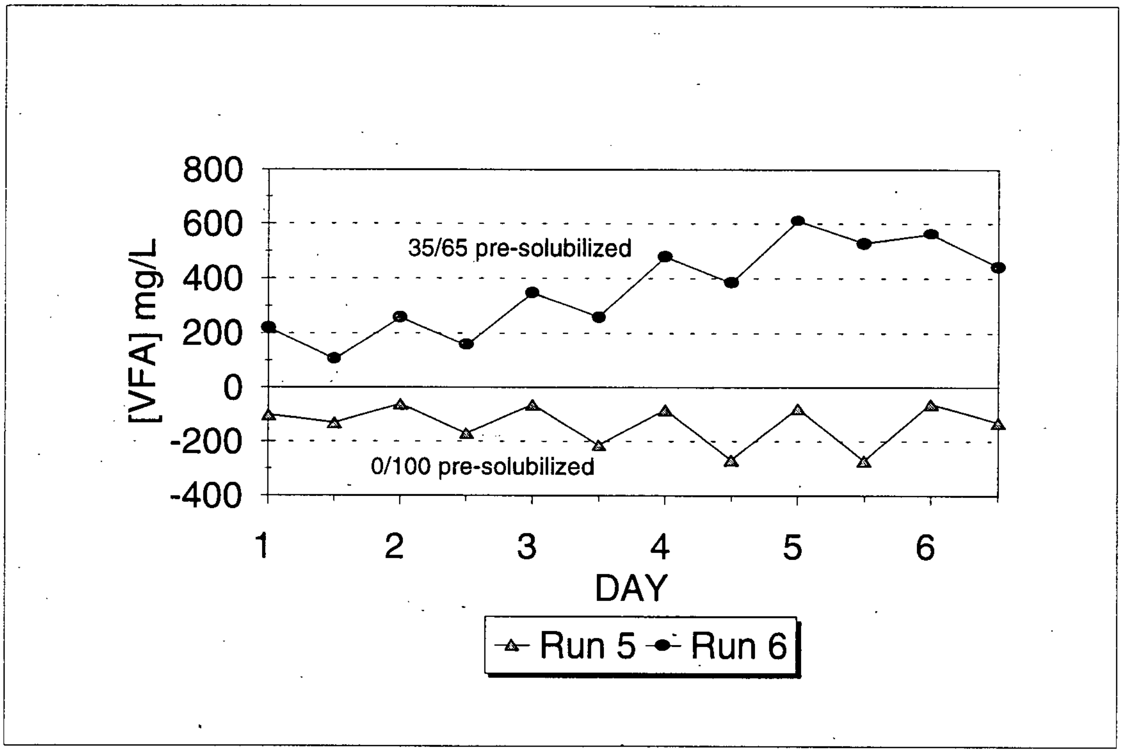
4.5.2 ATAD VFA Production

Figure 4.27 presents the net VFA production data for Runs 5 & 6. In both the control and test reactors in Run 5, production of VFA was minimal as compared with the levels attained in Run 4 with 100% secondary sludge, and there was a net consumption of VFA with pre-solubilized feed. In Run 6, net production was re-established and VFA concentrations, for both non-solubilized and solubilized feed, are similar to those reached in Run 3 with the 35/65 mix ratio. Both test reactors exhibited the same zig-zag pattern of VFA concentrations as was illustrated in the feed streams, with the same magnitude of fluctuation (different scales used in figures). The impact of NaOH addition is obvious.

As undertaken for Runs 1 through 4, a comparison of the difference between the test and control reactor for each run is required to eliminate sludge variability and allow assessment of the test variable, pre-solubilization in this case. Figure 4.28 is a plot of these differences. Although levels in the first 3 days would indicate that pre-solubilization did not enhance VFA production, the results from days 4, 5 & 6 present conflicting evidence. With 100% secondary sludge, the reduction in VFA accumulation to below zero indicates pre-solubilization inhibits VFA accumulation. On the other hand, the increase in VFA concentrations with mixed sludge would indicate that VFA accumulation was "eventually" enhanced. Since all runs were acclimatized to new feed conditions for a minimum of 6 days (2 full retention times), these results potentially indicate that this was insufficient time, specifically with the additional impact of pre-solubilization. Other interpretations are also possible. Further discussion of the variability in Run 5 & 6 is presented in the next section.



(a) Control



(b) Test

FIGURE 4.27: Net VFA Production, Runs 5 & 6

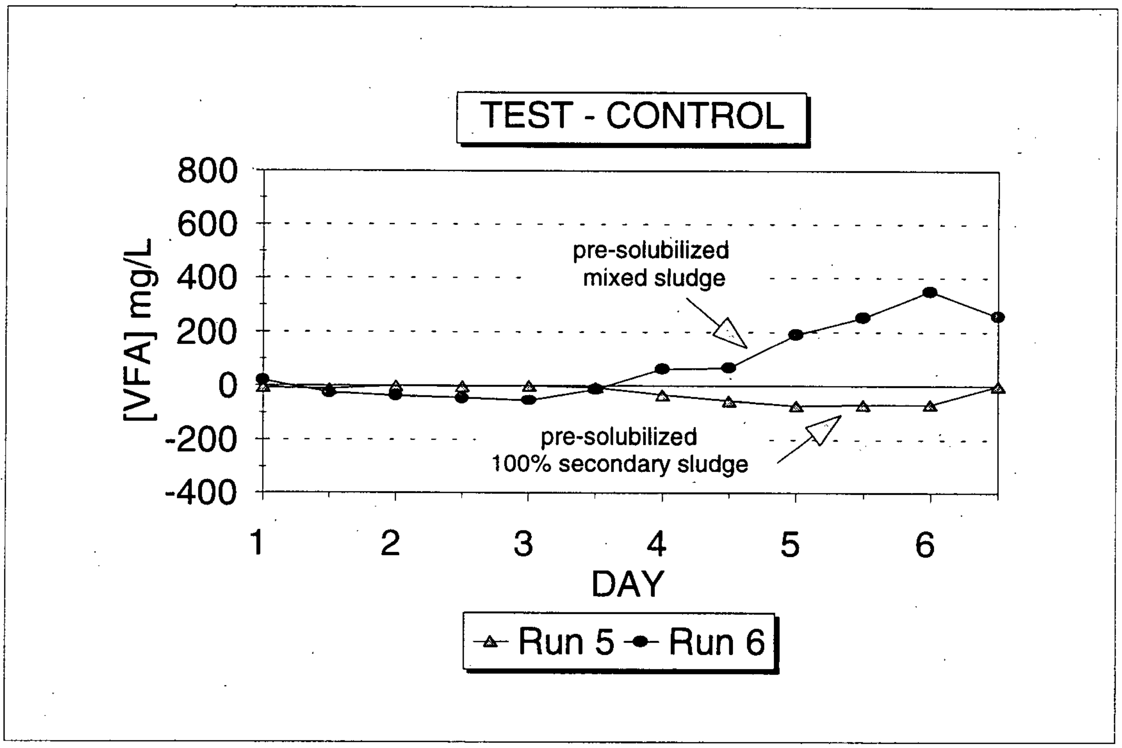


FIGURE 4.28: ATAD VFA Accumulation as a Result of Pre-solubilization

4.6 VFA Production - Run Inconsistency

Due to additional experimental variability that resulted from both, the limited capacity of the pilot scale facility, and operational variability that could not be adequately measured, the results of Runs 5 & 6 are discussed separately in this section.

In comparison of the results obtained for the control reactors in Runs 5 & 6 (non-solubilized experiments), to previous runs with the same mix ratios, it can be seen that other variables effected VFA production. Figures 4.29 and 4.30 illustrate the differences between the average VFA concentrations for the same sludge mix ratios in different runs. In Runs 4 & 5, although feed concentrations were similar, accumulations in ATAD in Run 5 were almost zero while, in Run 4, the average concentration was 810 mg/L. There is less inconsistency between Runs 3 & 6 where feed and ATAD VFA concentrations respectively, were within the same range, and the increase of VFA with digestion was relatively the same. The lower ATAD levels in Run 6 can be attributed to the lower feed concentrations.

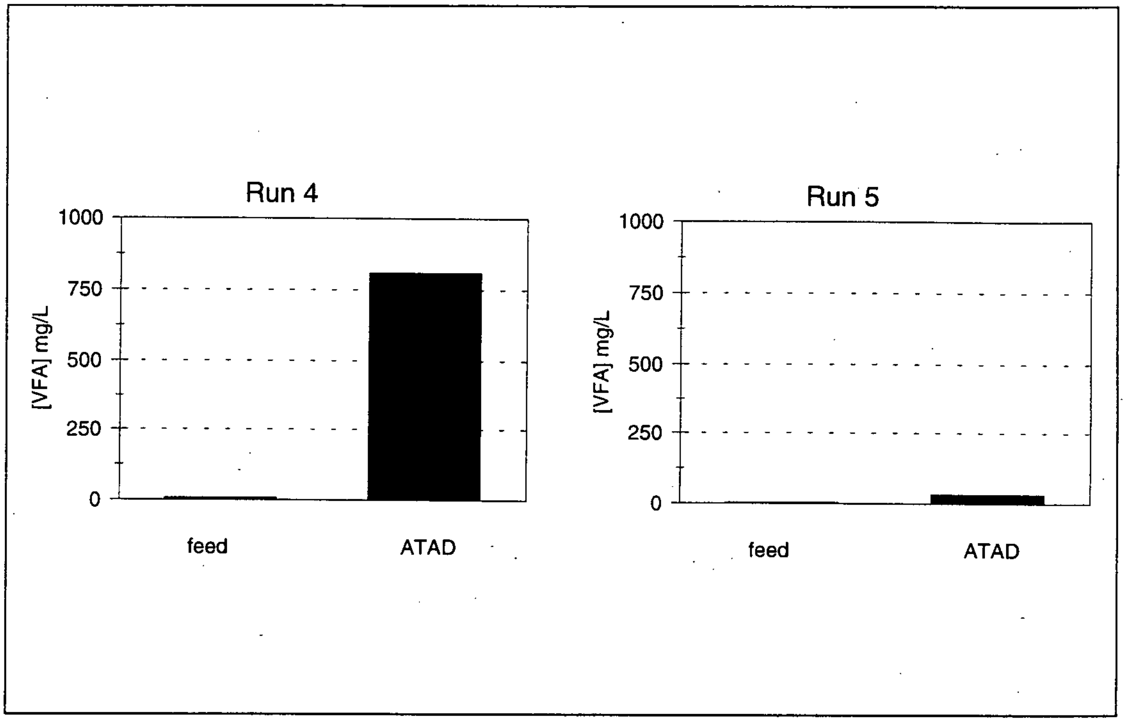


FIGURE 4.29: Run Inconsistency with 100% Secondary Sludge

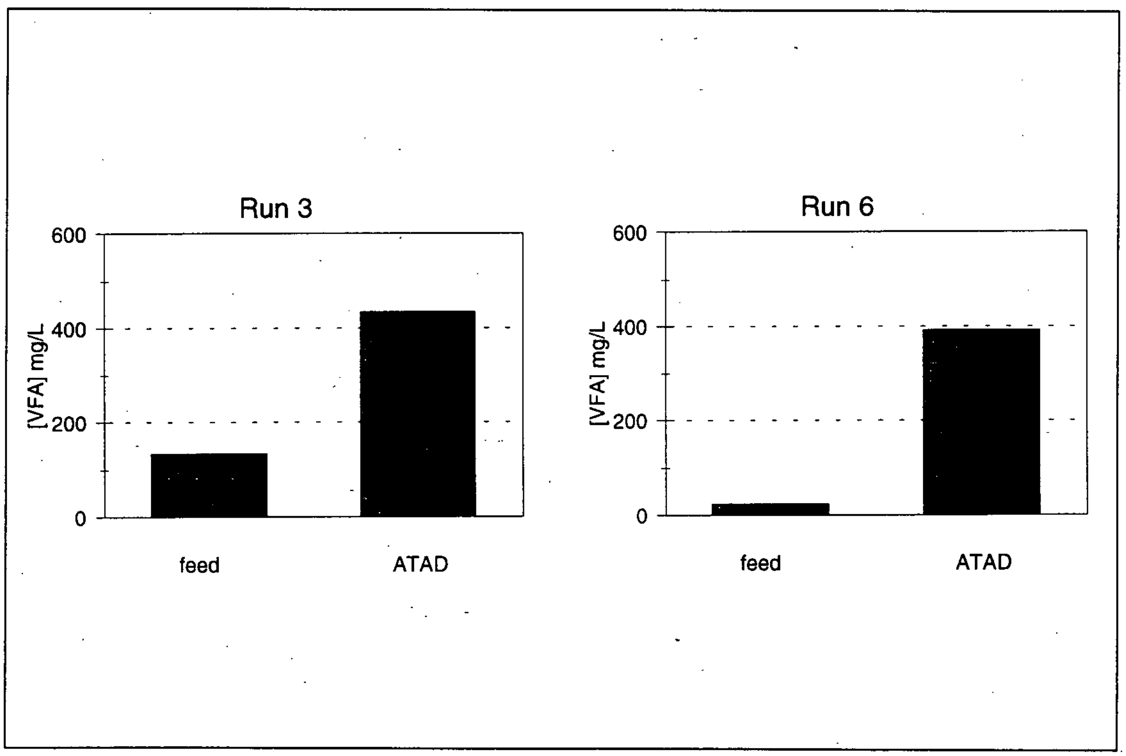


FIGURE 4.30: Run Inconsistency with 35/65 Mix Sludge Ratio

As detailed in the Method and Materials section, in order to secure a sufficient quantity of secondary sludge for Runs 5 & 6, feeding of the reactors was stopped for 10 days, resulting in an increase in reactor retention time. It is possible that, as a result, the process culture was starved and a phase of endogenous respiration or sporulation was stimulated (Sonnleitner & Fietcher, 1983a). As a consequence, upon re-establishing the hourly feeding, the process micro-organisms were initially inhibited with respect to efficient digestion and thus, VFA production. This would explain the larger inconsistency with Run 5 which was initiated just 10 days after the down period, versus Run 6 which had an additional 12 days to recover.

At the same time, wasting rates from the wastewater treatment process were also increased for sludge build-up and, as in the end of Run 4, TS consistency of the feed decreased through Run 5, potentially resulting in decreased digester performance. With a change in the sludge mix ratio to 35/65 in Run 6, the demand on secondary sludge decreased and feed TS recovered to > 1%. In addition, feed VFA concentrations did not similarly increase with the increase in feed TS, supporting the assumption that it was digester performance that was reduced and resulted in reduced VFA production, not a reduction in influent VFA. Average influent levels of VFA dropped from 134 mg/L in Run 3, to 23 mg/L in Run 6 and still 392 mg/L of VFA accumulated during Run 6, as compared with 434 mg/L in Run 3.

During the period prior to Runs 5 & 6, the aeration studies were also carried out and potentially resulted in process upset that required a longer recovery period than was provided. Aeration levels were unexpectedly increased, due to discrepancies in calibration information, and DO levels above 4 mg/L were recorded. Previously all measurements had been < 1 mg/L. Consequently, the mixed culture of aerobic and facultative anaerobic microorganisms could have been shifted towards a predominantly aerobic culture. Treatment efficiencies would have been adversely affected by this shift, as well as by the subsequent shift back to a mixed population with the correction to airflow rates. VFA production would have similarly been depressed for this period, and potentially longer..

In indirect support of this "crash and recovery" theory, is the fact that both reactors appear to have recovered by Run 6. ATAD VFA concentrations are in the range of 400 mg/L, as they were in Run 3. Additionally, although the net production in Run 6 was still slightly lower than in Run 3, it could be a result of differences in aeration between Runs 1- 4 and Runs 5 & 6, or due to the apparent, inherent, higher production efficiency of the test reactor. No conclusions can be made at this time.

In summary, due to the unstable conditions, particularly obvious in Run 5, conclusions with respect to trends and relationships for the effect of pre-solubilization can not be established from the generated data. In addition, experiments were not rerun to check or correct for the process upset resulting from pre-solubilization; results with mixed sludge feed were sufficiently positive, and the additional costs and hazards associated with the use of chemicals were seen to outweigh the minimal evidence of VFA enhancement through pre-solubilization. At the same time, thermophilic temperatures should result in the lysis of mesophilic substrate microorganisms in the ATAD reactor, and at a fairly high rate. In this context, pre-solubilization is unnecessary and results in an increase in pH and pH variability in a system which has been shown to be inherently stable.

4.7 VFA Speciation

In all runs, acetate was the predominant species, both in the feed and in the ATAD reactors. Tables 4.10 and 4.11 list the average concentration of the 4 species measured, and the percentage that acetate represents of this total. Looking at the species concentrations in primary sludge, both the streams in Run 1 and the control in subsequent runs, it can be seen that almost the same proportion of the total concentration was represented by propionate. This corresponds to distributions attained in primary sludge fermenters (Chu et al., 1994; Atherton, 1995). Secondary sludge, on the other hand, had a consistently higher percentage of acetate as summarized in the table by the increasing proportion of acetate with each increase in the proportion of secondary sludge in mix ratios. At the same time, secondary sludge was analyzed separately in all runs, and the actual percentage of acetate was consistently high in Runs 1, 2 & 3, at 78%, 82% and 83% respectively.

With the pre-solubilization of sludge feed, acetate remained the predominant species; however, as the addition of NaOH resulted in the production of all 4 species, the actually % of acetate decreased. From the results in Appendix F, it was also observed that all species concentrations followed the daily zig-zag pattern illustrated by total VFA concentrations (see Section 4.5.1). Although the increase in acetate and total VFA concentrations would be beneficial in terms of supplementing Bio-P or anaerobic processes, the fluctuations may counteract the derived benefits.

Pre-solubilization of the feed streams did result in the an increase in soluble TP in the 100% secondary sludge feed stream, but did not significantly effect the mixed sludge feed; since mixing of primary and secondary sludge alone results in solubilization of stored phosphorus (Rabinowitz & Barnard, 1995). Figure 4.32 illustrates the different impact of solubilization on the two feed streams.

TABLE 4.10: VFA SPECIATION IN FEED SLUDGE

Sludge Mix Ratio (primary/secondary)	acetate (mg/L)	propionate (mg/L)	iso-butyric (mg/L)	butyric (mg/L)	% acetate
100/0 control	159	119	4	9	55 %
100/0 test	152	112	3	7	55 %
100/0	118	88	2	5	55 %
65/35	155	103	5	6	58 %
100/0	92	72	2	4	54 %
35/65	96	34	2	2	72 %
100/0	97	79	2	4	53 %
0/100	7	1	0	0	88 %
0/100	3	0	0	0	100 %
0/100 pre-solubilized	108	14	5	14	77 %
35/65	19	4	0	0	83 %
35/65 pre-solubilized	82	25	4	5	71 %

TABLE 4.11: VFA SPECIATION IN ATAD

Sludge Mix Ratio (primary/secondary)	acetate (mg/L)	propionate (mg/L)	iso-butyric (mg/L)	butyric (mg/L)	% acetate
100/0 control	132	4	12	0	89 %
100/0 test	152	4	8	0	93 %
100/0	220	33	18	0	81 %
65/35	502	33	27	3	89 %
100/0	198	13	2	0	93 %
35/65	414	13	7	0	95 %
100/0	198	4	2	0	98 %
0/100	739	48	23	0	91 %
0/100	31	0	0	0	100 %
0/100 pre-solubilized	4	0	0	0	100 %
35/65	365	8	19	0	93 %
35/65 pre-solubilized	404	29	45	0	85 %

4.8 Nutrients

Since one purpose of producing VFA in TAD is for recycle and use in BNR processes, investigation of the fate of nutrients is important. The following sections provide a record of phosphorus and nitrogen species. A detailed study of "nutrient fate" was previously done by Boulanger (1995), and is published elsewhere (Boulanger et al., 1994). The results of this study support the conclusion that most biologically stored phosphorus is released under TAD conditions, specifically under the oxygen limited environment established.

4.8.1 Phosphorus

Total phosphorus (TP) was generally conserved between influent and ATAD effluent (assuming small difference are the result of sampling and analytical error), thus allowing comparison of results. TP consistently increased with each addition of secondary sludge, as expected for Bio-P waste activated sludge. Variability in TP levels between the same mix ratios, tested in different runs, was low, except in Run 5 where concentrations were consistently lower.

Ortho-phosphate (PO_4) levels in primary sludge feed were consistent through experiments at 5 mg-P/L. Secondary sludge had consistently higher concentrations during the first 4 runs and resulted in a gradual increase in PO_4 levels in the test feed, as the proportion of secondary sludge was increased. In contrast, the 0/100 non-solubilized stream tested in Runs 5 had lower concentrations of PO_4 in both feed and ATAD streams, as compared to the same stream in Run 4, while the 35/65 non-solubilized stream in Run 6 was higher than the in Run 3. Pre-solubilization of feed resulted in increased PO_4 levels in the feed, but levels after digestion were the same. Other than in Run 1, ATAD resulted in an increase in PO_4 concentrations with all feed sludges. Figure 4.31 is a bar graph of average PO_4 concentrations in the feed streams and ATAD reactors, exact values are in Appendix G.

Pre-solubilization of the feed streams did result in the an increase in soluble TP in the 100% secondary sludge feed stream, but did not significantly effect the mixed sludge feed; since mixing of primary and secondary sludge alone results in solubilization of stored phosphorus (Rabinowitz & Barnard, 1995). Figure 4.32 illustrates the different impact of solubilization on the two feed streams.

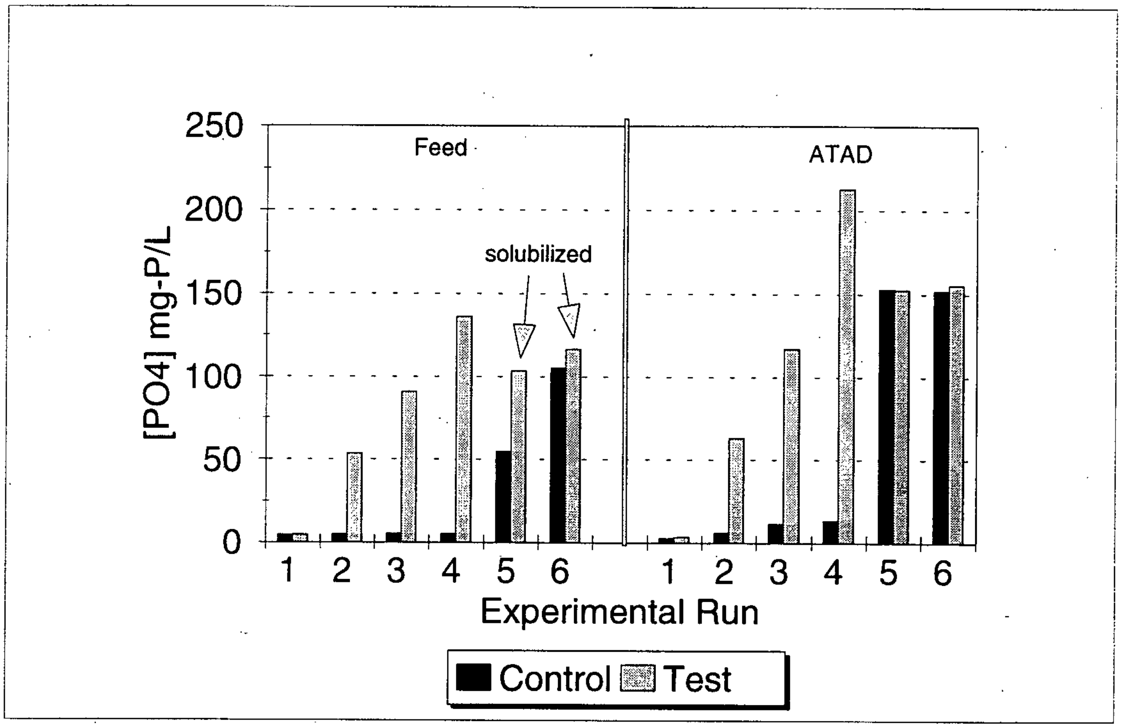


FIGURE 4.31: Fate of Ortho-Phosphate

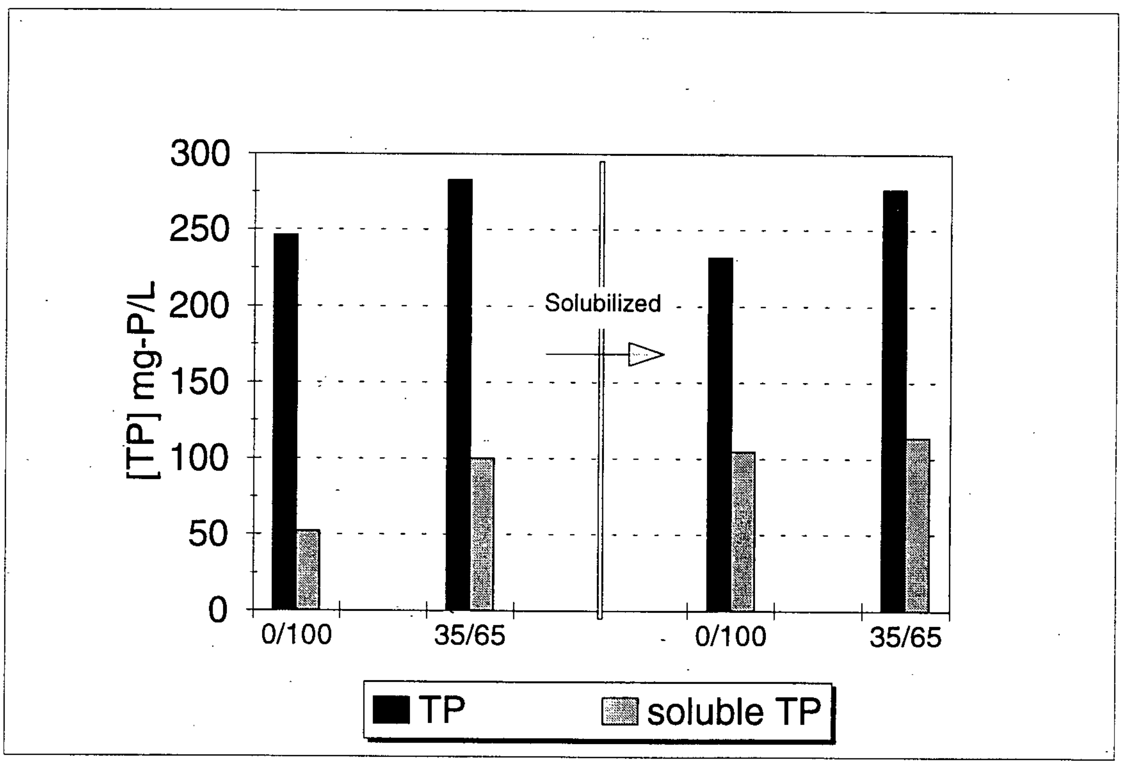


FIGURE 4.32: Solubilization of Phosphorus, TP

4.8.2 Nitrogen

TKN was generally conserved between influent and ATAD effluent, and consistently increased with each addition of secondary sludge. Less than complete conservation and recorded increases in TKN potentially could be attributed to sampling and analytical error, as % differences are less than 15% in most cases. Larger differences are associated with Runs 4 and 5, when the high demand for secondary sludge resulted in changes in sludge composition over the test period, and also, with larger concentration, most likely due to the additional errors associated with the dilution of samples. Boulanger (1995) recorded differences in off-gas nitrogen concentrations and attributed greater loses to nitrification/denitrification conversion. No evidence of this conversion was noted in this work. Variability in TKN levels between the same mix ratios, tested in different runs, was low except in Run 5, where concentrations were consistently lower than in Run 4. Again, this can be attributed to the high demand for secondary sludge and resulting decrease in sludge consistency.

Nitrate levels never exceeded 2 mg/L in either ATAD reactor, and were usually below 1 mg/L, confirming that nitrification was inhibited by the thermophilic temperatures maintained throughout the processing period.

Ammonia-N levels increased in the feed streams with increases in the fraction of secondary sludge, although not proportionally. Pre-solubilization of the feed sludge also resulted in increases in ammonia levels. The addition of NaOH resulted in increases within the first hour of up to 13 mg-N/L, with additional increases, over the next 12 hours, of as much as 60 mg-N/L. Although Knezevic (1993) also recorded increases in NH_4 concentrations with increases in mixing time after NaOH addition, increases were not of the same magnitude. Ammonia-N has been demonstrated to accumulate under the oxygen limited environment in ATAD (Mason et al., 1987b), and in all but the first run, NH_4 accumulated as a result of ATAD treatment. Pre-solubilization resulted in minimal additional increases in NH_4 in the ATAD reactors, as similarly observed for anaerobic digestion of pre-solubilized mixed sludge (Knezevic, 1993). Figure 4.33 is a bar graph of average feed and ATAD concentrations, exact values can be found in Appendix G.

Similar to the solubilization of phosphorus, pre-solubilization of the feed streams resulted in a noticeable increase in soluble TKN with 100% secondary sludge only; with the mixed sludge feed stream, no additional benefits were gained, as the material is solubilized when mixed when mixed with primary sludge.. Figure 4.34 depicts this transformation, using the average concentrations calculated for Runs 5 & 6.

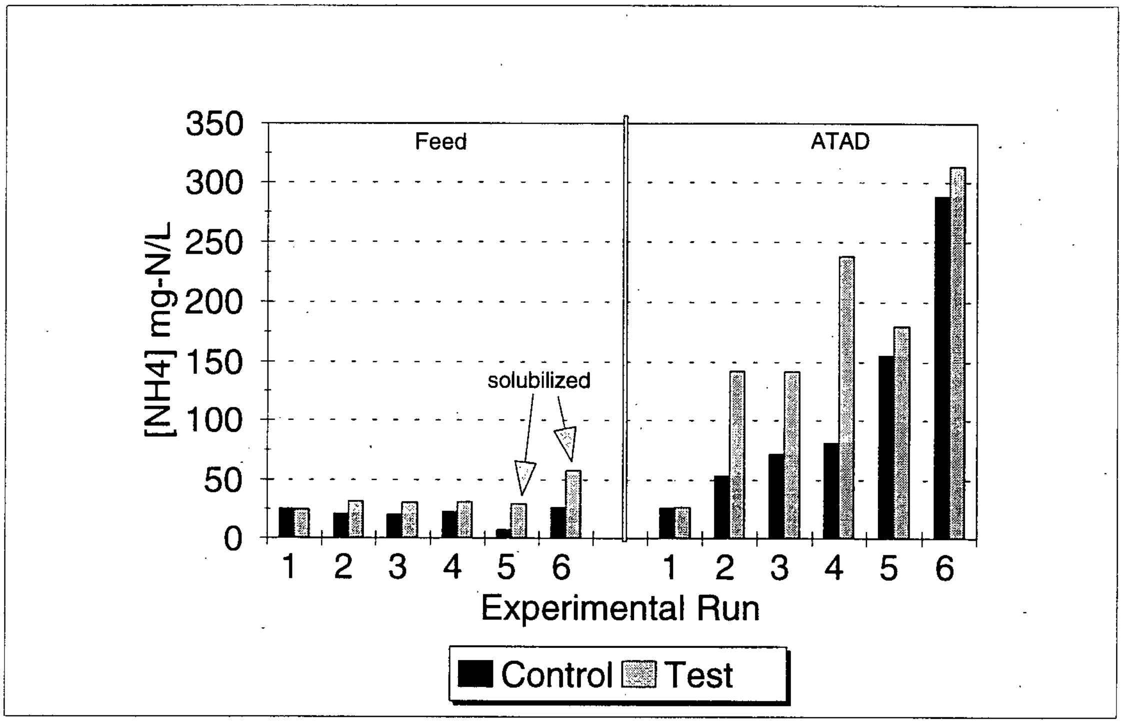


FIGURE 4.33: Fate of Nitrogen, Ammonia

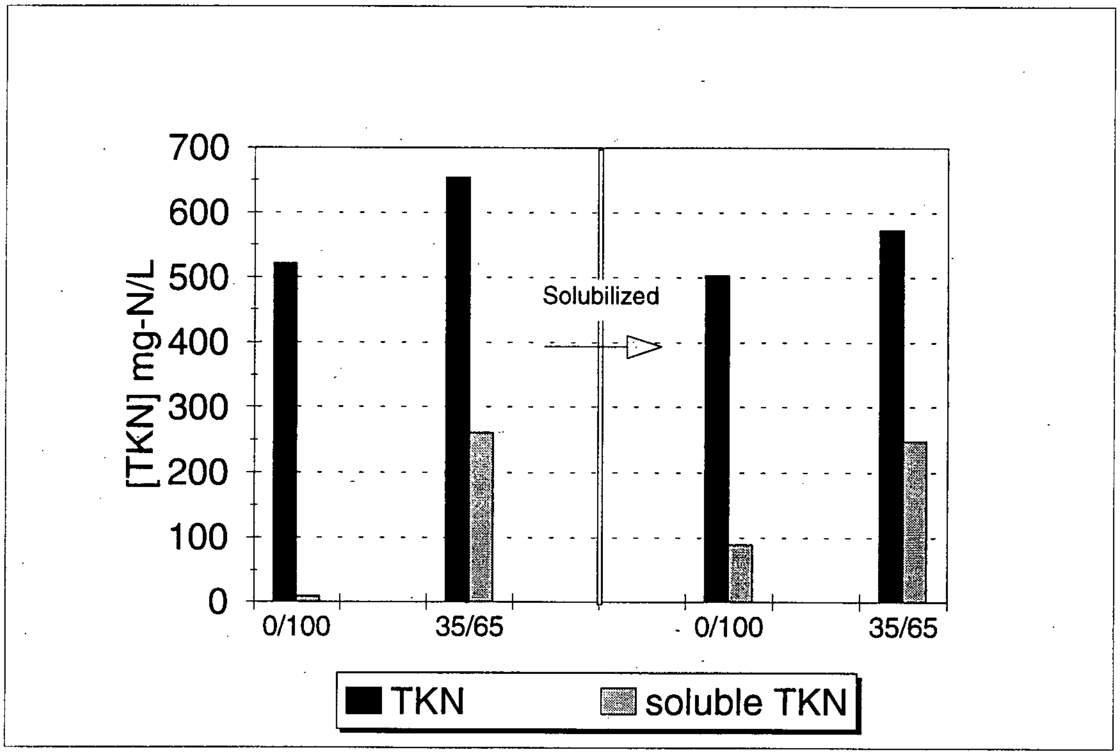


FIGURE 4.34: Solubilization of Nitrogen, TKN

4.9 Total Organic Carbon

TOC values confirm that NaOH solubilized the feed streams in Runs 5 & 6. Again, the effects of NaOH addition increased with mixing time; initial elevated TOC concentrations were further increased after 12 hours. Investigations on the effect of mixing time by Knezevic (1993) indicate that the increase is most rapid between 3 and 9 hours for 15 meq/L of NaOH. As illustrated in Figure 4.35,. the difference in TOC levels between the test and control reactors in Runs 1 to 4, also supports the assumption that the mixing of primary and secondary sludges alone results in solubilization of sludge components; however, in addition, the high level of TOC in the test feed in Run 4 indicates that secondary sludge contributed a high portion of solubilized material.

TAD should result in increased solubilization and thus, increased TOC. All runs, except the control reactor in Runs 2 & 3, exhibit this trend. This apparent discrepancies, as well as other small differences, may be a result of the use of average values calculated from the reduced sample size in Runs 1 to 4, or as a result of large multiplication factors required by the analyzer for the high concentrations in the sludge. Appendix H contains the complete data sets of TOC samples used for interpretation of the 6 runs.

In addition, it is interesting to note that pre-solubilization of the feed, in Runs 5 & 6, resulted in a reduction in overall TOC concentrations after digestion. This may be an indication that the addition of NaOH results in precipitation of material in TAD.

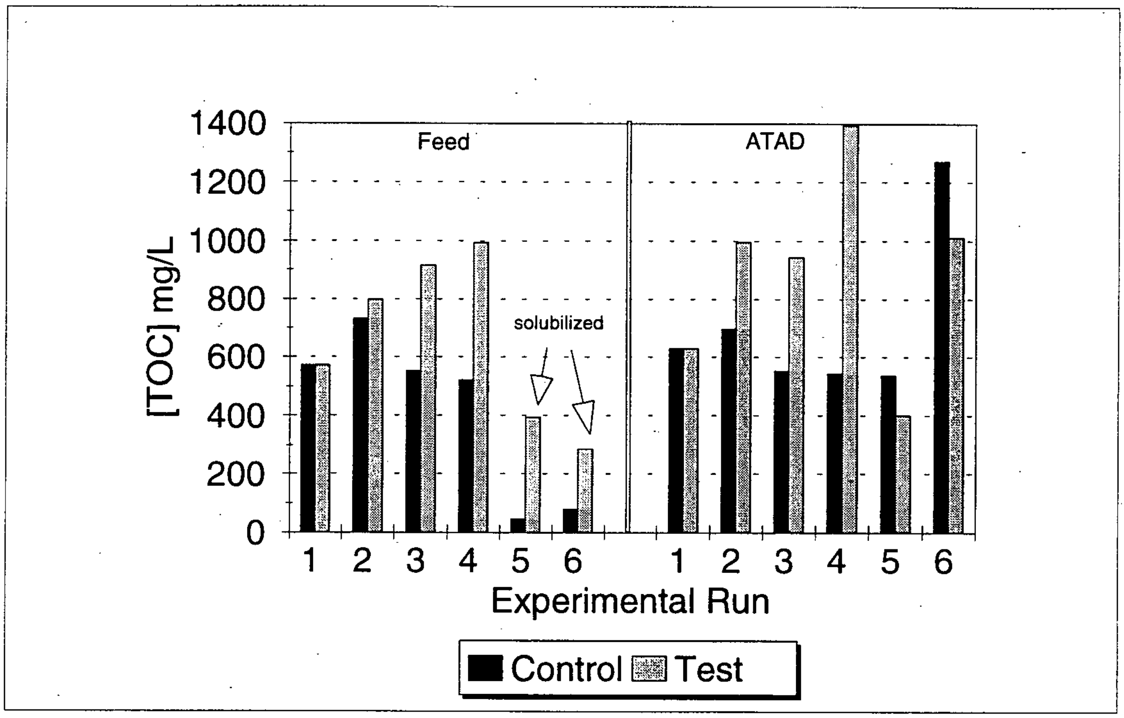


FIGURE 4.35: Averaged TOC

5.0 SUMMARY

5.1 Operating Conditions

In general, the operating conditions of the pilot scale ATAD reactors were stable throughout the experimental period, except for prior to, and during, Run 5:

- ATAD reactor retention time was maintained at 3 days
- Temperatures remained in the thermophilic range between 40°C and 52°C
- ORP values were consistent and ranged between -200 mV and -450 mV
- Airflow rates maintained DO < 1 mg/L and did not produce anaerobic conditions
- pH was stable and generally neutral in non-solubilized experiments
- Feed solids were maintained consistent with different streams, on average 1.1% TS

Additionally, the control reactor demonstrated an inherent difference from the test reactor with temperature and ORP values always being more positive, even with identical feed.

Although airflow rates were maintained consistent between the test and control reactor, average values were not consistent between runs and potentially effected VFA production.

Resulting TS destruction efficiencies in ATAD were not consistent between runs, and the control reactor exhibited higher efficiency for the same sludge mix ratios. The reduction in TS destruction, with increased proportions of secondary sludge, can not be associated directly with the change in mix ratio due to these differences. Similarly, the effect of pre-solubilization can not be accurately assessed in this pilot scale system.

The inconsistency of results in Runs 5 may be explained by an overall decrease in secondary sludge consistency and changes in the process culture in ATAD. The pilot plant wastewater treatment process was providing the mixed liquor for the secondary sludge used to feed the ATAD reactors. Although there were no obvious signs of process upset, due to the high wasting rates required to provide enough secondary sludge to the ATAD reactors, the mixed liquor became weaker, thus reducing the available substrate and nutrients for the process micro-organisms. Additionally, prior to receiving this feed, the reactors received no feed for a period of 10 days and may have still been recovering from a starvation period. Similarly, as a result of aeration studies during this same period, dissolved oxygen levels were increased to > 4 mg/L, which would have also resulted in a shift in the ATAD process culture; thus, the system may not have fully recovered before Run 5. Evidence to support this theory would normally be a drop in temperature due to reduced biological activity; however, the scale of the process and large energy contribution of the mixing and aeration device are capable of compensating for any loss in biological heat generation.

5.2 Enhancement of VFA Production

From the results presented, secondary sludge definitely enhanced VFA production in ATAD. Both mixed sludge feed and secondary sludge alone resulted in higher production and accumulation of VFA than the primary sludge control. Secondary sludge alone, produced the highest VFA concentrations. No relationship was established between increases in the proportion of secondary sludge and resulting increases in VFA.

In addition, ATAD resulted in consistent predominance of > 85% acetate in total VFA measurements. Feed streams consisting of a proportion of primary sludge demonstrated a co-dominance of acetate and propionate, but were similarly altered in ATAD.

The process upset described in the previous section resulted in inconsistent and low levels of VFA in Run 5.

5.3 Pre-Solubilization

The addition of NaOH was effective in pre-solubilizing secondary sludge, although results also illustrate that the mixing of primary and secondary sludge alone induces solubilization. Although, chemical pre-solubilization of feed sludge increases the concentration of VFA in the feed, it can not be determined what effect this pre-treatment has in ATAD, due to the inconsistencies with Run 5. Experiments were not rerun to check or correct this, since earlier runs provided consistent and positive results. In addition, chemical solubilization would result in additional costs, and increases in storage and handling requirements, in plant operations. Thermophilic temperatures alone cause the lysis of mesophilic substrate microorganisms in TAD; thus, pre-solubilization is unnecessary and introduces additional pH changes to the process affecting reactor stability.

5.4 Nutrients

As previously determined by Boulanger (1995), ATAD results in the release of stored phosphorus. At the same time, the mixing of secondary sludge with primary sludge alone results in a significant release before digestion. Nitrification is inhibited in the thermophilic environment of TAD, allowing ammonia to accumulate. The use of VFA enriched ATAD effluent, in recycle to nutrient removal processes, would require post-treatment of some type.

In contrast, in the land application of ATAD sludge, the associated nutrient solubilization correlates with an increase in availability for plants, particularly with nitrogen, through the accumulation of ammonia (Murray et al., 1990). In addition, the inhibition of nitrification in ATAD results in almost no nitrates; however, the conversion of ammonia to nitrates, on-site, can not be ruled out, thus the possibility for groundwater contamination can not be ruled out.

5.5 Phosphorus Release Mitigation

As highlighted by Rabinowitz & Barnard (1995), and by Niedbala (1995) in studies in Penticton, BC, mitigation of nutrient release for supernatant recycle can be achieved with chemical treatment of the return stream. To minimize the requirements of this procedure, effective dewatering before digestion will reduce the volume of digested sludge requiring treatment. In addition, rapid dewatering with aeration will prevent the release of nutrients to the liquid stream, as will thickening primary and secondary sludges separately. Nutrient release may also be reduced by promoting the formation of struvite ($MgNH_4PO_4$), without chemical addition.

Chemical pre-treatment for the precipitation of phosphorus during digestion, as suggested by Niedbala (1995) for anaerobic digestion, does not appear to be an option here considering the effect that NaOH had on the pH stability of ATAD. The use of lime, $Ca(OH)_2$, or other chemicals, might prove better than NaOH and could be investigated for use in ATAD.

Additionally, an alternative option may be found in the nuclear power industry. Studies have recently been conducted on the use of filamentous blue-green algae in recycle lines to remove N and P (Radway et al., 1994). The algae was introduced, at the point of discharge from a thermal process, into a recycle line with extended retention time of 1 day. The algae was then harvested before reintroduction to process, and used for reinoculation of the discharge plume. Tested on a range of temperature variations similar to that of TAD effluent, it was found that 82% of PO4 and 70% of TP could be removed. Temperature fluctuations, inherent in uncontrolled cooling, had minimal effects on efficiency.

5.6 Alternative Applications

As highlighted in the review of thermophilic aerobic digestion, ATP in dual digestion has demonstrated to improve anaerobic digester performance. Since VFA, specifically acetate, are utilized in methanogenic reactions, the demonstrated enhancement of VFA production could also be applied in further enhancement of anaerobic digestion. Chu (1995) proposes that the syntropic relationship between acetogenic and methanogenic reactions could be uncoupled, to allow for separate and complete optimization of methanogenic reactions.

Land application of the ATAD digested sludge can also be considered, as a result of the pasteurization effects of TAD, as well as the demonstrated increase in nutrient availability. Although increased levels of VFA, as produced with the digestion of secondary sludge in ATAD in this research, are considered an indicator of non-stabilized sludge for land disposal, increases in the retention time in ATAD, as a result of both regulatory requirements and the additional retention time of subsequent stages in a full process train, would result in the consumption of VFA.

6.0 CONCLUSIONS AND RECOMMENDATIONS

Based on the results of the 6 experiments performed in the pilot scale ATAD units at UBC, the following conclusions are made in response to project objectives:

1. Secondary sludge enhances VFA production and accumulation in TAD, in comparison to primary sludge alone.

2. Secondary sludge alone, enhances VFA production and accumulation in TAD, in comparison to primary sludge, or to a mix of primary and secondary sludge.

3. Pre-solubilization of secondary sludge with NaOH increases VFA production in feed sludge (undigested); however, no conclusions can be drawn with respect to TAD.

4. Chemical pre-solubilization of feed produces fluctuations in ATAD operating parameters.

5. TAD consistently results in > 85% acetate with respect to total VFA production.

6. Pre-solubilization with NaOH results in solubilization of substrate, particularly the release of stored phosphorus.

7. Mixing of primary and secondary sludge results in solubilization of substrate, particularly the release of stored phosphorus.

8. TAD results in additional solubilization and release of phosphorus.

9. TAD results in inhibition of nitrification and accumulation of ammonia.

10. Pre-solubilization with NaOH results in reduced overall solubilization of TAD effluent, as measured by TOC.

In addition, the following conclusions were made, based on analysis of other parameter measured in the study, as well as observations of process operations:

- Variations in airflow rates, within the oxygen limited aeration state established, appear to effect VFA production - lower airflow rates produce higher VFA concentrations.
- Changes in mixed liquor and secondary sludge quality (thinner and weaker) and increases in aeration to aerobic levels, results in process upset of ATAD.
- Inherent differences appear to exist between the two ATAD reactors effecting temperature, ORP and solids destruction.

Based on these conclusions and the results of this study, the following recommendations are made:

1. No further investigation of pre-solubilization with NaOH.
2. Pilot and full scale investigation of the impact of using VFA enriched TAD effluent for recycle to BNR processes.
3. Investigation into the impact of post-treatment of TAD effluent for mitigation of nutrient loading to BNR processes.
4. In future research, more accurate control and measurement of airflow rates to eliminate any secondary effects in assessment of other variables.
5. In future research and evaluation of ATAD facilities, determination of VS and VSS, in addition to TS, to more accurately assess treatment efficiency.
6. With respect to UBC's pilot plant ATAD unit, confirmation and quantification of inherent differences in operating performance.

REFERENCES

American Public Health Association, American Water Works Association, and Water Pollution Control Federation (1989), *Standard Methods for the Examination of Water and Wastewater*, 18th edition, APHA, AWWA & WPCF, Washington, DC, USA.

Anderson, B.C. and Mavinic, D.S. (1993), *Behaviour and Control of Nutrients in the Enhanced Aerobic Digestion Process: Pilot-scale Studies*, Environmental Technology, 14(4):301-318.

Anderson, B.C., Mavinic, D.S. and Oleszkiewicz, J.A. (1995), *Stabilization of Combined Wastewater Sludge: Anaerobic Processes*, Canadian Journal of Civil Engineering, National Research Council Canada, 22(2):223-234.

Appleton Jr., A.R., Leong, C.J, and Venosa, A.D. (1986a), *Pathogen and Indicator Organism Destruction by the Dual Digestion System*, J. WPCF, 58 (10):992-999.

Appleton Jr., A.R. and Venosa, A.D. (1986b), *Technology Evaluation of the Dual Digestion System*, J. WPCF, 58 (7):764-773.

Atherton, H. (1995), *Primary Sludge Fermentation Using a Pilot-Scale Mainstream Fermenter to Enhance Biological Phosphorus Removal*, M.A.Sc. Thesis, Department of Civil Engineering, University of British Columbia, Vancouver, Canada.

Baier, H. and Zwiefelhofer, H.P. (1991), *Effects of Aerobic Thermophilic Pretreatment on Anaerobic Sludge Stabilisation and Subsequent Treatment Steps*, Treatment and Use of Sewage Sludge and Liquid Agricultural Wastes, ed. L'Hermite, P., Elsevier Applied Science, New York, USA, p.520-534.

Bomio, M., Sonnleitner, B. and Fiechter, A. (1989), *Growth and Biocatalytic Activities of Aerobic Thermophilic Populations in Sewage Sludge*, Appl. Microbiol. Biotechnol., 32:356-362.

Booth, M.G. and Tramontini, E. (1984), *Thermophilic Sludge Digestion Using Oxygen and Air*, Chapter 15, Sewage Sludge Stabilization and Disinfection, Ellis Harwood Ltd., Chichester, England, p.293-311.

Boulanger, M. (1995), *The Effect of Varying Air Supply Upon Supernatant Quality in Autoheated Thermophilic Aerobic Digesters Treating Waste Sludge from a Biological Phosphorus Removal Process*, M.A.Sc. Thesis, Department of Civil Engineering, University of British Columbia, Vancouver, Canada.

Boulanger, M., Fries, K. and Mavinic, D. S. (1995), *The Effect of Air Supply on Quality of Return Flows from ATAD Sludge Stabilization*, Proceedings of the WEF 68th Annual Conference & Exposition, Water Environment Federation WEFTEC'95, Oct 21-25, 1995,Miami Beach, FL, p. 303-311.

Boulanger, M., Mavinic, D.S. and Nemeth, L. (1994), *The Effect of Air Supply on Solids Destruction and Nutrient Balance for Thermophilic Aerobic Digesters*, Proceedings of CSCE Environmental Engineering Conference,Winnipeg, MB, Canada, June 1- 4, 1994, Vol. III, p.67-76.

Brock, T.D. and Madigan, M.T., (1991), *Biology of Microorganisms*, 6th Edition, Prentice Hall, New Jersey, U.S.

Bruce, A.M. (1987), *Other Invesigations of Thermophilic Aerobic Digestion in the UK - Fundamental Aspects of Aerobic Thermophilic Biodegradation*, Treatment of Seweage: Thermophilic Aerobic Digestion and Processing Requirements for Land Filling, eds. Bruce, A., Colin, F. and Newman, P., Elsevier Applied Science, London, UK, p.39-50.

Bruce, A.M. and Oliver, B. (1987), *Heating and Cooling of Sewage Sludge - Some Recent Developments*, Water Pollution Control, 86(1):104-115.

Burnett, C.H. (1995), *An Overview of Autothermal Thermophilic Aerobic Digestion Facilities in Europe and Canada*, Proceedings of WEF Specialty Conference - New and Emerging Environmental Technologies and Products for Wastewater Treatment and Stormwater Collection, June 4-7, 1995, Toronto, ON,Canada, p.5-33 to 5-44.

Chu, A. (1995), *Volatile Fatty Acid Metabolism in Thermophilic Aerobic Digestion of Sludge*, Ph.D. Thesis, Department of Civil Engineering, University of British Columbia, Vancouver, Canada.

Chu, A., Mavinic, D.S., Kelly, H.G. and Ramey, W.D. (1994), *Volatile Fatty Acid Production in Thermophilic Aerobic Digestion of Sludge*, Wat. Res., 28(7):1513-1522.

Chynoweth, D.P. and Mah, R.A. (1970) *Volatile Acid Formation in Sludge Digestion*, Anaerobic Biological Treatment Processes, p. 41-54..

Deeney, K., Hahn, H., Leonhard, D. and Heidman, J. (1991), *Autoheated Thermophilic Aerobic Digestion*, Water Environment & Technology, October, p. 65-72.

Edgington, R. and Clay, S. (1993), *Evaluation and Development of a Thermophilic Aerobic Digester at Castle Donington Sewage-Treatment Works*, J. IWEM, April, 7:149-155.

Fiechter, A. and Sonnleitner, B. (1988), *Themophilic Aerobic Stabilization*, Sewge Sludge Treatment and Use, eds. Dirkzwager, A.H. and l'Hermite, P., Elsevier Applied Science, New York, USA, p.291-301.

Fuggle, R.W. and Spensley, R.A. (1985), *New Developments in Sludge Digestion and Pasteurization*, Water Pollution Control, 84:33-43.

Gould, M.S. and Drnevich, R.F. (1978), *Autothermal Thermophilic Aerobic Digestion*, J. Env. Eng. Div., ASCE, 104 (EE2): 259-270.

Grueninger, H., Sonnleitner, B. and Fiechter, A (1984), *Bacterial Diversity in Thermophilic Aerobic Sewage Sludge, III. A Source of Organisms Producing Heat-Stable Industrially Useful Enzymes*, Eur. J. Appl. Microbiol. Biotechnol., 19:414-421.

Hamer, G. (1987), *Fundamental Aspects of Aerobic Thermophilic Biodegradation*, Treatment of Seweage: Thermophilic Aerobic Digestion and Processing Requirements for Land Filling, eds. Bruce, A., Colin, F. and Newman, P., Elsevier Applied Science, London, UK , p.2-19.

Hamer, G. and Bryers, J.D. (1985), *Aerobic Thermophilic Sludge Treatment - Some Biotechnological Concepts*, Conservation & Recycling, 8(1-2):267-284.

Hamer, G. and Zwiefelhofer, H.P. (1986), *Aerobic Thermophilic Hygienization - A Supplement to Anaerobic Mesophilic Waste Sludge Digestion*, Chemical Engineering Research & Design, 6(6):417-424.

Häner, A., Mason, C.A. and Hamer, G. (1994), *Death and Lysis During Aerobic Thermophilic Sludge Treatment: Characterization of Recalcitrant Products*, Wat. Res., 28(4):863-869.

Jakob, J., Roos, H-J. and Siekmann, K. (1988), *Aerobic-Thermophilic Methods for Disinfecting and Stabilizing Sewage Sludge*, Sewage Sludge Treatment and Use, eds Dirkzwager, A. H. and l'Hermite, P., Elsevier Applied Science, New York, USA, p.378-389.

Kabrick, R.M. and Jewell, W.J. (1982), *Fate of Pathogens in Thermophilic Aerobic Sludge Digestion*, Water Research, 16:1051-1060.

Kambhu, K. and Andrews, J.F. (1969), *Aerobic Thermophilic Process for the Biological Treatment of Wates - Simulation Studies*, J. WPCF, 41(5):R127-R141, Part 2.

Kelly, H.G (1996), personnal communication, Dayton & Knight Ltd., Vancouver, BC, Canada..

Kelly, H.G. (1991), *Autothermal Tehmophilic Aerobic Digestion: A Two-Year Appraisal of Canadian Facilities*, Proceedings of 1991 ASCE Environmental Engineering Specialty Conference, Reno, Nevada, p. 296-301.

Kelly, H.G. (1990), *Demonstration of an Improved Digestion Process for Municipal Sewage Sludges*, Supply and Services Canada, Contract KE405-8-6575/01-SE, UP-D8-010.

Kelly, H.G., Jennings, C., Sivyer, D., Robinson, L., Frese, H. and Cale, C. (1995), *Hot Tips for Autothermal Aerobic Digestion*, Operations Forum, 12(5), May.

Kelly, H.G., Melcer, H., and Mavinic, D.S., (1993), *Autothermal Thermophilic Aerobic Digestion of Municipal Sludges: A One-Year, Full-Scale Demonstration Project*, Water Environ. Res., 65(7):849-861.

Knezevic, Z. (1993), *Enhanced Anaerobic Digestion of Combined Wastewater Sludges Through Solubilization of Waste Activated Sludge*, M.A.Sc. Thesis, Department of Civil Engineering, University of British Columbia, Vancouver, Canada.

Langeland, G., Paulsrud, B. and Haugan, B-E. (1984), *Aerobic Thermophilic Stabilization, Inactivation of Micro-organisms in Sewage Sludge by Stabilization Processes*, eds. Strauch, D., Havelaar and l'Hermite, P., Elsevier Applied Science, New York, USA, p. 38-47.

Loll, U. (1987), *Combined, Aerobic, Thermophilic and Anaerobic Digestion of Sewage Sludge*, Treatment of Seweage: Thermophilic Aerobic Digestion and Processing Requirements for Land Filling, eds. Bruce, A., Colin, F. and Newman, P., Elsevier Applied Science, London, UK, p.20-28.

Mason, C.A., Hamer, G., Fleischmann, T. and Lang, C. (1987a), *Bioparticulate Solubilization and Biodegradation in Semi-Continuous Aerobic Thermophilic Digestion*, Water, Air and Soil Pollution, 34(August):399-407.

Mason, C.A., Hamer, G., Fleischmann, T. and Lang, C. (1987b), *Aerobic Themophilic Biodegradation of Microbial Cells*, Appl. Microbiol. Biotechnol., 25:568-576.

Mason, C.A., Häner, A. and Hamer, G. (1992), *Aerobic Thermophilic Waste Sludge Treatment*, Wat. Sci. Tech., 25(1):113-118.

McIntosh, K.B. and Oleszkiewicz, J.A. (1996), *Voaltile Fatty Acid Production in Aerobic Thermophilic Pre-Treatment of Sludge*, Proceedings of 4th Environmental Engineering Specialty Conference, CSCE, May 29-June 1, 1996, Edmonton, AB,Canada, p.373-382.

Morgan, S.F. and Gunson, H.G. (1987), *The Development of an Aerobic Thermophilic Sludge Digestion System in the UK*, Treatment of Seweage: Thermophilic Aerobic Digestion and Processing Requirements for Land Filling, eds. Bruce, A., Colin, F. and Newman, P., Elsevier Applied Science, London, UK , p.29-38.

Morgan, S.F., Gunson, H.G., Littlewood, M.H. and Winstanley, R. (1984), *Aerobic Thermophilic Digestion of Sludge Using Air*, Chaper 14, Sewage Sludge Stabilization and Disinfection, Ellis Harwood Ltd., Chichester, England, p.278-292..

Murray, K.C., Tong, A. and Bruce, A.M. (1990), *Thermophilic Aerobic Digestion - A Reliable And Effective Process for Sludge Treament at Small Works*, Wat. Sci. Tech., 22 (3-4):225-232.

Niedbala, D. (1995), *Pilot-Scale Studies of the Anaerobic Digestin of Combined Wastewater Sludges and Mitigation of Phosphorus Release*, M.A.Sc. Thesis, Department of Civil Engineering, University of British Columbia, Vancouver, Canada.

Pagilla, K.R., Craney, K.C. and Kido, W.H. (1995), *Aerobic Thermophilic Pretreatment of Mixed Sludge for Pathogen Reduction and Nocardia Control*, Proceedings of WEF Specialty Conference - New and Emerging Environmental Technologies and Products for Wastewater Treatment and Stormwater Collection, June 4-7, 1995, Toronto, ON, Canada, p.5-21 to 5-32.

Ponti, C., Sonnleitner, B. and Fiechter, A. (1995), *Aerobic Thermophilic Treatment of Sewage Sludge at Pilot Plant Scale - 1. Operating Conditions, and 2. Technical Solutions and Process Design*, Journal of Biotechnology, 38:173-19.

Rabinowitz, B. and Barnard, J.L. (1995), *Sludge Handling for Biological Nutrient Removal Plants*, IAWQ 1994-95 Yearbook, London, England, p.11-19.

Radway, J.C., Weissman, J.C, Wilde, E.W. and Benemann, J.R. (1994), *Nutrient Removal by Thermophilic Fischerella (Mastigocladus Laminosus) in a Simulated Algaculture Process*, Bioresource Technology, 50(3):227-233.

Rimkus, R.R., Ryan, J.M. and Cook, E.J. (1982), *Full-scale Thermophilic Digestion at the West-Southwest Sewage Treatment Works*, Chicago, Illinois, J. WPCF, 54 (11):1447-1457.

Russell, N.J. (1984), *Mechanisms of Thermal Adaptation in Bacteria: Blueprints for Survival,* TIBS, March, p.108-112.

Sharp, D.W.A., ed., (1990) *The Penguin Dictionary of Chemistry*, 2nd edition, Penguin Books, UK.

Smith Jr., J.E., Young, K.W. and Dean, R.B. (1975), *Biological Oxidation and Disinfection of Sludge*, Water Research, 9:17-24.

Smyth, R. (1996), personnel comminucation, Saitherm Engineering Ltd., North Vancouver, BC, Canada.

Sonnleitner, B. (1983), *Biotechnology of Thermophilic Bacteria - Growth, Products and Applications,* Advances in Biochemical Engineering/Biotechology, Vol. 28, Springer-Verlag, Berlin, p.70-138.

Sonnleitner, B. and Fiechter, A. (1983a), *Bacterial Diversity in Thermophilic Aerobic Sewage Sludge, I. Active Biomass and Its Fluctuations,* Eur. J. Appl. Microbiol. Biotechnol., 18:47-51.

Sonnleitner, B. and Fiechter, A. (1983b), *Bacterial Diversity in Thermophilic Aerobic Sewage Sludge, II. Types of Organisms and Their Capacities,* Eur. J.Appl. Microbiol. Biotechnol., 18:174-180.

Sonnleitner, B. and Fiechter, A. (1983c), *Thermophilic Microflora in Aerated Sewage Sludge,* Processing and Use of Sewage Sludge, Proceedings of the Third International Symposium, Commission of the European Communities, September 27-30, 1983, Brighton, p.235-236.

Sonnleitner, B. and Fiechter, A. (1985), *Microbial Flora Studies inThermophilic Aerobic Sludge Treatment,* Conservation & Recycling, 8 (1-2):303-313.

Strauch, D., Hammel, H-E. and Philipp, W. (1985), *Investigations of the Hygienic Effect of Single Stage and Two-Stage Aerobic-Thermophilic Stabilization of Liquid Raw Sludge*, Inactivation of Micro-organisms in Sewage Sludge by Stabilization Processes, Elsevier Applied Science, New York, USA, p. 48-63.

Surucu, G.A., Chian, E.S.K. and Engelbrecht, R.S. (1976), *Aerobic Thermophilic Treatment of High Strength Wastetwaters,* J. WPCF, 48(4):669-679.

Trim, B.C. and McGlashan J.E. (1984), *Sludge Stabilisation and Disinfection by Means of Autothermal Aerobic Digestion with Oxygen,* Wat. Sci. Tech., 17:563-573.

Tyagi, R.D., Tran, F.T. and Agbebavi, T.J. (1990), *Mesophilic and Themophilic Aerobic Digestion of Municipal Sludge in an Airlift U-Shaped Bioreactor*, Biological Wastes, 31:251-266.

U.S. EPA (1990), *Autothermal Thermophilic Aerobic Digestion of Municipal Wastewater Sludge,* Environmental Regulations and Technology, Cincinnati, OH, EPA/625/10-90/007, September.

Vismara, R. (1985), *A Model for Autothermic Aerobic Digestion: Effects of Scale Depending on Aeration Efficiency and Sludge Concentration,* Water Research, 19(4):441-447.

Wolf, P. (1982), *Aerobic Thermophilic Stabilization of Sludge Versus Anaerobic Digestion and Other Kinds of Sludge Treatment at Middle-Sized Plants with Respect to Power Conservation and Economy*, Wat. Sci. Tech., 14:727-738.

Wolinski, W.K. (1985), *Aerobic Thermophilic Sludge Stabilization Using Air (with discussion)*, Water Polution Control, 8(8):433-445.

Zwiefelhofer, H.P. (1985), *Aerobic-Thermophilic/Anaerobic-Mesophilic Two-Stage Seage Sludge Treatment: Practical Experiences in Switzerland*, Conservaton & Recycling, 8 (1-2):285-301.

APPENDICES

APPENDIX A: ABBREVIATIONS

ATAD	autothermal thermophilic aerobic digestion
ATP	aerobic thermophilic pretreatment
AVG	average
BC	British Columbia, Canada
C	control feed/reactor
CH_4 or CH4	menthane
CO_2 or CO2	carbon dioxide
DO	dissolved oxygen
L	litre
MAX	maximum
meq/L	milliequivalen per litre
MIN	minimum
ML	mixed liquor
mL	millilitre
NaOH	sodium hydroxide
NH_4 or NH4	ammonia nitrogen
NO_x or NOx	nitrate and nitrite nitrogen
N_2 or N2	nitrogen (gas)
O_2 or O2	oxygen
PO_4 or PO4	ortho-phosphate (soluble phosphorus)
STDS	standard deviation, sample
T	test feed/reactor
TAD	thermophilic aerobic digestion
TKN	total Keidjal nitrogen
TOC	total organic carbon
TP	total phosphorus
TS	total solids
UBC	University of British Columbia
VFA	volatile fatty acids
VS	volatile solids
VSS	volatile suspended solids

Date

09/02 a	month/day am (ie. September 2nd)
10/17 p	month/day pm (ie. October 17th)

Mix Ratio

35/65	35% primary sludge/65% secondary sludge

APPENDIX B: PHOTOS

FIGURE B1: UBC Pilot Plant Facility (within trailer) with trickling filter tower unit

FIGURE B2: Raw Sewage Storage Tanks (sodium bicarbonate being added)

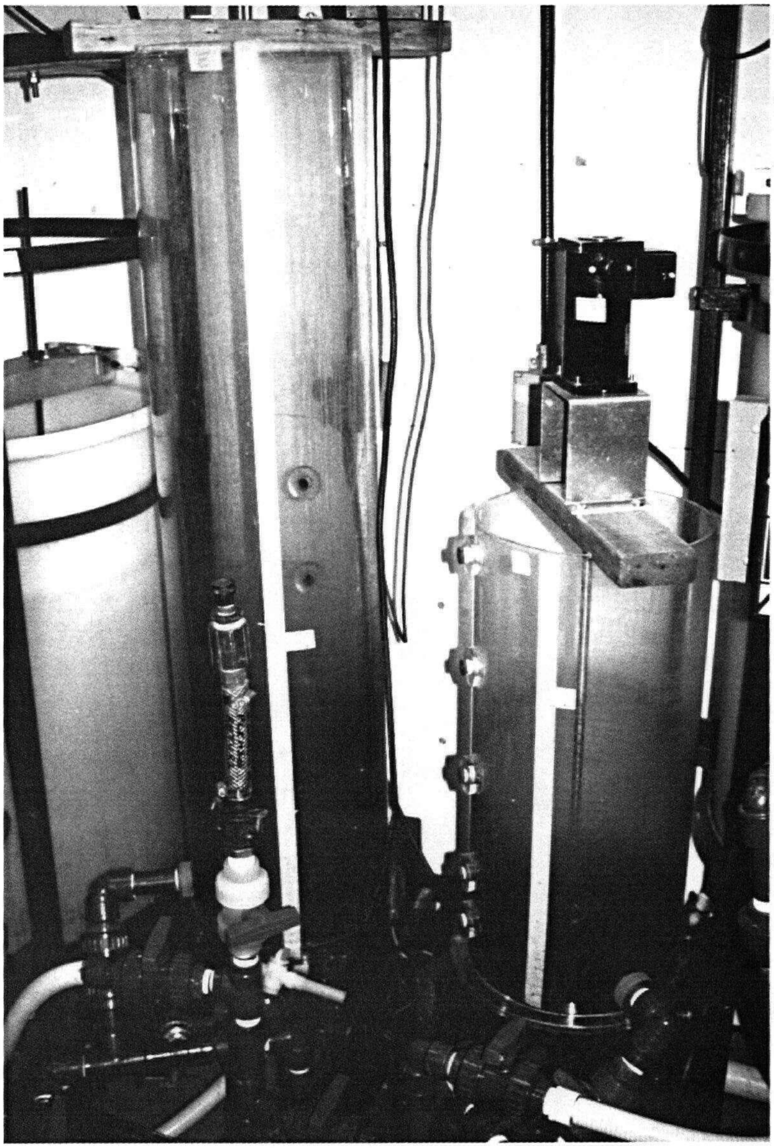


FIGURE B3: Sludge Feed Tanks for ATAD Reactors with mixers

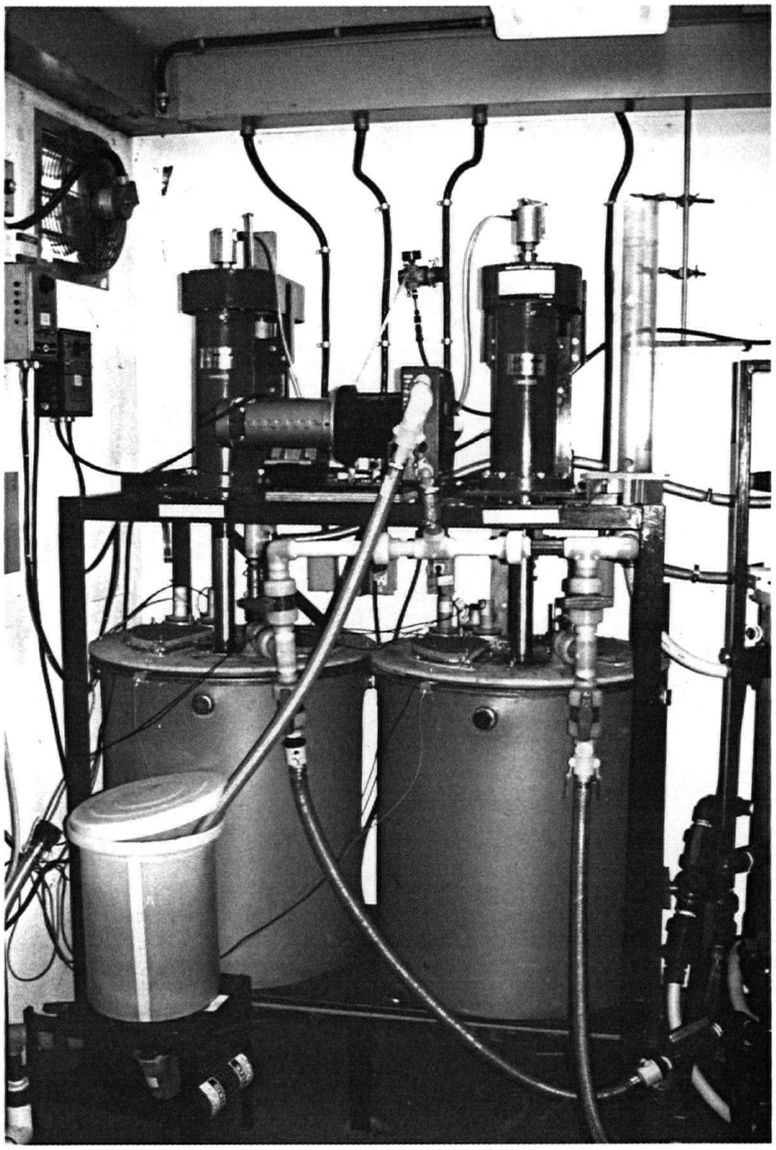
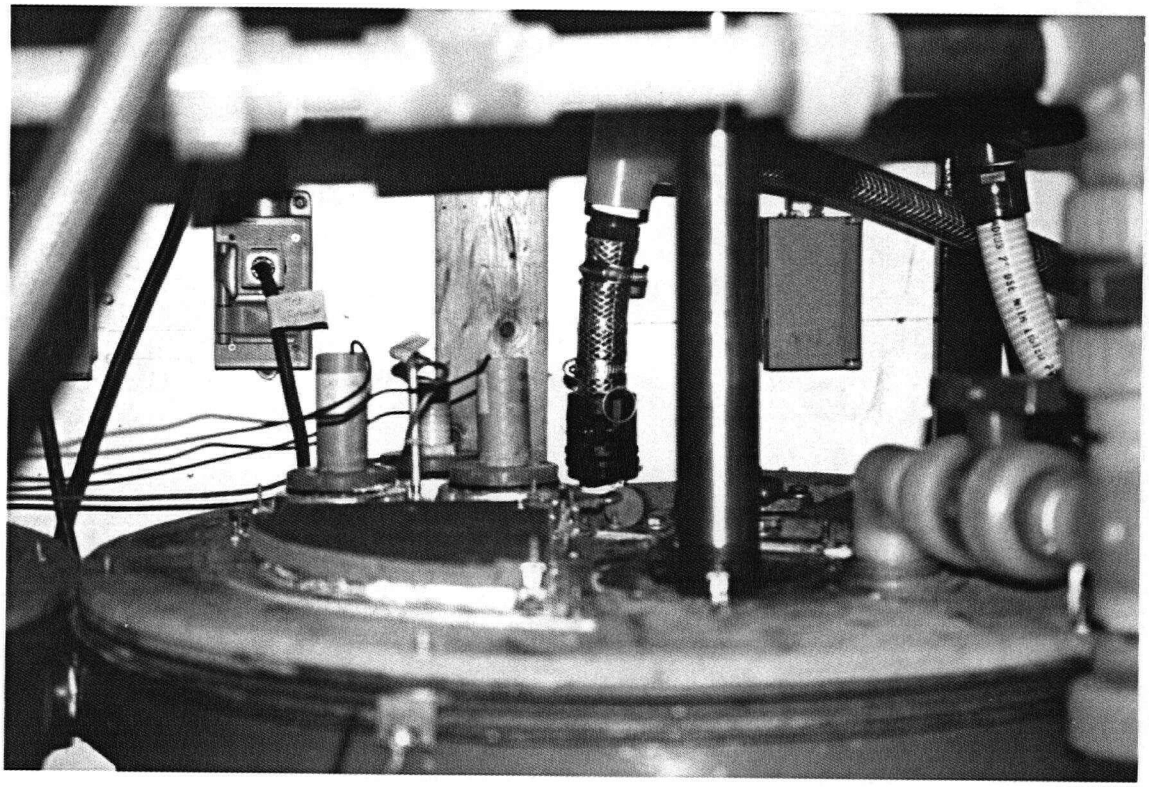
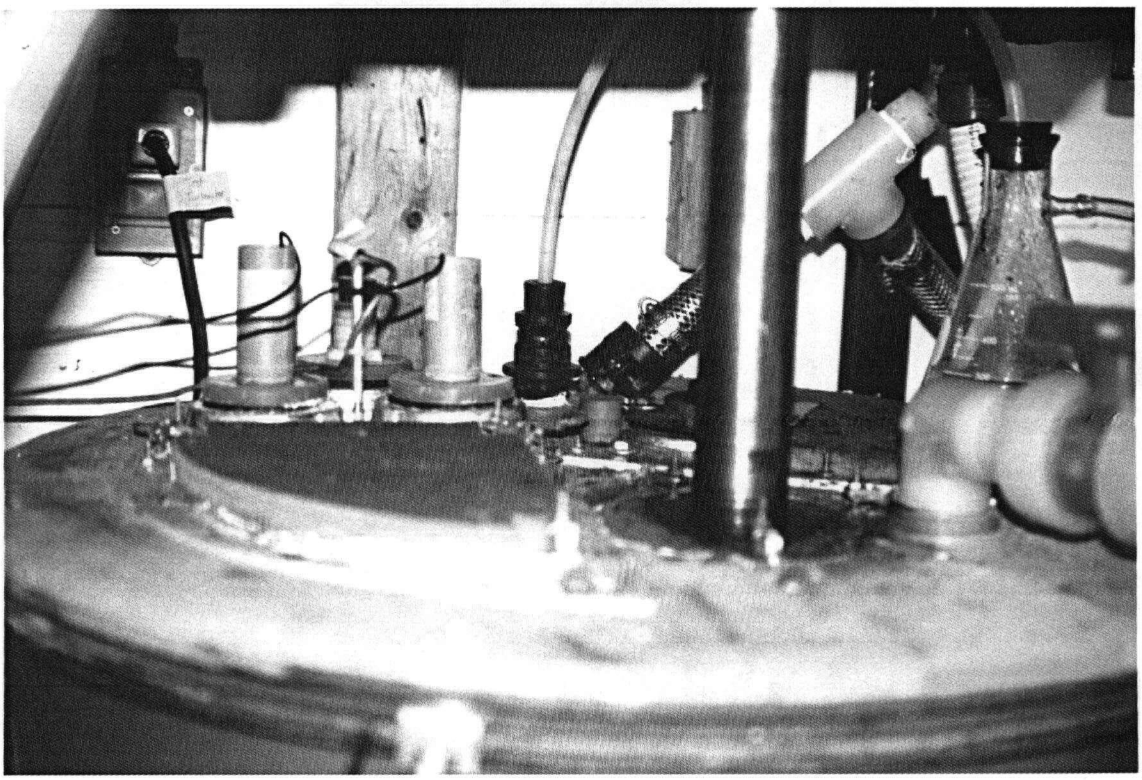


FIGURE B4: ATAD Reactors with Turborator Mixing/Aeration Device
(wasting bucket bottom left)

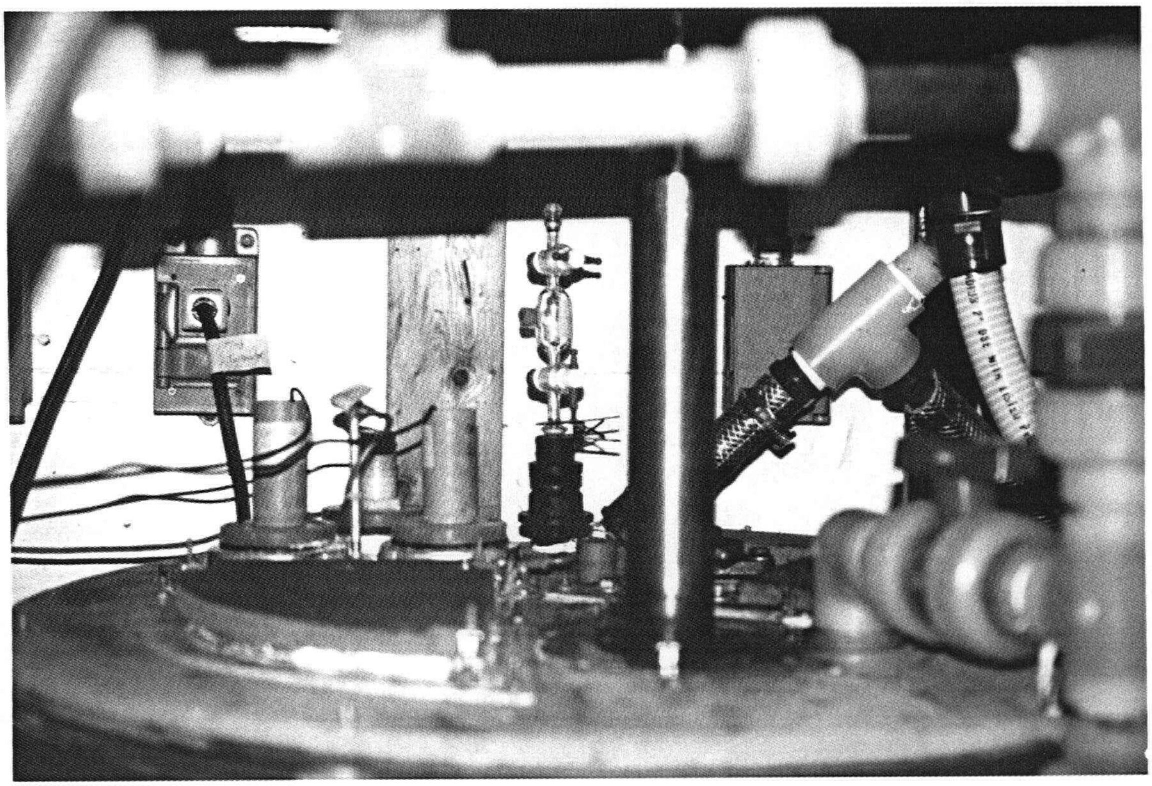


(a) off-gases vented directly to atmosphere



(b) off-gases vented through water trap

FIGURE B5: ATAD Reactor Lid showing perforation of Turborator shaft, monitoring probes and air exhaust



(c) off-gases sampling vial attached to outlet port

FIGURE B5: ATAD Reactor Lid showing perforation of Turborator shaft, monitoring probes and air exhaust

APPENDIX C: OPERATING DATA

RUN 1 - CONTROL 100/0, TEST 100/0 - OPERATING DATA

		CONTROL ATAD REACTOR, 100/0							TEST ATAD REACTOR, 100/0						
		external sample							external sample						
DAY	DATE	DO(mg/L)	pH	T (oC)	T (oC)	rpm	Airflow (ml/min)	ORP (mV)	DO(mg/L)	pH	T (oC)	T (oC)	rpm	Airflow (ml/min)	ORP (mV)
1	9/11 a	0.8			48.4	918	22	-248	0.6		45	45.8	907	22	-327
	p	0.9	6.60		47.9	931	37	-238	0.6	6.83		45.0	933	37	-318
2	9/12 a	0.5	6.32		48.5	934	46	-246	0.6	6.78	45	45.8	931	46	-318
	p	0.4	6.59		47.7	927	57	-237	0.3	6.72		45.2	931	57	-306
3	9/13 a	0.3	6.50		48.5	928	51	-245	0.3	6.69		46.1	931	51	-319
	p	0.3	6.53		49.0	929	53	-236	0.5	6.63		46.5	934	53	-317
4	9/14 a	0.3	6.46		49.3	930	51	-244	0.3	6.65		47.0	932	51	-317
	p	0.4	6.41		49.6	929	55	-241	0.3	6.69		47.2	938	55	-310
5	9/15 a	0.4	6.52		50.3	929	50	-245	0.4	6.62		48.0	940	50	-322
	p	0.3	6.43		49.9	925	55	-243	0.3	6.62		47.5	930	55	-319
6	9/16 a	0.3	6.29		49.8	924	54	-244	0.3	6.68		47.5	932	54	-321
	p	0.3	6.45		50.0	922	49	-245	0.3	6.60		47.6	930	49	-331

AVG	0.4	6.46	0	49.1	927	48	-243	0.4	6.68	45	46.6	931	48	-319
STDS	0.2	0.10	0	1.1	4	10	9	0.1	0.07	0	1.1	8	10	14
MIN	0.3	6.29	0	46.1	918	22	-306	0.3	6.60	45	43.6	907	22	-409
MAX	0.9	6.60	0	51.1	934	57	-201	0.6	6.83	45	48.7	940	57	-281
MEDIAN	0.3	6.46	0	49.0	929	51	-242	0.3	6.67	0	46.6	932	51	-319

(shaded) DO probe placed in reactor for reading

NOTE: Internal temperature and ORP readings taken every 5 minutes. Values in table represent the average value over a 12 hour period; however, statistical values calculated from original data.

RUN 2 - CONTROL 100/0, TEST 65/35 - OPERATING DATA

		CONTROL ATAD REACTOR, 100/0							TEST ATAD REACTOR, 100/0						
		external sample							external sample						
DAY	DATE	DO(mg/L)	pH	T (oC)	T (oC)	rpm	Airflow (ml/min)	ORP (mV)	DO(mg/L)	pH	T (oC)	T (oC)	rpm	Airflow (ml/min)	ORP (mV)
1	9/27 a	0.2	6.60	37.5	49.5	924	26	-245	0.2	6.56	38.3	45.5	912	26	-381
	p	0.3	6.46		49.5	927	26	-249	0.3	6.63	38.0	44.8	932	26	-361
2	9/28 a	0.3	6.48	38.6	49.5	927	24	-252	0.3	6.65	39.0	45.0	930	24	-366
	p	0.3	6.65	40.2	51.0	923	28	-252	0.3	6.70	39.3	44.7	933	28	-380
3	9/29 a	0.2	6.55	37.8	49.7	919	27	-256	0.3	6.61	38.0	44.7	934	27	-367
	p	0.4	6.72	37.8	49.1	928	32	-258	0.3	6.66	39.3	44.4	932	32	-374
4	9/30 a	0.2	6.63	38.1	49.1	927	28	-254	0.2	6.68	39.0	44.7	928	28	-376
	p	0.3	6.60	37.1	48.4	924	26	-252	0.3	6.66	37.5	44.3	932	26	-371
5	10/01 a	0.3	6.72	37.8	48.2	924	23	-252	0.2	6.78	38.3	44.5	932	23	-372
	p	0.2	6.74	36.6	47.8	923	27	-257	0.2	6.83	37.3	44.2	928	27	-381
6	10/02 a	0.2	6.79	37.3	47.0	919	28	-264	0.2	6.92	37.5	44.1	923	28	-377
	p	0.2	6.78	37.1	46.7	929	26	-266	0.2	6.93	37.7	43.6	935	26	-379

AVG	0.2	6.64	37.8	48.8	925	27	-255	0.2	6.72	38.3	44.5	929	27	-374
STDS	0.0	0.11	1.0	1.2	3	2	7	0.0	0.12	0.7	0.5	6	2	9
MIN	0.2	6.46	36.6	46.3	919	23	-305	0.2	6.56	37.3	43.4	912	23	-424
MAX	0.4	6.79	40.2	52.0	929	32	-241	0.3	6.93	39.3	46.1	935	32	-353
MEDIAN	0.2	6.64	37.7	49.1	924	26	-254	0.2	6.67	38.2	44.5	932	26	-374

NOTE: Internal temperature and ORP readings taken every 5 minutes. Values in table represent the average value over a 12 hour period; however, statistical values calculated from original data.

RUN 3 - CONTROL 100/0, TEST 35/65 - OPERATING DATA

DAY	DATE	Trailer Air T (oC)	CONTROL ATAD REACTOR, 100/0 external sample DO(mg/L)	pH	T (oC)	T (oC)	rpm	Airflow (ml/min)	ORP (mV)	TEST ATAD REACTOR, 100/0 external sample DO(mg/L)	pH	T (oC)	T (oC)	rpm	Airflow (ml/min)	ORP (mV)
1	10/12 a	<15	0.3	6.80	34.9	43.5	922	34	-279	0.2	7.10	38.0	43.8	938	34	-399
	p	<15	0.3	6.81	36.5	43.9	926	37	-272	0.3	7.01	39.6	43.7	933	37	-400
2	10/13 a	<15	0.2	6.88	34.2	44.0	925	34	-273	0.2	6.96	36.8	43.6	935	34	-394
	p	<15	0.3	6.98	35.4	43.6	928	40	-262	0.3	6.97	36.5	42.8	930	40	-390
3	10/14 a	<15	0.2	6.88	32.7	43.6	930	37	-262	0.2	6.98	34.5	42.7	932	37	-389
	p	>15	0.3	6.95	36.6	44.7	938	49	-248	0.3	7.02	38.6	43.4	943	49	-386
4	10/15 a	>15	0.3	6.98	37.1	45.9	938	37	-252	0.3	7.07	38.9	44.6	944	37	-388
	p	<15	0.3	7.05	36.9	46.3	937	49	-241	0.2	6.93	39.3	44.6	938	49	-394
5	10/16 a	<15	0.3	6.97	36.6	46.3	937	43	-254	0.3	6.92	39.0	44.7	935	43	-397
	p	>15	0.3	7.01	37.6	46.3	937	48	-261	0.2	6.95	38.1	44.3	942	48	-392
6	10/17 a	<15	0.3	6.90	34.7	46.2	935	43	-277	0.3	6.96	38.9	44.3	931	43	-399
	p	<15	0.2	7.02	36.6	45.8	939	43	-262	0.3	6.97	37.8	43.8	947	43	-392
AVG			0.3	6.94	35.8	45.0	933	41	-262	0.3	6.99	38.0	43.9	937	41	-393
STDS			0.0	0.08	1.4	1.2	6	6	14	0.0	0.05	1.5	0.7	6	6	9
MIN			0.2	6.80	32.7	43.1	922	34	-353	0.2	6.92	34.5	42.4	930	34	-466
MAX			0.3	7.05	37.6	46.7	939	49	-229	0.3	7.10	39.6	45.1	947	49	-367
MEDIAN			0.3	6.96	36.6	45.5	936	41	-262	0.3	6.97	38.4	43.9	937	41	-394

NOTE: Internal temperature and ORP readings taken every 5 minutes. Values in table represent the average value over a 12 hour period; however, statistical values calculated from original data.

RUN 4 - CONTROL 100/0, TEST 0/100 - OPERATING DATA

DAY	DATE	Trailer Air T (oC)	CONTROL ATAD REACTOR, 100/0 external sample DO(mg/L)	pH	T (oC)	T (oC)	rpm	Airflow (ml/min)	ORP (mV)	TEST ATAD REACTOR, 100/0 external sample DO(mg/L)	pH	T (oC)	T (oC)	rpm	Airflow (ml/min)	ORP (mV)
1	10/27 a		0.2	7.14	36.6	44.9	938	48	-289	0.2	6.89	36.5	42.5	936	48	-427
	p	12.0	0.3	7.09	35.1	44.6	936	48	-270	0.3	6.77	36.3	42.1	943	48	-421
2	10/28 a	9.0	0.3	7.02	32.8	43.6	932	47	-260	0.3	6.74	36.3	41.9	942	47	-420
	p	11.0	0.4	7.08	34.7	42.9	938	47	-256	0.3	6.80	36.3	40.9	942	47	-422
3	10/29 a	12.0	0.2	7.07	33.0	42.5	940	47	-277	0.3	6.80	35.2	40.7	946	47	-422
	p	17.0	0.3	6.95	35.8	43.3	942	53	-280	0.3	6.76	0.7	40.6	942	53	-418
4	10/30 a	15.0	0.4	6.95	36.1	44.4	948	53	-294	0.3	6.82	36.3	42.1	949	53	-420
	p	16.0	0.3	6.98	35.9	44.8	938	51	-282	0.3	6.97	37.2	42.3	938	51	-420
5	10/31 a	14.5	0.4	6.96	36.1	44.8	938	49	-278	0.3	6.95	36.6	43.0	939	49	-425
	p	15.0	0.4	6.87	36.1	44.5	939	57	-273	0.3	6.89	37.4	42.6	938	57	-424
6	1101 a	15.0	0.3	6.94	35.9	44.7	941	53	-265	0.3	7.01	37.3	43.1	938	53	-420
	p	14.5	0.3	6.95	36.6	44.9	937	55	-269	0.3	6.98	38.1	43.1	939	55	-417
AVG		13.7	0.3	7.00	35.4	44.2	939	51	-275	0.3	6.87	33.7	42.1	941	51	-421
STDS		2.4	0.1	0.08	1.3	0.9	4	3	13	0.0	0.10	10.4	0.9	4	3	7
MIN		9.0	0.2	6.87	32.8	41.8	932	47	-316	0.2	6.74	0.7	39.9	936	47	-454
MAX		17.0	0.4	7.14	36.6	45.5	948	57	-212	0.3	7.01	38.1	43.6	949	57	-359
MEDIAN		14.5	0.3	6.97	35.9	44.5	938	50	-274	0.3	6.86	36.4	42.3	941	50	-422

NOTE: Internal temperature and ORP readings taken every 5 minutes. Values in table represent the average value over a 12 hour period; however, statistical values calculated from original data.

RUN 5 - CONTROL 0/100, TEST 0/100 solubilized - OPERATING DATA

		Trailer Air	CONTROL ATAD REACTOR, 100/0									TEST ATAD REACTOR, 100/0								
			external sample									external sample								
DAY	DATE	T (oC)	Feed pH	Feed T (oC)	DO(mg/L)	pH	T (oC)	T (oC)	rpm	Airflow (ml/min)	ORP (mV)	Feed pH*	Feed T(oC)	DO(mg/L)	pH	T (oC)	T (oC)	rpm	Airflow (ml/min)	ORP (mV)
1	11/20 a	14.5	6.30	12.0	0.2	7.20	36.8	43.2	936	39	-326	10.40	12.4	0.2	7.89	38.0	42.0	931	41	-432
	p	12.0	6.40	12.2	0.2	7.03	35.6	43.1	936	39	-336	9.17	13.2	0.2	7.77	36.8	41.4	934	40	-424
2	11/21 a	14.5	6.45	12.1	0.2	7.13	35.1	42.8	936	39	-322	10.52	12.6	0.2	7.75	36.8	41.0	928	39	-401
	p	15.0	6.62	12.9	0.3	7.33	35.6	43.0	939	39	-303	9.15	14.1	0.3	7.88	37.7	41.1	937	40	-323
3	11/22 a	16.0	6.61	13.9	0.3	7.27	36.8	43.7	943	39	-307	10.29	14.4	0.2	7.81	38.0	42.5	935	41	-340
	p	16.0	6.48	14.4	0.2	7.26	37.3	44.4	941	41	-332	8.70	15.6	0.2	7.79	40.2	43.2	947	39	-142
4	11/23 a	17.0	6.56	15.4	0.3	7.30	37.5	45.1	946	40	-350	10.01	16.1	0.3	7.76	40.1	44.4	949	39	-133
	p	17.0	6.60	15.6	0.2	7.02	36.9	45.5	934	40	-345	8.37	16.4	0.2	7.76	39.3	44.7	954	39	-255
5	11/24 a	17.0	6.40	15.0	0.2	7.20	38.4	45.4	932	39	-353	9.89	15.5	0.2	7.70	40.9	44.9	954	39	-296
	p	16.5	6.51	15.1	0.3	7.18	37.8	45.7	945	41	-360	8.35	16.2	0.3	7.70	41.2	45.1	953	39	-284
6	11/25 a	16.0	6.60	13.6	0.2	7.21	36.8	44.7	939	39	-359	11.10	14.1	0.2	7.75	39.3	44.3	947	39	-336
	11/26 a	15.5	6.75	12.6	0.2	7.21	36.3	43.4	935	39	-272	9.94	13.4	0.2	7.89	39.6	42.9	933	41	-28
AVG		15.6	6.52	13.7	0.2	7.20	36.7	44.1	939	40	-327	9.66	14.5	0.2	7.79	39.0	43.1	942	40	-269
STDS		1.4	0.12	1.4	0.0	0.10	1.0	1.1	4	1	48	0.90	1.4	0.0	0.07	1.5	1.5	10	1	152
MIN		12.0	6.30	12.0	0.2	7.02	35.1	42.5	932	39	-403	8.35	12.4	0.2	7.70	36.8	40.5	928	39	-467
MAX		17.0	6.75	15.6	0.3	7.33	38.4	45.9	946	41	-33	11.10	16.4	0.3	7.89	41.2	45.5	954	41	120
MEDIAN		16.0	6.54	13.8	0.2	7.21	36.8	43.6	938	39	-340	9.92	14.3	0.2	7.77	39.3	42.9	942	39	-318

* at time of NaOH addition

[shaded] 12 hrs after addition

NOTE: Internal temperature and ORP readings taken every 5 minutes. Values in table represent the average value over a 12 hour period; however, statistical values calculated from original data.

RUN 6 - CONTROL 35/65, TEST 35/65 solubilized - OPERATING DATA

		Trailer Air	CONTROL ATAD REACTOR, 100/0									TEST ATAD REACTOR, 100/0								
			external sample									external sample								
DAY	DATE	T (oC)	Feed pH	Feed T (oC)	DO(mg/L)	pH	T (oC)	T (oC)	rpm	Airflow (ml/min)	ORP (mV)	Feed pH*	Feed T(oC)	DO(mg/L)	pH	T (oC)	T (oC)	rpm	Airflow (ml/min)	ORP (mV)
1	12/02 a	15.0	6.33	13.2	0.3	6.91	36.3	43.2	936	39	-350	9.26	13.4	0.3	7.52	38.8	42.2	959	39	-421
	p	18.5	6.29	14.3	0.3	6.67	37.6	43.5	941	43	-355	7.67	15.1	0.3	7.52	40.1	42.4	949	39	-424
2	12/03 a	19.0	6.46	16.1	0.2	6.95	37.8	44.8	945	44	-354	9.26	16.3	0.2	7.58	40.0	43.6	951	39	-428
	p	19.0	6.13	16.1	0.3	6.74	38.8	45.7	939	44	-368	7.40	16.8	0.3	7.46	40.5	43.9	942	41	-437
3	12/04 a	18.5	6.38	14.6	0.2	6.75	37.2	44.4	939	44	-377	9.04	14.9	0.2	7.44	39.1	43.4	938	40	-441
	p	16.5	6.49	14.0	0.3	6.87	36.9	44.3	931	41	-363	7.47	14.7	0.2	7.38	39.5	42.9	942	41	-437
4	12/05 a	15.0	6.36	13.1	0.3	6.90	36.1	44.2	850	39	-362	9.03	13.4	0.3	7.30	38.9	43.3	938	43	-443
	p	15.0	6.41	12.2	0.3	6.97	36.6	42.9	941	40	-348	7.48	12.9	0.3	7.31	38.3	42.4	949	41	-439
5	12/06 a	16.0	6.70	13.2	0.3	6.96	36.8	43.9	946	39	-354	9.73	13.4	0.3	7.31	38.6	42.4	955	40	-433
	p	16.5	6.49	12.9	0.3	6.97	37.3	44.3	935	40	-343	8.41	13.5	0.3	7.29	38.5	42.2	944	42	-431
6	12/07 a	17.5	6.50	13.4	0.2	7.02	36.7	44.0	937	40	-337	9.08	13.7	0.3	7.35	39.0	42.4	956	40	-428
	p	15.0	6.39	12.1	0.4	7.07	36.7	44.0	934	39	-342	7.43	12.9	0.4	7.29	38.0	42.2	942	40	-437
AVG		16.8	6.41	13.8	0.3	6.90	37.1	44.1	931	41	-354	8.44	14.3	0.3	7.40	39.1	42.8	947	40	-433
STDS		1.6	0.14	1.3	0.1	0.12	0.7	0.8	26	2	15	0.89	1.3	0.1	0.10	0.8	0.6	7	1	9
MIN		15.0	6.13	12.1	0.2	6.67	36.1	42.1	850	39	-448	7.40	12.9	0.2	7.29	38.0	41.7	938	39	-468
MAX		19.0	6.70	16.1	0.4	7.07	38.8	46.2	946	44	-317	9.73	16.8	0.4	7.58	40.5	44.2	959	43	-408
MEDIAN		16.5	6.40	13.3	0.3	6.93	36.9	44.0	938	40	-353	8.72	13.6	0.3	7.37	39.0	42.5	947	40	-433

* at time of NaOH addition

[shaded] 12 hrs after addition

NOTE: Internal temperature and ORP readings taken every 5 minutes. Values in table represent the average value over a 12 hour period; however, statistical values calculated from original data.

APPENDIX D: AIRFLOW AND AIR COMPOSITION DATA

AIRFLOW DATA (mL/min) - RUNS 1 to 4

DAY	DATE	Control am	Control pm	Test am	Test pm	Daily Average Control	Daily Average Test
	09/03		41		41	41	41
	09/04	32	25	32	25	29	29
	09/05	28	34	28	34	31	31
	09/06	37	43	37	43	40	40
	09/07	34	53	34	53	43	43
	09/08	55	55	55	55	55	55
	09/09	54	66	54	66	60	60
Run 1	09/10	62	28	62	28	45	45
1	09/11	21	37	21	37	29	29
2	09/12	46	57	46	57	51	51
3	09/13	51	53	51	53	52	52
4	09/14	51	55	51	55	53	53
5	09/15	50	55	50	55	52	52
6	09/16	53	49	53	49	51	51
	09/17	49	65	49	65	57	57
	09/18	53	61	53	61	57	57
	09/19	59	61	59	61	60	60
	09/20	53	59	53	59	56	56
	09/21	57	57	57	57	57	57
	09/22						
	09/23	55	60	55	60	57	57
	09/24	60	28	60	28	44	44
	09/25	16	30	16	30	23	23
Run 2	09/26	28	25	28	25	27	27
1	09/27	26	26	26	26	26	26
2	09/28	24	28	24	28	26	26
3	09/29	27	32	27	32	29	29
4	09/30	28	26	28	26	27	27
5	10/01	23	27	23	27	25	25
6	10/02	28	26	28	26	27	27
	10/03	27	32	27	32	30	30
	10/04	29	28	29	28	28	28
	10/05	31	32	31	32	32	32
	10/06	26	26	26	26	26	26
	10/07	26	29	26	29	27	27
	10/08	24	37	24	37	30	30
	10/09	41	40	41	40	40	40
	10/10	34	40	34	40	37	37
Run 3	10/11	34	47	34	47	40	40
1	10/12	34	37	34	37	35	35
2	10/13	34	40	34	40	37	37
3	10/14	37	49	37	49	43	43
4	10/15	37	49	37	49	43	43
5	10/16	43	48	43	48	45	45
6	10/17	43	43	43	43	43	43
	10/18	43	38	43	38	40	40
	10/19	36	43	36	43	39	39
	10/20	38	37	38	37	37	37
	10/21	35	34	35	34	34	34
	10/22	37	49	37	49	43	43
	10/23	65	49	65	49	57	57
	10/24	49	55	49	55	52	52
	10/25	49	52	49	52	50	50
Run 4	10/26	47	50	47	50	49	49
1	10/27	48	48	48	48	48	48
2	10/28	47	47	47	47	47	47
3	10/29	47	53	47	53	50	50
4	10/30	53	51	53	51	52	52
5	10/31	49	57	49	57	53	53
6	11/01	53	55	53	55	54	54
	11/02	54	53	54	53	54	54
	11/03	49	57	49	57	53	53
	11/04	53	53	53	53	53	53
	11/05	49	49	49	49	49	49
	11/06	49	47	49	47	48	48

AVG	41	44	41	44	43	43
STDS	12	12	12	12	11	11
MIN	16	25	16	25	23	23
MAX	65	66	65	66	60	60
MEDIAN	43	47	43	47	43	43

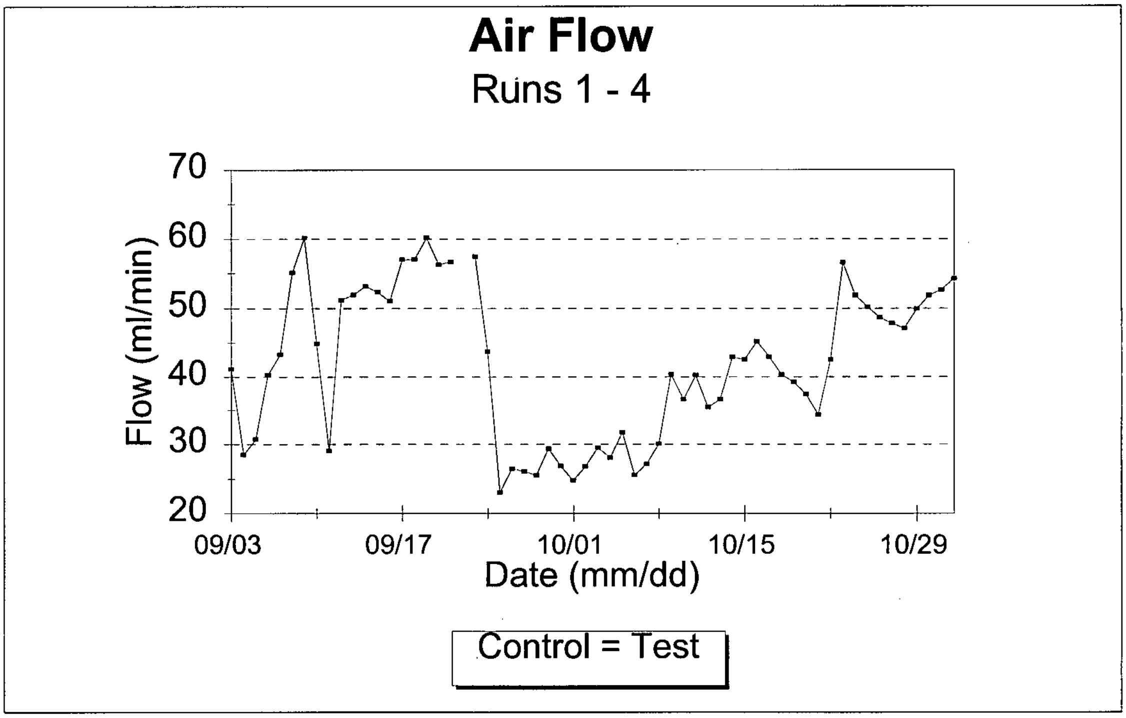
AIRFLOW DATA (mL/min) - RUNS 5 & 6

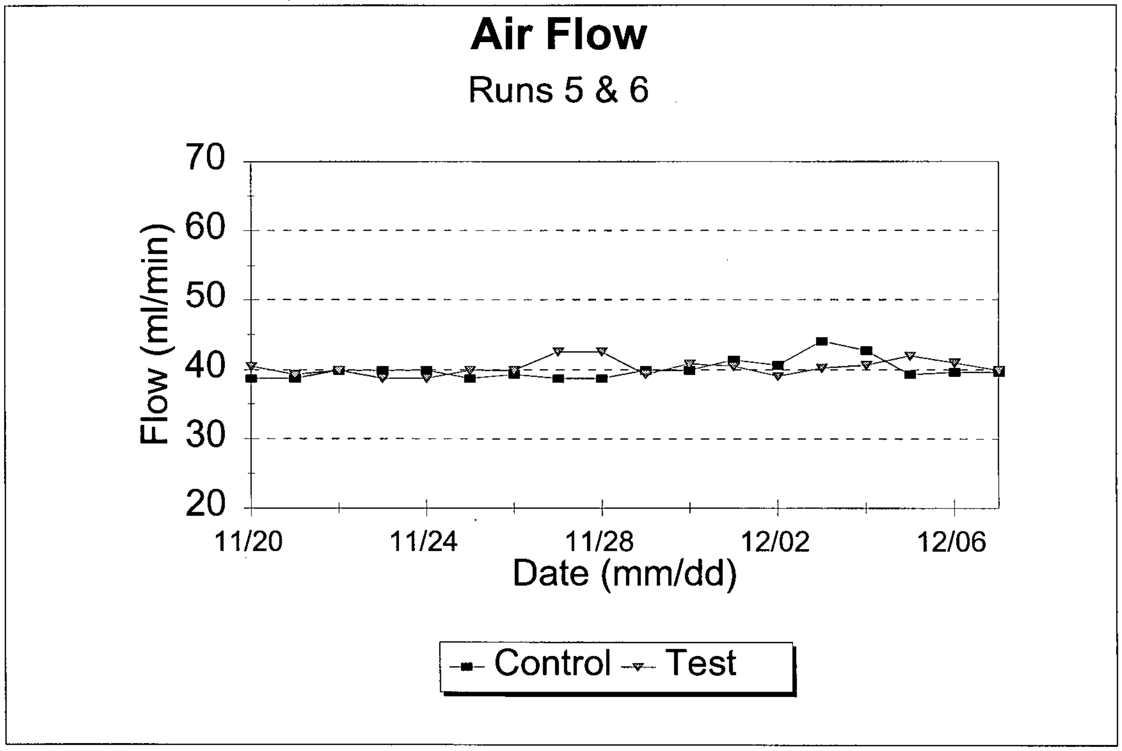
DAY	DATE	Control am	Control pm	Test am	Test pm	Daily Average Control	Daily Average Test
	11/07	47	255	47	255	151	151
	11/08	255	314	255	786	285	521
	11/09	314	132	397	397	223	397
	11/10	113	53	93	89	83	91
	11/11	39	56	100	161	47	130
	11/12	54	69	172	236	62	204
	11/13	64	105	224	224	85	224
	11/14	98	95	208	95	96	152
	11/15	90	111	95	113	101	104
	11/16	110	96	110	96	103	103
	11/17	77	56	81	56	66	69
	11/18	39	39	41	41	39	41
Run 5	11/19	39	40	41	41	39	41
1	11/20	39	39	41	40	39	41
2	11/21	39	39	39	40	39	39
3	11/22	39	41	41	39	40	40
4	11/23	40	40	39	39	40	39
5	11/24	39	41	39	39	40	39
6	11/25	39	39	39	41	39	40
7	11/26	38	41	39	41	39	40
	11/27	39	39	41	44	39	43
	11/28	39	39	44	41	39	43
	11/29	41	39	38	41	40	39
	11/30	39	41	38	44	40	41
Run 6	12/01	39	44	41	40	41	41
1	12/02	39	43	39	39	41	39
2	12/03	44	44	39	41	44	40
3	12/04	44	41	40	41	43	41
4	12/05	39	40	43	41	39	42
5	12/06	39	40	40	42	40	41
6	12/07	40	39	40	40	40	40

AVG	66	69	83	107	68	95
STDS	63	63	84	152	57	111
MIN	38	39	38	39	39	39
MAX	314	314	397	786	285	521
MEDIAN	39	41	41	41	40	41

ALL DATA COMBINED

AVG	50	52	55	65	51	60
STDS	39	39	53	91	36	68
MIN	16	25	16	25	23	23
MAX	314	314	397	786	285	521
MEDIAN	40	43	41	43	43	43


Air Flow
Runs 1 - 4
70
60
50
40
30
20
Flow (ml/min)
09/03
09/17
10/01
10/15
10/29
Date (mm/dd)
Control = Test


Air Flow
Runs 5 & 6
70
60
50
40
30
20
Flow (ml/min)
11/20
11/24
11/28
12/02
12/06
Date (mm/dd)
Control
Test

REACTOR HEADSPACE/OFF-GAS AIR ANALYSIS (% composition)

DAY	DATE		CO_2 (%)			O_2 (%)			N_2 (%)			CH_4 (%)		
			ambient	C ATAD	T ATAD	ambient	C ATAD	T ATAD	ambient	C ATAD	T ATAD	ambient	C ATAD	T ATAD
Run 4														
1	10/27	lab air	0.147	0.535	0.410	20.408	19.819	19.834	79.445	79.646	79.756	n.d.	n.d.	n.d.
2	10/28													
3	10/29													
4	10/30	lab air	n.d.	0.576	0.291	20.397	19.473	19.805	79.603	79.951	79.904	n.d.	n.d.	n.d.
5	10/31	lab air	n.d.	2.280	1.760	20.351	16.866	17.790	79.469	80.854	80.450	n.d.	n.d.	n.d.
6	11/01	lab air	n.d.	2.223	1.399	20.468	17.465	18.615	79.532	80.312	79.986	n.d.	n.d.	n.d.
	11/02													
	11/03	lab air	n.d.	0.643	0.454	20.438	19.262	19.969	79.562	80.095	79.577	n.d.	n.d.	n.d.
	11/04													
	11/05													
	11/06	lab air	0.052	0.928	0.434	20.335	18.969	20.155	79.613	80.130	79.371	n.d.	n.d.	n.d.
	11/07	lab air	0.042	0.897	0.388	20.371	19.256	20.002	79.587	79.847	79.610	n.d.	n.d.	n.d.
	11/08	trailer air	n.d.	2.676	1.137	20.390	17.704	18.183	79.610	79.620	80.680	n.d.	n.d.	n.d.
	11/09	trailer air	n.d.	0.648	1.058	20.258	19.739	19.612	79.742	79.613	79.330	n.d.	n.d.	n.d.
	11/10	lab air	n.d.	2.700	0.596	19.934	16.308	19.448	80.066	80.992	79.956	n.d.	n.d.	n.d.
	11/11	trailer air	n.d.	0.654	0.787	20.321	19.431	19.246	79.679	79.915	79.967	n.d.	n.d.	n.d.
	11/12													
	11/13													
	11/14	trailer air	n.d.	1.446	0.753	20.074	18.246	19.208	79.926	80.308	80.039	n.d.	n.d.	n.d.
	11/15	trailer air	n.d.	1.344	0.485	21.023	19.627	19.946	78.977	79.029	79.569	n.d.	n.d.	n.d.
	11/16	trailer air	0.057	1.628	0.540	20.454	18.330	19.778	79.489	80.042	79.682	n.d.	n.d.	n.d.
	11/17	trailer air	n.d.	1.387	0.513	20.366	18.306	19.657	79.634	80.307	79.830	n.d.	n.d.	n.d.
	11/18	trailer air	n.d.	1.913	0.421	20.196	18.019	19.970	79.804	79.978	79.609	n.d.	n.d.	n.d.
Run 5	11/19													
1	11/20													
2	11/21	trailer air	n.d.	2.537	0.533	20.350	16.849	19.481	79.650	80.613	79.986	n.d.	n.d.	n.d.
3	11/22	trailer air	n.d.	1.399	0.579	20.225	18.369	19.405	79.775	80.232	80.016	n.d.	n.d.	n.d.
4	11/23	trailer air	n.d.	1.266	0.699	20.432	18.542	19.221	79.568	80.192	80.080	n.d.	n.d.	n.d.
5	11/24	trailer air	n.d.	1.691	0.882	20.344	17.864	18.914	79.656	80.445	80.204	n.d.	n.d.	n.d.
6	11/25	no air		1.480	0.745		18.339	19.219		80.135	80.036	n.d.	n.d.	n.d.
7	11/26	trailer air	n.d.	1.042	0.347	20.199	19.043	19.835	79.801	79.915	79.818	n.d.	n.d.	n.d.
	11/27													
	11/28													
	11/29	lab air	n.d.	1.207	0.538	20.450	18.755	19.564	79.550	80.038	79.898	n.d.	n.d.	n.d.
	11/30	lab air	n.d.	1.790	0.457	20.272	17.910	19.519	79.728	80.300	80.024	n.d.	n.d.	n.d.
Run 6	12/01	lab air	n.d.	1.396	0.588	19.993	18.805	19.541	80.007	79.799	79.871	n.d.	n.d.	n.d.
1	12/02	lab air	n.d.	1.706	0.649	20.285	18.567	19.028	79.715	79.727	80.323	n.d.	n.d.	n.d.
2	12/03	lab air	n.d.	1.660	0.576	20.171	18.296	19.500	79.829	80.044	79.920	n.d.	n.d.	n.d.
3	12/04	no air		2.576	0.485		17.313	19.646		80.111	79.869	n.d.	n.d.	n.d.
4	12/05	lab air	n.d.	1.562	0.556	20.264	18.677	19.735	79.736	79.761	79.709	n.d.	n.d.	n.d.
5	12/06	lab air	n.d.	2.347	0.539	19.475	17.508	19.724	80.525	80.145	79.737	n.d.	n.d.	n.d.
6	12/07	lab air	n.d.	2.645	0.570	20.134	17.301	19.341	79.866	80.054	80.089	n.d.	n.d.	n.d.
AVG			0.010	1.574	0.651	20.289	18.353	19.448	79.695	80.069	79.900	0.000	0.000	0.000
STDS			0.031	0.671	0.315	0.247	0.904	0.521	0.257	0.377	0.287	0.000	0.000	0.000
MIN			0.000	0.535	0.291	19.475	16.308	17.790	78.977	79.029	79.330	0.000	0.000	0.000
MAX			0.147	2.700	1.760	21.023	19.819	20.155	80.525	80.992	80.680	0.000	0.000	0.000

[ ] blank cell, no sample taken

n.d. not detected

REACTOR HEADSPACE/OFF-GAS AIR ANALYSIS (% composition)

DAY	DATE		CO2 (%) ambient	CO2 (%) C ATAD	CO2 (%) T ATAD	O2 (%) ambient	O2 (%) C ATAD	O2 (%) T ATAD	N2 (%) ambient	N2 (%) C ATAD	N2 (%) T ATAD	CH4 (%) ambient	CH4 (%) C ATAD	CH4 (%) T ATAD
Run 4														
1	10/27	lab air	0.147	0.535	0.410	20.408	19.819	19.834	79.445	79.646	79.756	n.d.	n.d.	n.d.
2	10/28													
3	10/29													
4	10/30	lab air	n.d.	0.576	0.291	20.397	19.473	19.805	79.603	79.951	79.904	n.d.	n.d.	n.d.
5	10/31	lab air	n.d.	2.280	1.760	20.351	16.866	17.790	79.469	80.854	80.450	n.d.	n.d.	n.d.
6	11/01	lab air	n.d.	2.223	1.399	20.468	17.465	18.615	79.532	80.312	79.986	n.d.	n.d.	n.d.
	11/02													
	11/03	lab air	n.d.	0.643	0.454	20.438	19.262	19.969	79.562	80.095	79.577	n.d.	n.d.	n.d.
	11/04													
	11/05													
	11/06	lab air	0.052	0.928	0.434	20.335	18.969	20.155	79.613	80.130	79.371	n.d.	n.d.	n.d.
	11/07	lab air	0.042	0.897	0.388	20.371	19.256	20.002	79.587	79.847	79.610	n.d.	n.d.	n.d.
	11/08	trailer air	n.d.	2.676	1.137	20.390	17.704	18.183	79.610	79.620	80.680	n.d.	n.d.	n.d.
	11/09	trailer air	n.d.	0.648	1.058	20.258	19.739	19.612	79.742	79.613	79.330	n.d.	n.d.	n.d.
	11/10	lab air	n.d.	2.700	0.596	19.934	16.308	19.448	80.066	80.992	79.956	n.d.	n.d.	n.d.
	11/11	trailer air	n.d.	0.654	0.787	20.321	19.431	19.246	79.679	79.915	79.967	n.d.	n.d.	n.d.
	11/12													
	11/13													
	11/14	trailer air	n.d.	1.446	0.753	20.074	18.246	19.208	79.926	80.308	80.039	n.d.	n.d.	n.d.
	11/15	trailer air	n.d.	1.344	0.485	21.023	19.627	19.946	78.977	79.029	79.569	n.d.	n.d.	n.d.
	11/16	trailer air	0.057	1.628	0.540	20.454	18.330	19.778	79.489	80.042	79.682	n.d.	n.d.	n.d.
	11/17	trailer air	n.d.	1.387	0.513	20.366	18.306	19.657	79.634	80.307	79.830	n.d.	n.d.	n.d.
	11/18	trailer air	n.d.	1.913	0.421	20.196	18.019	19.970	79.804	79.978	79.609	n.d.	n.d.	n.d.
Run 5	11/19													
1	11/20													
2	11/21	trailer air	n.d.	2.537	0.533	20.350	16.849	19.481	79.650	80.613	79.986	n.d.	n.d.	n.d.
3	11/22	trailer air	n.d.	1.399	0.579	20.225	18.369	19.405	79.775	80.232	80.016	n.d.	n.d.	n.d.
4	11/23	trailer air	n.d.	1.266	0.699	20.432	18.542	19.221	79.568	80.192	80.080	n.d.	n.d.	n.d.
5	11/24	trailer air	n.d.	1.691	0.882	20.344	17.864	18.914	79.656	80.445	80.204	n.d.	n.d.	n.d.
6	11/25	no air		1.480	0.745		18.339	19.219		80.135	80.036	n.d.	n.d.	n.d.
7	11/26	trailer air	n.d.	1.042	0.347	20.199	19.043	19.835	79.801	79.915	79.818	n.d.	n.d.	n.d.
	11/27													
	11/28													
	11/29	lab air	n.d.	1.207	0.538	20.450	18.755	19.564	79.550	80.038	79.898	n.d.	n.d.	n.d.
	11/30	lab air	n.d.	1.790	0.457	20.272	17.910	19.519	79.728	80.300	80.024	n.d.	n.d.	n.d.
Run 6	12/01	lab air	n.d.	1.396	0.588	19.993	18.805	19.541	80.007	79.799	79.871	n.d.	n.d.	n.d.
1	12/02	lab air	n.d.	1.706	0.649	20.285	18.567	19.028	79.715	79.727	80.323	n.d.	n.d.	n.d.
2	12/03	lab air	n.d.	1.660	0.576	20.171	18.296	19.500	79.829	80.044	79.920	n.d.	n.d.	n.d.
3	12/04	no air		2.576	0.485		17.313	19.646		80.111	79.869	n.d.	n.d.	n.d.
4	12/05	lab air	n.d.	1.562	0.556	20.264	18.677	19.735	79.736	79.761	79.709	n.d.	n.d.	n.d.
5	12/06	lab air	n.d.	2.347	0.539	19.475	17.508	19.724	80.525	80.145	79.737	n.d.	n.d.	n.d.
6	12/07	lab air	n.d.	2.645	0.570	20.134	17.301	19.341	79.866	80.054	80.089	n.d.	n.d.	n.d.
AVG			0.010	1.574	0.651	20.289	18.353	19.448	79.695	80.069	79.900	0.000	0.000	0.000
STDS			0.031	0.671	0.315	0.247	0.904	0.521	0.257	0.377	0.287	0.000	0.000	0.000
MIN			0.000	0.535	0.291	19.475	16.308	17.790	78.977	79.029	79.330	0.000	0.000	0.000
MAX			0.147	2.700	1.760	21.023	19.819	20.155	80.525	80.992	80.680	0.000	0.000	0.000

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n.d. not detected

APPENDIX E: TOTAL SOLIDS AND SOLIDS DESTRUCTION DATA

TOTAL SOLIDS DATA (g/L) - RUNS 1 to 4

Day	Date	Primary Sludge	Unsettled ML (A-side)	Unsettled ML (B-side)	Secondary Sludge	Control Feed	Test Feed	Control ATAD	Test ATAD	Feed Variability T-C Feed
pre Run 1	08/23 a	7.52	4.01		13.51	8.00	7.04	6.47	6.87	-0.96
	08/24 a	7.70	4.14		13.02	7.62	7.77	6.21	5.95	0.15
	08/25 a	11.00	3.70		15.24	10.97	11.02	6.30	6.58	0.05
	08/26 a	8.77	3.91		14.20	9.64	7.90	6.03	6.57	-1.74
	08/27 a	7.24	4.73		4.74	7.16	7.31	6.62	6.56	0.15
	08/28 a	9.01	4.18			9.01	9.00	6.75	6.89	-0.01
	08/29 a	9.47	3.80		15.73	9.59	9.34	6.16	6.82	-0.25
	08/30 a	10.09	4.07		14.76	9.19	10.98	6.98	7.18	1.79
	08/31 a	13.31	3.83		15.70	14.96	11.66	7.80	7.61	-3.30
	09/01 a	12.59	4.13		6.70	12.94	12.23	7.53	8.09	-0.71
	09/02 a	11.00	4.60		16.00	10.99	11.00	7.60	7.42	0.01
	09/03 a	12.35	4.65		9.80	13.30	11.40	6.65	6.87	-1.90
	09/04 a	11.68	4.72		17.38	11.38	11.97	7.84	7.24	0.59
	09/05 a	14.70	4.61		15.94	15.42	13.98	6.61	7.31	-1.44
	09/06 a	13.95	4.33		16.98	13.73	14.17	8.13	8.24	0.45
	09/07 a	14.96	3.82		7.56	17.08	12.83	8.59	9.26	-4.25
	09/08 a	14.09	3.90		16.82	14.65	13.54	7.94	8.69	-1.11
	09/09 a	13.36	4.13		15.81	13.24	13.49	7.93	8.48	0.25
Run 1	09/10 a	16.58	0.77		7.74	16.23	16.94	8.80	8.90	0.71
1	09/11 a	13.52			15.19	13.00	14.03	8.85	8.36	1.02
1.5	09/11 p	13.52				13.61	13.42	8.35	8.50	-0.20
2	09/12 a	12.36	4.17		8.05	12.51	12.21	8.42	9.08	-0.30
2.5	09/12 p	13.64				14.03	13.25	8.32	8.72	-0.77
3	09/13 a	13.41	4.29		7.36	14.02	12.79	8.05	9.06	-1.23
3.5	09/13 p	14.12				15.58	12.65	8.18	9.28	-2.93
4	09/14 a	13.11	4.11		9.15	14.09	12.12	8.38	9.32	-1.97
4.5	09/14 p	12.43				12.72	12.14	8.09	9.16	-0.59
5	09/15 a	12.64	4.26		9.46	13.56	11.73	8.23	9.26	-1.83
5.5	09/15 p	12.11				12.69	11.54	8.52	9.49	-1.15
6	09/16 a	11.91	4.00		9.65	12.32	11.51	8.79	9.08	-0.81
6.5	09/16 p	13.34				13.73	12.96	8.46	9.45	-0.77
	09/17 a									
	09/18 a	8.66	3.83		11.28	8.18	9.14	8.08	8.90	0.96
	09/19 a	9.43	4.30		10.64	9.20	9.67	7.89	8.80	0.47
	09/19 p	11.01			16.36	10.77	11.24			0.47
	09/20 a	13.34	4.40		18.95	13.34	12.24	7.83	9.14	-1.10
pre Run 2	09/21 a	14.56	4.05		13.14	14.56	13.21	8.58	9.67	-1.35
	09/22 a	10.90	4.07		12.81	10.90	13.85	8.53	10.13	2.95
	09/23 a	11.87	4.07		11.17	11.87	12.74	8.56	10.50	0.86
	09/24 a	9.19	4.70		11.95	9.19	13.73	8.61	10.06	4.54
	09/25 a	12.47	4.00		10.95	12.47	11.06	8.40	10.61	-1.42
Run 2	09/26 a	13.74			19.01	13.74	15.68	8.52	10.13	1.94
1	09/27 a	16.31	4.57		12.20	16.31	13.27	8.63	10.70	-3.04
1.5	09/27 p	14.76				14.76	13.28	10.19	11.51	-1.49
2	09/28 a	11.03	3.97		10.97	11.03	12.80	9.02	10.60	1.77
2.5	09/28 p	11.68				11.68		10.21	10.97	
3	09/29 a	13.64	3.55		11.44	13.64	12.26	9.03	10.85	-1.39
3.5	09/29 p	13.61				13.61	13.48	9.65	10.63	-0.13
4	09/30 a	11.69	3.40		11.69	11.69	12.61	9.36	10.76	0.92
4.5	09/30 p	10.06				10.06	13.60	9.58	10.97	3.55
5	10/01 a	11.97	3.43		10.63	11.97	11.33	8.73	10.65	-0.64
5.5	10/01 p	10.73				10.73	11.66	7.86	10.58	0.93
6	10/02 a	11.36	3.70		10.61	11.36	12.20	8.62	10.58	0.84
6.5	10/02 p	9.48				9.48	12.73	8.32	10.80	3.25
	10/03 a	9.97			11.32	9.97	9.88			-0.09
pre Run 3	10/04 a	9.19			10.34	9.19	9.56			0.37
	10/05 a	4.43			12.33	4.43	9.25			4.82
	10/06 a	10.21			10.49	10.21	9.14			-1.07
	10/07 a	10.55			10.11	10.55	9.84			-0.71
	10/08 a	12.35			10.22	12.35	10.65			-1.70
	10/09 a	14.73			9.10	14.73	10.62			-4.11
	10/10 a	8.11			10.46	8.11	11.47			3.36
Run 3	10/11 a	12.84			9.77	12.84	11.07			-1.77
1	10/12 a	14.74	2.89		14.69	14.74	15.02	8.91	8.75	0.28
1.5	10/12 p	17.78				17.78	15.35	9.23	9.40	-2.43
2	10/13 a	9.93	3.43		9.22	9.93	10.59	10.11	9.68	0.66
2.5	10/13 p	11.86		1.93		11.86	9.92	9.71	9.69	-1.94
3	10/14 a	11.60	3.73		8.30	11.60	9.99	9.87	9.61	-1.61
3.5	10/14 p	12.61		2.04		12.61	10.79	8.90	9.49	-1.82
4	10/15 a	9.22	3.87		16.15	9.22	15.64	9.18	9.31	6.42
4.5	10/15 p	11.04		2.27		11.04	15.21	8.84	9.68	4.16
5	10/16 a	16.99	3.80		7.50	16.99	10.78	8.78	10.25	-6.21
5.5	10/16 p	12.92		2.48	7.46	12.92	11.12	8.77	10.02	-1.80
6	10/17 a	13.40	4.17		10.69	13.40	12.37	9.66	10.29	-1.03
6.5	10/17 p	12.58		2.67	8.58	12.58	10.98	9.16	10.05	-1.60
pre Run 4	10/18 a	4.52	3.81	2.61	10.11	4.52	10.11			5.59
	10/18 p	1.75				1.75				
	10/19 a	1.30	3.86	2.69	14.80	1.30	14.80			13.50
	10/20 a	1.39	3.83	2.54	8.08	1.39	8.08			6.69
	10/21 a	15.51	3.94	2.75	8.32	15.51	8.32			-7.19
	10/22 a	15.77	4.12	2.95	8.67	15.77	8.67			-7.10
	10/23 a	18.93	4.09	2.94	17.60	18.93	17.60			-1.33
	10/24 a	13.71	4.26	2.90	10.17	13.71	10.17			-3.54
	10/25 a	14.52	4.25	2.88	19.63	14.52	19.63			5.11
Run 4	10/26 a	14.69	4.08	2.72	17.63	14.69	17.63			2.94
1	10/27 a	13.43	4.32	2.77	13.92	13.43	13.92	11.36	13.09	0.49
1.5	10/27 p	14.43			13.51	14.43	13.51	10.02	12.63	-0.92
2	10/28 a	13.37	4.31	3.71	14.69	13.37	14.69	10.71	12.78	1.32
2.5	10/28 p	13.75			14.50	13.75	14.50	9.88	12.40	0.75
3	10/29 a	11.36	4.41	3.67	8.49	11.36	8.49	10.17	12.86	-2.87
3.5	10/29 p	11.69			7.93	11.69	7.93	9.98	11.87	-3.76
4	10/30 a	12.53	4.40	3.87	10.08	12.53	10.08	10.26	11.39	-2.45
4.5	10/30 p	11.30			9.81	11.30	9.81	9.40	10.79	-1.49
5	10/31 a	13.32	4.48	3.91	9.77	13.32	9.77	9.59	10.65	-3.55
5.5	10/31 p	11.22			9.80	11.22	9.80	9.09	10.21	-1.42
6	11/01 a	11.69	4.52	4.03	9.67	11.69	9.67	9.09	9.94	-2.02
6.5	11/01 p	11.81			9.95	11.81	9.95	8.59	9.48	-1.86
	11/02 a	10.94	4.54	4.17	18.25	10.94	18.25			7.31

	Primary Sludge	Unsettled ML (A-side)	Unsettled ML (B-side)	Secondary Sludge	Control Feed	Test Feed	Control ATAD	Test ATAD		Feed Variability T-C Feed
AVG	11.82	4.03	2.98	11.93	11.93	11.90	8.57	9.50	AVG	-0.14
AVG (%)	1.18%	0.40%	0.30%	1.19%	1.19%	1.19%	0.86%	0.95%		
STDS	3.09	0.56	0.66	3.43	3.18	2.49	1.12	1.60	STDS	3.00
MIN	1.30	0.77	1.93	4.74	1.30	7.04	6.03	5.95	MIN	-7.19
MAX	18.93	4.73	4.17	19.63	18.93	19.63	11.36	13.09	MAX	13.50

no sample
lost sample
5 hours of pre-mixing before feeding and sample

TOTAL SOLIDS DATA (g/L) - RUNS 5 & 6

Day	Date	Primary Sludge	Unsettled ML (A-side)	Unsettled ML (B-side)	Secondary Sludge	Control Feed	Test Feed	Control ATAD	Test ATAD	Feed Variability T-C Feed
pre Run 5	11/03 a		4.69	4.39	14.80	no feed	no feed			
(no solubilization)	11/04 a		4.46	4.46	13.13	no feed	no feed			
	11/05 a		4.33	4.36		no feed	no feed			
	11/06 a		2.84	4.66		no feed	no feed	10.71	12.15	
	11/07 a		5.02	4.54		no feed	no feed	11.14	11.80	
	11/08 a		5.79	4.37		no feed	no feed		11.74	
pre Run 5	11/09 a		4.88	4.27	15.67	15.67	15.50	11.42	11.43	-0.17
	11/10 a		4.89	4.05	13.98	13.98	15.64	11.26	12.02	1.66
	11/11 a		4.68	3.70	9.17	9.17	11.03	11.35	12.12	1.86
	11/12 a		5.03	3.75	8.07	8.07	9.19	10.86	11.72	1.12
	11/13 a		4.96	4.15	13.42	13.42	11.75	9.41	10.92	-1.67
	11/14 a		4.89	4.00	11.20	11.20	12.37	9.61	10.61	1.17
	11/15 a		4.91	3.49	10.55	10.55	11.48	9.73	10.03	0.93
	11/16 a		5.07	3.81	10.27	10.27	10.10	10.57	10.74	-0.17
	11/17 a		4.84	3.70	9.42	9.42	9.36	9.18	9.16	-0.06
	11/18 a		5.63	4.99	10.59	10.59	8.62	9.10		-1.97
Run 5	11/19 a		4.62	3.57	10.29	10.29	9.15			-1.14
1	11/20 a		4.69	3.58	9.46	9.46	7.93	8.93	8.33	-1.53
1.5	11/20 p				9.81	9.81	7.97	8.96	9.20	-1.84
2	11/21 a		4.89	3.61	9.01	9.01	7.43	8.75	7.90	-1.58
2.5	11/21 p				9.03	9.03	7.49	8.65	7.75	-1.54
3	11/22 a		4.94	3.81	9.23	9.23	8.22	8.53	7.71	-1.01
3.5	11/22 p				9.20	9.20	8.01	8.28	7.49	-1.19
4	11/23 a		4.60	3.81	8.81	8.81	8.46	8.42	7.37	-0.35
4.5	11/23 p				9.04	9.04	8.71	8.15	7.42	-0.33
5	11/24 a		4.90	3.61	9.08	9.08	9.14	8.28	7.24	0.06
5.5	11/24 p				8.73	8.73	5.64	8.10	7.27	-3.09
6	11/25 a		5.05	4.75	2.33	2.33	4.12	8.34	7.29	1.79
	11/25 p									
	11/26 a		4.58	3.45	6.39	6.39	3.69	7.26	6.66	-2.70
pre Run 6	11/26 p	13.20			16.60	10.47	9.96			-0.51
	11/27 a	7.93			18.60	11.12	11.60			0.48
	11/28 a	14.45			14.64	11.63	11.71	8.64	7.90	0.08
	11/29 a	4.82			14.1	11.76	11.15	9.03	8.92	-0.61
	11/30 a	10.87			7.67	12.32	11.95	9.21	8.93	-0.37
Run 6	12/01 a	6.90			9.37	12.33	11.89	9.82	9.43	-0.44
1	12/02 a	7.70			3.47	13.15	11.54	10.07	9.74	-1.61
1.5	12/02 p					13.32	11.36	10.56	9.99	-1.96
2	12/03 a	9.14			14.12	13.44	11.79	10.75	10.03	-1.65
2.5	12/03 p					13.18	11.76	10.47	9.99	-1.42
3	12/04 a	9.91			14.30	13.64	12.82	10.66	9.77	-0.82
3.5	12/04 p					13.37	12.70	10.84	9.97	-0.67
4	12/05 a	8.44			15.48	14.28	13.38	11.05	10.11	-0.90
4.5	12/05 p					14.14	13.29	11.25	10.28	-0.85
5	12/06 a	7.19			7.26	9.68	9.07	11.57	10.56	-0.61
5.5	12/06 p					9.72	9.49	11.30	10.21	-0.23
6	12/07 a	6.05			16.72	14.52	13.99	10.63	9.63	-0.53
6.5	12/07 p					15.27	14.13	11.14	10.46	-1.14

	Primary Sludge	Unsettled ML (A-side)	Unsettled ML (B-side)	Secondary Sludge	Control Feed	Test Feed	Control ATAD	Test ATAD		Feed Variability T-C Feed
AVG	8.88	4.79	4.01	10.50	9.51	8.93	9.74	9.48	AVG	-0.62
AVG (%)	0.89%	0.48%	0.40%	1.05%	0.95%	0.89%	0.97%	0.95%		
STDS	2.84	0.52	0.45	3.99	4.42	4.33	1.25	1.63	STDS	1.14
MIN	4.82	2.84	3.45	0.00	0.00	0.00	7.26	6.66	MIN	-3.09
MAX	14.45	5.79	4.99	18.60	15.67	15.64	11.57	12.15	MAX	1.86

ALL DATA COMBINED

	Primary Sludge	Unsettled ML (A-side)	Unsettled ML (B-side)	Secondary Sludge	Control Feed	Test Feed	Control ATAD	Test ATAD		Feed Variability T-C Feed
AVG	11.50	4.26	3.54	11.46	11.13	10.90	8.98	9.49	AVG	-0.29
AVG (%)	1.15%	0.43%	0.35%	1.15%	1.11%	1.09%	0.90%	0.95%		
STDS	3.19	0.65	0.76	3.67	3.80	3.50	1.29	1.61	STDS	2.59
MIN	1.30	0.77	1.93	0.00	0.00	0.00	6.03	5.95	MIN	-7.19
MAX	18.93	5.79	4.99	19.63	18.93	19.63	11.57	13.09	MAX	13.50

no sample
lost sample
5 hours of pre-mixing before feeding and sample

TOTAL SOLIDS DESTRUCTION DATA (g/L) - RUNS 1 to 4

Day	Date	Control Feed	Control ATAD	TS Destruction	Run Average	Test Feed	Test ATAD	TS Destruction	Run Average
	08/23	8.00	6.47	-		7.04	6.87	-	
	08/24	7.62	6.21	22%		7.77	5.95	15%	
	08/25	10.97	6.30	19%		11.02	6.58	11%	
	08/26	9.64	6.03	32%		7.90	6.57	24%	
	08/27	7.16	6.62	30%		7.31	6.56	26%	
	08/28	9.01	6.75	27%		9.00	6.89	21%	
	08/29	9.59	6.16	28%		9.34	6.82	15%	
	08/30	9.19	6.98	19%		10.98	7.18	16%	
	08/31	14.96	7.80	16%		11.66	7.61	22%	
	09/01	12.94	7.53	33%		12.23	8.09	24%	
	09/02	10.99	7.60	39%		11.00	7.42	36%	
	09/03	13.30	6.65	49%		11.40	6.87	41%	
	09/04	11.38	7.84	37%		11.97	7.24	37%	
	09/05	15.42	6.61	44%		13.98	7.31	36%	
	09/06	13.73	8.13	39%		14.17	8.24	34%	
	09/07	17.08	8.59	36%		12.83	9.26	31%	
	09/08	14.65	7.94	48%		13.54	8.69	36%	
	09/09	13.24	7.93	48%		13.49	8.48	37%	
Run 1	09/10	16.23	8.80	41%		16.94	8.90	33%	
1	09/11	13.31	8.60	41%		13.72	8.43	43%	
2	09/12	13.27	8.37	41%		12.73	8.90	40%	
3	09/13	14.80	8.11	43%		12.72	9.17	37%	
4	09/14	13.41	8.24	40%		12.13	9.24	29%	
5	09/15	13.12	8.37	39%		11.64	9.38	25%	
6	09/16	13.02	8.63	37%	40%	12.23	9.26	24%	33%
	09/17								
	09/18	8.18	8.08	38%		9.14	8.90	25%	
	09/19	9.20	7.89	26%		9.67	8.80	18%	
	09/19	10.77				11.24			
	09/20	13.34	7.83	17%		12.24	9.14	9%	
pre Run 2	09/21	14.56	8.58	23%		13.21	9.67	12%	
	09/22	10.90	8.53	34%		13.85	10.13	17%	
	09/23	11.87	8.56	34%		12.74	10.50	20%	
	09/24	9.19	8.61	31%		13.73	10.06	24%	
	09/25	12.47	8.40	21%		11.06	10.61	21%	
Run 2	09/26	13.74	8.52	24%		15.68	10.13	19%	
1	09/27	15.54	9.41	20%		13.27	11.10	18%	
2	09/28	11.35	9.62	31%		12.80	10.79	19%	
3	09/29	13.63	9.34	31%		12.87	10.74	23%	
4	09/30	10.87	9.47	30%		13.11	10.86	16%	
5	10/01	11.35	8.29	31%		11.49	10.61	18%	
6	10/02	10.42	8.47	29%	29%	12.46	10.69	14%	18%
	10/03	9.97				9.88			
pre Run 3	10/04	9.19				9.56			
	10/05	4.43				9.25			
	10/06	10.21				9.14			
	10/07	10.55				9.84			
	10/08	12.35				10.65			
	10/09	14.73				10.62			
	10/10	8.11				11.47			
Run 3	10/11	12.84				11.07			
1	10/12	16.26	9.07	24%		15.19	9.07	18%	
2	10/13	10.90	9.91	20%		10.26	9.68	23%	
3	10/14	12.11	9.39	30%		10.39	9.55	22%	
4	10/15	10.13	9.01	31%		15.42	9.49	21%	
5	10/16	14.96	8.78	21%		10.95	10.14	16%	
6	10/17	12.99	9.41	24%	25%	11.68	10.17	17%	19%
pre Run 4	10/18	4.52				10.11			
	10/18	1.75							
	10/19	1.30				14.80			
	10/20	1.39				8.08			
	10/21	15.51				8.32			
	10/22	15.77				8.67			
	10/23	18.93				17.60			
	10/24	13.71				10.17			
	10/25	14.52				19.63			
Run 4	10/26	14.69				17.63			
1	10/27	13.93	10.69	25%		13.72	12.86	19%	
2	10/28	13.56	10.30	28%		14.60	12.59	26%	
3	10/29	11.53	10.07	28%		8.21	12.36	19%	
4	10/30	11.92	9.83	24%		9.95	11.09	9%	
5	10/31	12.27	9.34	24%		9.79	10.43	4%	
6	11/01	11.75	8.84	26%	26%	9.81	9.71	-4%	12%
	11/02	10.94				18.25			
AVG				31%				23%	
STDS				9%				10%	
MIN				16%				-4%	
MAX				49%				43%	

no sample
lost sample
5 hours of pre-mixing before feeding and sample

TOTAL SOLIDS DESTRUCTIONS DATA (g/L) - RUNS 5 & 6

Day	Date	Control Feed	Control ATAD	TS Destruction	Run Average	Test Feed	Test ATAD	TS Destruction	Run Average
pre Run 5	11/03	no feed				no feed			
(no solubilization	11/04	no feed				no feed			
	11/05	no feed				no feed			
	11/06	no feed	10.71			no feed	12.15		
	11/07	no feed	11.14			no feed	11.80		
	11/08	no feed				no feed	11.74		
pre Run 5	11/09	15.67	11.42			15.50	11.43		
	11/10	13.98	11.26	28%		15.64	12.02	22%	
	11/11	9.17	11.35	23%		11.03	12.12	22%	
	11/12	8.07	10.86	16%		9.19	11.72	17%	
	11/13	13.42	9.41	10%		11.75	10.92	9%	
	11/14	11.20	9.61	6%		12.37	10.61	0%	
	11/15	10.55	9.73	11%		11.48	10.03	10%	
	11/16	10.27	10.57	10%		10.10	10.74	9%	
	11/17	9.42	9.18	14%		9.36	9.16	19%	
	11/18	10.59	9.10	10%		8.62			
Run 5	11/19	10.29				9.15			
1	11/20	9.64	8.95	11%		7.95	8.77	3%	
2	11/21	9.02	8.70	14%		7.46	7.83	9%	
3	11/22	9.22	8.41	13%		8.12	7.60	7%	
4	11/23	8.93	8.29	11%		8.59	7.40	6%	
5	11/24	8.91	8.19	10%		7.39	7.26	10%	
6	11/25	4.36	7.80	13%	12%	3.91	6.98	13%	8%
pre Run 6	11/26	10.47				9.96			
	11/27	11.12				11.60			
	11/28	11.63	8.64	0%		11.71	7.90	7%	
	11/29	11.76	9.03	18%		11.15	8.92	20%	
	11/30	12.32	9.21	20%		11.95	8.93	22%	
Run 6	12/01	12.33	9.82	18%		11.89	9.43	19%	
1	12/02	13.24	10.32	15%		11.45	9.87	15%	
2	12/03	13.31	10.61	16%		11.78	10.01	15%	
3	12/04	13.51	10.75	17%		12.76	9.87	16%	
4	12/05	14.21	11.15	16%		13.34	10.20	15%	
5	12/06	9.70	11.44	16%		9.28	10.39	18%	
6	12/07	14.90	10.89	13%	16%	14.06	10.05	15%	16%

			TS Destruction				TS Destruction	
AVG			14%				13%	
STDS			6%				6%	
MIN			0%				0%	
MAX			28%				22%	

ALL DATA COMBINED

			TS Destruction				TS Destruction	
AVG			25%				20%	
STDS			11%				10%	
MIN			0%				-4%	
MAX			49%				43%	

- (black) no sample
- (dark grey) lost sample
- (light grey) 5 hours of pre-mixing before feeding and sample

NOTE: am and pm samples were averaged to provide a 'daily' values for calculations

APPENDIX F: VFA DATA

RUN 1 - CONTROL 100/0, TEST 100/0 - VFA DATA (mg/L)

		Unsettled Mixed Liquor (A-side)												Settled Mixed Liquour (Secondary Sludge)											
		ACETIC			PROPIONIC			ISO-BUTYRIC			BUTYRIC			ACETIC			PROPIONIC			ISO-BUTYRIC			BUTYRIC		
DAY	DATE	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
1	9/11 a													97.698			36.657			4.875			n.d.		
	p																								
2	9/12 a		6.134	10.792	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	83.445	87.178	81.272	29.030	31.218	27.257	3.371	4.094	2.841	n.d.	n.d.	n.d.
	p																								
3	9/13 a		5.403	4.040	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	76.214	68.707	70.041	13.873	13.384	12.683	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p																								
4	9/14 a		7.284	4.163	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	59.281	63.098	56.780	12.639	13.617	11.594	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p																								
5	9/15 a		5.496	4.215	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	66.309	62.286	64.027	13.697	14.090	11.826	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p																								
6	9/16 a		6.378	4.832	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	54.090	52.944	55.403	10.495	8.837	9.705	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p																								

(shaded) sample eliminated due to carry-over interference
n.d. not detected
detection limit = 1.000 mg/L

RUN 1 - CONTROL 100/0, TEST 100/0 - VFA DATA (mg/L)

		Control Reactor Feed, 100/0												Test Reactor Feed, 100/0											
		ACETIC			PROPIONIC			ISO-BUTYRIC			BUTYRIC			ACETIC			PROPIONIC			ISO-BUTYRIC			BUTYRIC		
DAY	DATE	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
1	9/11 a	148.844			106.774			2.663			8.448			152.583			101.463			2.400			5.300		
	p	194.168	174.539	196.867	146.510	132.523	150.736	5.232	4.595	5.137	10.780	11.695	13.193	164.738	164.049	168.561	120.940	125.542	125.830	2.983	3.314	3.468	8.294	9.596	10.032
2	9/12 a	174.684	162.378	161.992	133.386	117.199	114.010	5.412	4.059	3.788	9.747	8.790	9.085	182.985	150.334	156.320	131.631	106.786	109.368	4.029	3.158	3.728	8.954	6.761	7.265
	p	180.427	175.858	177.401	127.736	124.853	126.907	5.582	4.663	5.055	10.043	10.000	9.387	178.148	171.904	200.537	129.073	124.529	151.545	4.478	4.672	5.991	9.185	7.341	10.820
3	9/13 a	147.091	143.115	161.667	107.250	105.643	116.481	4.027	3.352	4.171	6.452	6.859	8.290	134.563	133.619	134.186	98.604	97.346	98.009	2.896	3.087	3.512	4.600	3.924	5.303
	p	159.929	161.490	157.880	123.976	125.262	126.277	4.213	3.857	3.674	10.721	9.930	10.142	151.960	148.355	155.045	117.606	119.734	120.133	4.020	4.120	3.541	7.888	7.094	8.564
4	9/14 a	148.112	151.193	156.393	126.411	136.318	127.859	4.467	4.163	4.233	10.967	11.887	12.141	136.939	141.793	138.906	109.563	112.706	110.732	3.205	3.888	3.107	8.540	8.172	8.400
	p	151.173	155.926	148.258	113.172	122.444	120.692	3.706	3.990	3.720	9.377	12.324	10.249	151.558	156.208	156.540	124.074	123.079	122.191	3.958	3.868	4.220	8.326	8.034	9.160
5	9/15 a	126.447	148.462	153.112	92.654	108.074	113.471	2.800	3.110	3.979	6.600	7.000	6.800	149.345	142.301	139.475	106.077	106.674	99.409	3.945	4.041	3.100	6.063	6.674	5.000
	p	168.722	167.574	166.255	115.930	122.642	113.573	4.263	3.363	4.040	7.200	7.249	7.801	152.145	151.552	151.190	107.036	113.371	107.681	2.653	4.013	2.000	1.000	1.088	1.200
6	9/16 a	150.768	157.032	155.196	112.136	115.937	113.649	3.500	3.604	3.571	7.000	8.558	5.974	139.704	139.458	147.534	102.374	102.402	101.703	2.741	2.836	2.700	6.100	5.700	4.300
	p	152.888	143.593	146.194	107.982	111.156	113.477	3.000	3.200	3.400	6.000	7.300	6.869	142.512	136.117	135.475	104.593	105.280	104.879	2.400	2.900	2.500	6.500	6.187	6.100

RUN 1 - CONTROL 100/0, TEST 100/0 - VFA DATA (mg/L)

		Control ATAD Reactor, 100/0												Test ATAD Reactor, 100/0											
		ACETIC			PROPIONIC			ISO-BUTYRIC			BUTYRIC			ACETIC			PROPIONIC			ISO-BUTYRIC			BUTYRIC		
DAY	DATE	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
1	9/11 a	160.794			2.777			14.018			n.d.			162.832			4.555			11.094			n.d.		
	p	124.154	139.007	123.527	4.694	4.384	2.552	12.102	13.783	12.080	n.d.	n.d.	n.d.	162.541	183.822	154.695	3.265	3.644	2.941	11.745	13.595	10.954	n.d.	n.d.	n.d.
2	9/12 a	137.669	134.796	132.072	3.143	2.151	2.197	11.988	12.779	10.895	n.d.	n.d.	n.d.	155.395	163.951	162.413	4.285	4.258	4.450	10.727	12.071	11.722	n.d.	n.d.	n.d.
	p	117.368	117.229	116.373	3.891	2.645	2.459	10.472	11.116	10.659	n.d.	n.d.	n.d.	135.812	153.353	135.507	2.020	2.083	1.364	8.788	10.577	8.758	n.d.	n.d.	n.d.
3	9/13 a	127.128	120.724	130.519	3.695	2.476	2.479	11.622	10.272	11.449	n.d.	n.d.	n.d.	141.190	147.019	145.867	3.105	3.202	3.157	7.036	7.264	6.788	n.d.	n.d.	n.d.
	p	111.082	104.634	106.617	2.120	2.110	1.682	10.330	10.672	9.584	n.d.	n.d.	n.d.	146.440	146.954	147.066	3.527	4.127	4.005	6.193	6.057	6.229	n.d.	n.d.	n.d.
4	9/14 a	136.790	131.955	135.083	2.667	2.590	9.128	11.544	11.919	12.432	n.d.	n.d.	n.d.	151.591	132.228	161.819	4.653	3.475	4.431	6.914	5.244	7.720	n.d.	n.d.	n.d.
	p	123.132	125.804	124.954	5.717	3.708	3.112	10.960	11.194	11.417	n.d.	n.d.	n.d.	159.041	165.601	171.899	7.691	4.555	4.759	5.289	5.917	6.018	n.d.	n.d.	n.d.
5	9/15 a	137.584	144.254	149.642	3.209	3.197	5.889	11.822	11.558	12.129	n.d.	n.d.	n.d.	142.643	166.839	162.482	2.455	4.811	5.966	6.237	6.724	7.245	n.d.	n.d.	n.d.
	p	141.577	129.346	144.118	6.760	4.861	5.796	12.811	10.500	11.631	n.d.	n.d.	n.d.	152.294	137.459	145.096	3.181	3.085	3.363	5.316	4.901	4.901	n.d.	n.d.	n.d.
6	9/16 a	139.588	146.465	144.076	3.415	11.498	5.924	12.956	12.266	12.367	n.d.	n.d.	n.d.	132.631	127.050	128.657	1.914	1.793	1.913	4.912	4.272	4.665	n.d.	n.d.	n.d.
	p	129.600	123.745	134.959	4.831	3.719	3.003	10.750	10.984	10.965	n.d.	n.d.	n.d.	151.640	158.449	161.321	5.151	4.877	4.905	4.401	4.768	4.727	n.d.	n.d.	n.d.

RUN 2 - CONTROL 100/0, TEST 65/35 - VFA DATA (mg/L)

Unsettled Mixed Liquor (A-side)

		ACETIC			PROPIONIC			ISO-BUTYRIC			BUTYRIC		
DAY	DATE	A	B	C	A	B	C	A	B	C	A	B	C
1	9/27 a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p												
2	9/28 a		18.925	7.841	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p												
3	9/29 a		20.591	8.454	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p												
4	9/30 a		15.386	4.204	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p												
5	10/01 a		6.965	13.068	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p												
6	10/02 a		31.879	11.639	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p												

Settled Mixed Liquor (Secondary Sludge)

		ACETIC			PROPIONIC			ISO-BUTYRIC			BUTYRIC		
DAY	DATE	A	B	C	A	B	C	A	B	C	A	B	C
1	9/27 a	71.471	73.632	78.791	8.427	8.703	9.555	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p												
2	9/28 a	63.665	53.228	62.377	9.548	9.154	9.249	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p												
3	9/29 a	69.942	62.982	64.189	9.607	9.263	9.211	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p												
4	9/30 a	73.982	74.730	59.169	12.441	17.900	16.169	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p												
5	10/01 a	65.465	71.136	98.544	19.263	20.156	27.471	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p												
6	10/02 a	90.846	88.697	113.545	19.773	18.207	28.297	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p												

(shaded) sample eliminated due to carry-over interference
n.d. not detected
detection limit = 1.000 mg/L

RUN 2 - CONTROL 100/0, TEST 65/35 - VFA DATA (mg/L)

Control Reactor Feed, 100/0 (Primary Sludge)

		ACETIC			PROPIONIC			ISO-BUTYRIC			BUTYRIC		
DAY	DATE	A	B	C	A	B	C	A	B	C	A	B	C
1	9/27 a	87.460	133.731	97.156	73.057	103.129	64.743	1.000	2.000	1.000	4.600	7.447	4.200
	p	148.581	129.277	134.931	83.937	90.554	105.127	n.d.	2.000	2.000	5.453	5.937	5.955
2	9/28 a	93.230	95.901	73.601	78.930	69.178	55.584	1.000	1.000	1.000	5.100	4.200	3.500
	p	149.926	134.459	102.789	98.205	110.032	111.694	n.d.	4.000	2.000	5.674	6.607	6.979
3	9/29 a	121.702	128.129	113.893	108.380	107.990	88.701	2.000	2.000	2.000	5.600	5.600	5.400
	p	128.033	129.444	130.414	107.659	102.341	101.700	2.000	2.000	2.000	5.500	4.700	4.900
4	9/30 a	119.479	101.112	111.906	93.698	82.784	88.782	2.000	2.000	2.000	4.900	4.700	5.800
	p	158.930	148.847	121.723	91.134	109.415	58.577	n.d.	2.000	2.000	6.839	6.286	5.500
5	10/01 a	113.622	112.210	91.371	85.940	90.192	73.157	2.000	4.000	2.000	4.400	4.700	3.300
	p	126.252	87.676	91.347	64.357	71.840	77.382	n.d.	2.000	2.000	5.500	4.600	4.200
6	10/02 a	108.939	103.339	112.492	86.759	76.571	85.863	2.000	2.000	2.000	4.700	3.800	4.000
	p	142.977	131.668	129.886	80.174	92.588	94.498	n.d.	2.000	2.000	6.200	4.700	4.000

Test Reactor Feed, 65/35

		ACETIC			PROPIONIC			ISO-BUTYRIC			BUTYRIC		
DAY	DATE	A	B	C	A	B	C	A	B	C	A	B	C
1	9/27 a	137.202	112.498	155.060	88.596	61.999	92.535	4.000	2.000	4.000	5.867	4.600	6.650
	p	209.858	212.181	190.899	161.654	164.639	148.715	4.295	4.300	4.300	12.901	12.176	12.318
2	9/28 a	119.326	108.628	112.809	73.871	63.022	64.364	4.000	4.000	4.000	4.900	4.400	4.200
	p	170.537	147.871	141.142	131.648	94.942	112.491	4.000	4.000	4.000	7.049	6.385	7.063
3	9/29 a	149.423	134.146	146.012	111.055	92.829	105.744	4.000	4.000	4.000	5.400	5.600	4.900
	p	127.479	107.281	127.137	94.143	75.138	89.244	4.800	2.400	4.800	4.700	3.800	4.400
4	9/30 a	150.423	104.520	158.087	92.912	69.100	98.316	4.800	4.800	4.800	7.106	4.900	6.675
	p	257.103	245.885	219.124	175.102	161.332	141.672	10.502	8.739	7.521	10.798	9.599	8.416
5	10/01 a	103.627	112.960	91.352	59.364	63.304	51.170	2.400	2.400	2.400	3.300	4.000	3.100
	p	145.867	146.709	147.118	93.486	93.005	93.344	6.000	6.000	6.000	4.600	4.400	4.400
6	10/02 a	142.359	143.186	155.174	84.185	82.179	87.358	3.600	4.800	2.400	3.800	3.800	4.000
	p	209.572	213.604	229.295	141.237	151.223	151.982	6.832	6.600	7.185	6.543	6.603	7.453

RUN 2 - CONTROL 100/0, TEST 65/35 - VFA DATA (mg/L)

Control ATAD Reactor, 100/0

		ACETIC			PROPIONIC			ISO-BUTYRIC			BUTYRIC		
DAY	DATE	A	B	C	A	B	C	A	B	C	A	B	C
1	9/27 a	215.810	232.393	201.688	10.320	9.845	9.050	14.471	18.554	10.754	n.d.	n.d.	n.d.
	p	211.026	228.296	225.096	12.065	11.061	10.362	15.620	18.440	12.481	n.d.	n.d.	n.d.
2	9/28 a	176.620	241.498	244.065	9.951	12.033	14.471	13.109	14.466	13.345	n.d.	n.d.	n.d.
	p	169.565	130.087	172.483	9.889	7.035	7.797	17.016	9.879	11.256	n.d.	n.d.	n.d.
3	9/29 a	197.005	203.980	208.772	8.966	6.654	7.532	16.114	16.828	13.110	n.d.	n.d.	n.d.
	p	212.795	242.587	239.984	19.247	13.018	13.092	21.082	21.643	21.929	n.d.	n.d.	n.d.
4	9/30 a	215.703	231.918	233.546	25.745	10.436	10.194	19.714	22.320	21.384	n.d.	n.d.	n.d.
	p	234.064	241.151	238.028	16.023	10.805	10.702	22.570	22.058	22.850	n.d.	n.d.	n.d.
5	10/01 a	195.339	244.946	236.973	21.480	8.241	37.015	16.455	22.634	19.726	n.d.	n.d.	n.d.
	p	183.125	212.661	180.786	14.951	10.785	9.266	18.231	18.866	17.907	n.d.	n.d.	n.d.
6	10/02 a	263.035	255.268	261.747	26.115	10.041	10.219	19.040	18.915	21.199	n.d.	n.d.	n.d.
	p	208.116	244.770	268.788	12.784	14.981	31.145	15.176	15.205	25.023	n.d.	n.d.	n.d.

Test ATAD Reactor, 65/35

		ACETIC			PROPIONIC			ISO-BUTYRIC			BUTYRIC		
DAY	DATE	A	B	C	A	B	C	A	B	C	A	B	C
1	9/27 a	492.378	506.952	465.314	46.148	56.931	44.299	35.570	48.718	39.210	8.431	8.319	7.470
	p	483.249	482.591	463.824	31.932	38.588	34.831	38.174	46.004	45.798	9.427	8.829	9.083
2	9/28 a	383.169	368.389	388.519	20.200	18.514	22.435	29.206	13.573	35.565	3.100	2.200	2.900
	p	432.684	484.463	455.231	37.648	41.893	42.169	22.838	37.668	38.509	5.900	5.500	5.500
3	9/29 a	496.112	515.037	507.983	37.529	55.426	40.288	23.933	46.238	38.508	4.400	4.000	4.000
	p	528.321	545.818	560.854	36.578	35.653	49.917	25.073	32.541	42.287	2.200	2.200	2.600
4	9/30 a	483.879	556.945	517.442	35.031	36.270	37.561	22.044	29.990	33.623	2.200	2.400	2.600
	p	482.701	568.917	615.808	34.674	32.941	49.786	12.120	25.981	41.414	n.d.	n.d.	n.d.
5	10/01 a	476.065	512.555	502.925	24.172	21.753	21.509	15.066	19.739	19.675	n.d.	n.d.	n.d.
	p	518.867	514.643	513.356	40.242	19.184	18.890	18.713	15.392	15.185	n.d.	n.d.	n.d.
6	10/02 a	552.412	599.480	535.028	23.294	21.338	18.891	10.382	14.028	13.991	n.d.	n.d.	n.d.
	p	529.806	519.446	511.589	21.602	18.832	16.906	10.500	13.344	11.217	n.d.	n.d.	n.d.

RUN 3 - CONTROL 100/0, TEST 35/65 - VFA DATA (mg/L)

		Unsettled Mixed Liquor (am, A-side & pm, B-side)											
		ACETIC			PROPIONIC			ISO-BUTYRIC			BUTYRIC		
DAY	DATE	A	B	C	A	B	C	A	B	C	A	B	C
1	10/12 a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p	[redacted]											
2	10/13 a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p	[redacted]											
3	10/14 a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
4	10/15 a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
5	10/16 a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
6	10/17 a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

		Settled Mixed Liquor (Secondary Sludge)											
		ACETIC			PROPIONIC			ISO-BUTYRIC			BUTYRIC		
DAY	DATE	A	B	C	A	B	C	A	B	C	A	B	C
1	10/12 a	143.501	138.735	142.840	20.193	19.368	19.886	6.141	18.451	19.250	6.469	6.249	6.348
	p	[redacted]											
2	10/13 a	103.245	110.522	127.375	7.886	8.749	10.025	19.252	15.363	15.752	3.111	3.383	4.039
	p	[redacted]											
3	10/14 a	80.629	76.012	68.111	1.372	1.370	n.d.	15.308	8.900	7.582	n.d.	n.d.	n.d.
	p	[redacted]											
4	10/15 a	116.920	96.354	81.773	12.454	9.789	8.191	11.730	13.342	9.812	4.454	3.521	2.843
	p	[redacted]											
5	10/16 a	62.024	62.695	62.097	6.998	7.061	6.962	1.355	1.305	1.302	n.d.	n.d.	n.d.
	p	49.153	46.645	50.572	3.636	3.321	3.519	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
6	10/17 a	55.288	44.619	56.397	3.197	2.532	3.304	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p	55.282	54.561	55.094	4.842	4.832	4.877	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

n.d. not detected
detection limit = 1.000 mg/L

RUN 3 - CONTROL 100/0, TEST 35/65 - VFA DATA (mg/L)

		Control Reactor Feed, 100/0 (Primary Sludge)											
		ACETIC			PROPIONIC			ISO-BUTYRIC			BUTYRIC		
DAY	DATE	A	B	C	A	B	C	A	B	C	A	B	C
1	10/12 a	91.290	89.667	90.826	67.603	66.758	67.519	1.601	1.881	1.919	2.203	3.200	3.336
	p	152.156	142.147	152.017	134.682	124.647	135.094	3.091	2.573	3.053	7.965	7.031	7.760
2	10/13 a	60.267	68.478	69.068	43.216	49.463	50.012	n.d.	1.000	n.d.	1.800	2.500	2.700
	p	89.921	89.118	89.143	71.051	71.212	71.002	2.032	1.928	1.900	3.432	3.355	3.281
3	10/14 a	76.928	75.436	73.769	55.946	54.260	53.153	1.500	1.400	1.500	2.886	2.700	2.453
	p	87.377	96.072	129.959	77.043	87.480	118.963	1.600	2.091	2.742	4.330	5.034	6.833
4	10/15 a	67.152	68.602	40.637	48.311	48.847	26.890	n.d.	1.000	n.d.	2.715	2.913	1.300
	p	71.383	74.449	91.165	45.008	47.721	58.883	1.400	1.500	2.215	1.800	2.600	3.097
5	10/16 a	74.173	76.310	86.148	50.475	51.212	59.382	1.400	1.500	2.007	2.799	2.734	3.421
	p	105.102	109.718	108.698	82.458	86.099	85.269	2.705	2.855	2.706	5.146	5.281	5.001
6	10/17 a	86.604	99.216	84.412	66.720	77.664	63.926	1.839	2.326	1.400	3.860	4.687	3.693
	p	111.249	111.801	112.866	95.867	97.320	98.858	2.756	2.611	2.635	6.644	6.511	6.551

		Test Reactor Feed, 35/65											
		ACETIC			PROPIONIC			ISO-BUTYRIC			BUTYRIC		
DAY	DATE	A	B	C	A	B	C	A	B	C	A	B	C
1	10/12 a	91.277	94.958	85.172	27.005	28.571	25.596	3.006	2.886	1.917	3.387	3.024	2.275
	p	124.333	146.748	122.856	44.519	54.377	44.404	3.384	4.419	2.872	1.500	1.500	1.500
2	10/13 a	68.977	69.373	69.082	18.785	18.821	18.607	1.595	1.686	1.649	1.500	1.500	1.500
	p	93.899	70.469	87.140	29.480	21.340	27.968	2.200	1.300	1.982	n.d.	1.500	n.d.
3	10/14 a	89.158	83.543	83.608	25.610	23.217	23.810	1.800	1.700	1.900	1.500	1.500	1.500
	p	123.493	118.907	119.961	46.931	45.087	44.927	2.442	1.869	1.954	1.500	1.500	1.500
4	10/15 a	74.161	69.959	82.420	19.925	18.932	22.767	1.763	n.d.	2.587	1.823	1.800	2.296
	p	142.263	141.376	157.802	60.247	61.225	68.490	5.069	4.393	5.511	3.356	2.889	3.523
5	10/16 a	81.982	86.739	59.174	38.606	36.893	22.982	1.599	1.858	n.d.	1.500	1.800	1.500
	p	112.952	129.307	114.397	55.408	64.776	56.166	3.108	3.570	2.783	1.800	1.900	1.500
6	10/17 a	54.838	46.779	72.450	13.540	11.305	18.979	n.d.	n.d.	1.700	1.500	1.500	1.500
	p	90.017	89.262	91.862	29.801	29.675	30.401	2.132	1.943	1.959	1.500	1.500	1.500

RUN 3 - CONTROL 100/0, TEST 35/65 - VFA DATA (mg/L)

		Control ATAD Reactor, 100/0											
		ACETIC			PROPIONIC			ISO-BUTYRIC			BUTYRIC		
DAY	DATE	A	B	C	A	B	C	A	B	C	A	B	C
1	10/12 a	223.146	162.406	196.600	5.583	3.736	4.679	2.441	1.500	2.297	n.d.	n.d.	n.d.
	p	238.085	227.148	214.429	10.846	10.430	9.820	2.952	2.826	2.633	n.d.	n.d.	n.d.
2	10/13 a	249.703	219.714	228.974	10.626	9.006	9.646	3.564	2.687	3.178	n.d.	n.d.	n.d.
	p	198.493	148.608	214.853	5.122	4.354	5.647	1.848	1.600	2.328	n.d.	n.d.	n.d.
3	10/14 a	225.496	218.513	221.900	5.217	5.094	5.119	2.195	2.197	2.194	n.d.	n.d.	n.d.
	p	193.795	212.001	192.322	5.111	5.770	5.135	1.670	2.251	1.970	n.d.	n.d.	n.d.
4	10/15 a	118.864	228.774	222.093	2.186	4.421	4.288	1.000	2.474	2.104	n.d.	n.d.	n.d.
	p	207.562	229.751	184.307	2.952	3.274	2.543	1.400	1.400	n.d.	n.d.	n.d.	n.d.
5	10/16 a	183.319	183.297	193.351	4.602	4.656	4.944	1.200	1.200	1.400	n.d.	n.d.	n.d.
	p	188.493	183.589	173.715	3.606	3.510	3.310	1.400	1.400	1.600	n.d.	n.d.	n.d.
6	10/17 a	177.114	127.963	188.704	2.948	1.931	3.165	1.800	1.000	1.300	n.d.	n.d.	n.d.
	p	182.192	183.403	186.621	4.047	4.086	4.208	1.400	1.300	1.400	n.d.	n.d.	n.d.

		Test ATAD Reactor, 35/65											
		ACETIC			PROPIONIC			ISO-BUTYRIC			BUTYRIC		
DAY	DATE	A	B	C	A	B	C	A	B	C	A	B	C
1	10/12 a	333.778	369.732	363.861	9.183	10.315	10.207	4.367	4.764	4.645	n.d.	n.d.	n.d.
	p	425.848	425.051	407.389	19.751	19.686	18.994	7.805	7.327	7.318	n.d.	n.d.	n.d.
2	10/13 a	457.126	452.345	439.065	18.766	18.516	17.811	8.473	8.229	7.688	n.d.	n.d.	n.d.
	p	457.048	473.632	463.794	11.571	12.002	11.534	6.451	6.797	6.525	n.d.	n.d.	n.d.
3	10/14 a	426.725	405.226	426.852	9.612	8.968	9.600	5.202	4.668	5.205	n.d.	n.d.	n.d.
	p	382.283	410.297	351.682	8.610	9.364	7.567	5.466	5.995	4.424	n.d.	n.d.	n.d.
4	10/15 a	313.855	351.914	348.958	6.862	7.842	7.664	5.362	5.515	5.181	n.d.	n.d.	n.d.
	p	398.641	299.687	377.508	17.482	17.544	16.331	8.096	7.792	7.244	n.d.	n.d.	n.d.
5	10/16 a	453.634	464.243	473.473	25.281	26.147	26.625	9.744	12.022	10.431	n.d.	n.d.	n.d.
	p	455.869	466.254	466.657	10.173	10.407	10.192	6.876	6.846	6.970	n.d.	n.d.	n.d.
6	10/17 a	433.842	442.374	421.587	14.027	14.289	13.307	6.418	6.202	5.630	n.d.	n.d.	n.d.
	p	424.255	428.513	427.341	8.021	8.090	8.106	5.652	5.731	5.620	n.d.	n.d.	n.d.

RUN 4 - CONTROL 100/0, TEST 0/100 - VFA DATA (mg/L)

DAY	DATE	Unsettled Mixed Liquor (A-side) ACETIC A	B	C	PROPIONIC A	B	C	ISO-BUTYRIC A	B	C	BUTYRIC A	B	C	Unsettled Mixed Liquor (B-side) ACETIC A	B	C	PROPIONIC A	B	C	ISO-BUTYRIC A	B	C	BUTYRIC A	B	C
1	10/27 a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p																								
2	10/28 a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p																								
3	10/29 a	n.d.	n.d.	0.802	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p																								
4	10/30 a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p																								
5	10/31 a	n.d.	0.666	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p																								
6	11/01 a	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p																								

(shaded) below detection limit
n.d. not detected
detection limit = 1.000 mg/L

RUN 4 - CONTROL 100/0, TEST 0/100 - VFA DATA (mg/L)

DAY	DATE	Control Reactor Feed, 100/0 ACETIC A	B	C	PROPIONIC A	B	C	ISO-BUTYRIC A	B	C	BUTYRIC A	B	C	Test Reactor Feed, 0/100 (Secondary Sludge) ACETIC A	B	C	PROPIONIC A	B	C	ISO-BUTYRIC A	B	C	BUTYRIC A	B	C
1	10/27 a	96.525	76.908	78.029	71.572	57.401	57.788	1.600	1.200	1.200	3.058	2.205	2.200	16.635	11.800	17.273	5.495	3.964	5.182	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p	130.650	117.813	111.142	109.948	100.402	97.142	2.510	2.081	2.101	4.914	4.287	4.217	39.211	40.446	39.000	5.533	5.371	5.560	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
2	10/28 a	81.988	85.621	93.388	58.866	61.889	66.166	1.500	1.600	1.704	1.900	2.300	2.389	6.525	7.473	7.991	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p	138.487	140.197	149.468	114.321	116.766	125.966	2.497	2.490	2.676	4.244	4.043	4.510	1.502	1.164	1.048	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
3	10/29 a	81.667	72.110	67.124	57.350	49.465	46.684	1.497	2.800	1.100	2.646	2.333	2.200	0.895	0.874	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p	96.822	95.606	93.661	69.184	68.417	66.560	2.107	1.842	1.865	3.437	3.213	3.161	0.765	0.768	0.895	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
4	10/30 a	79.879	96.037	87.062	63.825	76.782	69.807	1.483	1.889	1.632	3.278	4.116	3.586	1.213	2.570	1.470	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p	109.204	90.657	109.564	92.685	75.980	93.671	2.166	1.647	2.167	4.409	3.494	4.468	0.898	n.d.	0.824	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
5	10/31 a	93.172	88.329	87.112	79.248	73.565	72.347	1.819	1.741	1.640	4.268	3.890	3.903	3.029	2.600	2.736	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p	104.812	114.930	103.852	95.229	106.468	95.432	1.995	2.314	2.024	5.200	5.843	5.053	2.188	2.191	2.189	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
6	11/01 a	71.697	84.198	80.792	69.660	70.863	66.178	1.300	1.525	1.600	3.631	3.757	3.493	3.028	2.979	2.877	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p	100.182	96.527	93.642	85.603	83.934	79.596	2.100	2.003	1.814	3.955	3.710	3.485	5.275	5.735	5.875	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

RUN 4 - CONTROL 100/0, TEST 0/100 - VFA DATA (mg/L)

DAY	DATE	Control ATAD Reactor, 100/0 ACETIC A	B	C	PROPIONIC A	B	C	ISO-BUTYRIC A	B	C	BUTYRIC A	B	C	Test ATAD Reactor, 0/100 ACETIC A	B	C	PROPIONIC A	B	C	ISO-BUTYRIC A	B	C	BUTYRIC A	B	C
1	10/27 a	214.612	200.528	204.172	2.616	2.412	2.491	2.342	1.743	1.776	n.d.	n.d.	n.d.	712.407	694.513	707.060	49.139	55.632	54.358	15.213	16.892	17.907	n.d.	n.d.	n.d.
	p	254.918	212.624	222.853	5.013	4.142	4.321	2.493	1.941	2.079	n.d.	n.d.	n.d.	766.898	760.962	739.759	63.266	63.163	62.022	20.636	21.448	20.561	n.d.	n.d.	n.d.
2	10/28 a	255.721	270.815	288.074	6.740	7.210	7.801	2.764	2.893	3.179	n.d.	n.d.	n.d.	829.120	824.622	821.898	64.371	65.124	64.624	25.839	25.263	25.081	n.d.	n.d.	n.d.
	p	192.150	214.527	207.157	1.351	1.836	1.738	1.351	1.836	1.738	n.d.	n.d.	n.d.	818.591	822.208	827.275	73.949	75.326	76.180	27.009	27.194	27.236	n.d.	n.d.	n.d.
3	10/29 a	145.119	189.390	213.791	2.295	3.010	3.453	1.400	1.741	2.041	n.d.	n.d.	n.d.	798.641	866.010	850.511	72.312	77.510	77.668	28.415	31.618	29.843	n.d.	n.d.	n.d.
	p	193.699	171.227	164.511	2.902	2.572	2.395	1.541	1.300	1.100	n.d.	n.d.	n.d.	805.555	815.078	834.897	66.959	67.581	69.199	28.626	28.734	30.326	n.d.	n.d.	n.d.
4	10/30 a	206.816	185.488	207.659	4.191	3.713	4.292	2.353	1.945	2.282	n.d.	n.d.	n.d.	814.408	810.756	803.375	52.076	50.885	50.658	29.110	29.274	28.589	n.d.	n.d.	n.d.
	p	185.466	201.491	194.643	4.441	4.855	4.645	2.055	2.238	2.196	n.d.	n.d.	n.d.	740.382	761.469	749.113	37.115	36.972	36.171	24.148	24.514	24.066	n.d.	n.d.	n.d.
5	10/31 a	192.434	218.755	199.657	4.161	4.774	4.333	2.022	2.493	2.179	n.d.	n.d.	n.d.	706.549	701.193	734.796	24.959	29.211	30.565	19.586	20.571	21.055	n.d.	n.d.	n.d.
	p	170.761	168.765	134.600	4.073	4.010	3.095	1.629	1.581	1.300	n.d.	n.d.	n.d.	651.386	638.268	661.922	26.739	21.545	25.900	17.824	16.416	18.937	n.d.	n.d.	n.d.
6	11/01 a	179.170	177.208	182.996	4.312	4.284	4.471	2.130	1.870	1.977	n.d.	n.d.	n.d.	619.383	613.058	603.266	17.344	20.651	20.143	17.769	17.993	17.440	n.d.	n.d.	n.d.
	p	167.870	167.840	157.576	4.047	4.164	3.822	1.872	1.716	1.474	n.d.	n.d.	n.d.	573.190	556.961	566.599	15.242	17.130	15.393	17.178	17.447	17.504	n.d.	n.d.	n.d.

RUN 5 - CONTROL 0/100, TEST 0/100 solubilized - VFA DATA (mg/L)

		Unsettled Mixed Liquor (A-side)												Unsettled Mixed Liquor (B-side)											
		ACETIC			PROPIONIC			ISO-BUTYRIC			BUTYRIC			ACETIC			PROPIONIC			ISO-BUTYRIC			BUTYRIC		
DAY	DATE	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
1	11/20 a	1.336	1.746	1.166	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	1.140	1.144	1.154	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p																								
2	11/21 a	2.025	1.007	2.659	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	3.119	3.164	3.335	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p																								
3	11/22 a	4.319	3.272	3.038	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	4.037	3.041	3.756	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p																								
4	11/23 a	1.900	2.500	2.600	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	3.182	3.290	2.930	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p																								
5	11/24 a	1.800	2.100	2.781	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	3.614	3.463	3.211	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p																								
6	11/25 a	3.687	2.500	3.843	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	5.341	4.394	6.053	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	11/26 a																								

n.d. not detected
detection limit = 1.000 mg/L

RUN 5 - CONTROL 0/100, TEST 0/100 solubilized - VFA DATA (mg/L)

		Control Reactor Feed, 0/100 (Secondary Sludge)												Test Reactor Feed, 0/100 solubilized											
		ACETIC			PROPIONIC			ISO-BUTYRIC			BUTYRIC			ACETIC			PROPIONIC			ISO-BUTYRIC			BUTYRIC		
DAY	DATE	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
1	11/20 a	1.288	1.162	1.201	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	96.240	101.680	97.360	4.550	5.110	4.600	2.500	2.800	2.700	3.300	3.500	3.300
	p	2.018	2.387	1.900	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	101.836	104.936	105.731	12.085	14.730	15.471	3.882	3.793	3.895	10.965	11.117	11.364
2	11/21 a	3.232	3.899	3.703	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	52.344	53.659	56.242	3.117	3.384	3.454	2.851	2.608	2.669	5.063	4.941	4.965
	p	2.000	2.326	2.197	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	139.984	125.310	136.466	15.290	16.282	17.699	4.695	3.909	4.294	19.825	17.174	19.118
3	11/22 a	5.329	6.331	4.364	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	54.248	60.400	56.452	2.640	3.240	2.938	3.249	3.490	3.193	4.893	5.294	4.942
	p	1.400	2.100	2.200	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	165.513	159.001	164.773	18.927	22.655	23.901	6.194	5.740	5.871	26.680	25.231	26.227
4	11/23 a	3.341	4.842	3.573	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	68.480	69.305	66.386	6.709	6.961	6.729	4.632	4.482	4.355	7.150	6.840	6.781
	p	2.200	2.500	1.900	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	197.030	190.114	203.440	28.708	37.163	38.847	9.642	9.047	9.694	34.662	33.027	35.341
5	11/24 a	3.491	2.200	4.081	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	63.172	65.020	66.820	5.512	7.060	5.850	4.909	4.818	4.919	6.325	6.095	6.308
	p	4.327	1.900	3.952	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	187.905	196.766	198.399	30.870	40.193	40.906	8.941	9.253	9.331	34.060	35.160	35.631
6	11/25 a	5.618	4.085	5.386	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	55.669	56.311	58.918	6.154	6.602	6.412	4.491	4.722	4.433	2.200	2.200	2.100
	11/26 a	2.100	3.049	2.500	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	94.100	106.626	122.932	8.630	10.156	12.294	4.876	5.621	6.440	7.554	8.554	10.021

RUN 5 - CONTROL 0/100, TEST 0/100 solubilized - VFA DATA (mg/L)

		Control ATAD Reactor, 0/100												Test ATAD Reactor, 0/100 solubilized											
		ACETIC			PROPIONIC			ISO-BUTYRIC			BUTYRIC			ACETIC			PROPIONIC			ISO-BUTYRIC			BUTYRIC		
DAY	DATE	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
1	11/20 a	12.799	11.975	14.006	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	4.043	4.999	4.349	n.d.	n.d.	n.d.	2.935	2.945	2.794	n.d.	n.d.	n.d.
	p	14.740	11.660	12.925	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	2.604	2.400	1.671	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
2	11/21 a	3.708	2.780	2.045	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	3.256	3.105	3.972	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p	5.087	3.061	1.970	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	2.533	2.691	2.781	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
3	11/22 a	5.730	3.803	3.119	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	4.394	3.463	3.907	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p	8.368	7.372	6.024	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	2.900	3.052	1.900	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
4	11/23 a	36.636	35.904	33.194	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	5.074	2.000	1.400	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p	63.639	60.589	60.784	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	3.975	16.000	1.000	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
5	11/24 a	74.831	74.941	76.852	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	4.888	4.484	1.600	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p	73.553	73.687	70.874	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	4.864	3.916	3.488	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
6	11/25 a	72.524	78.202	72.956	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	7.024	5.850	5.081	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	11/26 a	4.302	2.100	1.400	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	2.991	1.900	2.617	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.

RUN 6 - CONTROL 35/65, TEST 35/65 solubilized - VFA DATA (mg/L)

		Primary Sludge												Settled Mixed Liquor (Secondary Sludge)											
		ACETIC			PROPIONIC			ISO-BUTYRIC			BUTYRIC			ACETIC			PROPIONIC			ISO-BUTYRIC			BUTYRIC		
DAY	DATE	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
1	12/02 a	36.850	37.197	39.083	22.793	22.445	23.024	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	3.962	2.444	1.998	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p																								
2	12/03 a	42.641	42.146	40.922	27.710	26.734	25.593	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	1.200	1.100	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p																								
3	12/04 a	44.224	38.013	43.694	26.582	22.442	26.895	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p																								
4	12/05 a	40.279	39.691	37.771	21.558	21.180	20.158	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	1.298	1.000	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p																								
5	12/06 a	41.660	40.346	38.973	23.147	20.723	20.607	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	5.259	1.200	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p																								
6	12/07 a	38.590	33.552	37.867	20.176	16.821	19.770	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.
	p																								

below detection limit
lost sample
sample eliminated due to carry-over interference
n.d. not detected
detection limit = 1.000 mg/L

RUN 6 - CONTROL 35/65, TEST 35/65 solubilized - VFA DATA (mg/L)

		Control Reactor Feed, 35/65												Test Reactor Feed, 35/65 solubilized											
		ACETIC			PROPIONIC			ISO-BUTYRIC			BUTYRIC			ACETIC			PROPIONIC			ISO-BUTYRIC			BUTYRIC		
DAY	DATE	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
1	12/02 a	16.216	15.867	17.014	2.506	2.213	2.328	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	33.230	43.781	42.098	9.097	13.551	13.105	1.900	2.408	2.498	n.d.	n.d.	n.d.
	p	14.568	14.945	14.959	3.259	3.421	3.502	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	136.620	120.288	121.649	45.899	36.643	35.649	6.368	5.983	7.974	7.825	7.214	11.012
2	12/03 a	15.418	16.017	14.672	1.593	1.714	1.267	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	47.460	42.346	43.427	10.640	8.413	9.122	2.458	2.391	2.416	n.d.	n.d.	n.d.
	p	18.908	17.228	15.856	10.014	8.458	8.368	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	136.083	149.611	140.846	50.674	54.256	50.362	7.206	7.974	8.158	10.492	11.012	10.115
3	12/04 a	18.295	16.324	19.111	3.396	2.997	3.483	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	43.846	47.140	41.467	8.182	8.977	7.931	2.921	3.001	2.797	n.d.	n.d.	n.d.
	p	32.666	35.143	34.808	12.359	12.897	13.300	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	139.034	125.425	136.333	51.541	41.851	45.049	7.749	10.799	6.787	10.700	8.277	9.036
4	12/05 a	19.806	19.329	19.677	1.909	1.769	1.787	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	48.385	42.183	40.414	10.357	8.754	8.876	2.779	2.205	2.170	n.d.	n.d.	n.d.
	p	24.266	23.059	23.247	7.325	7.027	6.999	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	126.792	121.832	133.206	50.397	47.753	51.578	6.446	6.664	5.907	9.846	8.464	9.314
5	12/06 a	13.876	15.215	13.260	2.431	2.855	2.200	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	34.375	29.030	30.189	4.453	3.555	3.969	1.000	n.d.	1.060	n.d.	n.d.	n.d.
	p	23.395	25.541	27.840	4.758	5.669	6.227	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	90.276	101.509	92.515	22.519	25.376	21.768	3.151	3.717	3.358	6.544	7.436	6.202
6	12/07 a	13.307	13.662	13.210	0.354	0.308	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	43.564	38.712	39.075	5.784	4.955	5.094	2.068	2.097	2.100	n.d.	n.d.	n.d.
	p	13.314	12.818	12.777	3.809	3.383	3.544	n.d.	n.d.	n.d.	n.d.	n.d.	n.d.	118.219	121.761	105.551	40.203	39.851	34.048	5.240	4.871	5.070	10.201	9.957	8.359

RUN 6 - CONTROL 35/65, TEST 35/65 solubilized - VFA DATA (mg/L)

		Control ATAD Reactor, 35/65												Test ATAD Reactor, 35/65 solubilized											
		ACETIC			PROPIONIC			ISO-BUTYRIC			BUTYRIC			ACETIC			PROPIONIC			ISO-BUTYRIC			BUTYRIC		
DAY	DATE	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C	A	B	C
1	12/02 a	251.780	236.147	257.149	3.347	2.447	2.824	3.076	1.998	3.213	n.d.	n.d.	n.d.	188.062	189.268	183.999	34.847	41.828	40.096	33.902	54.877	54.154	n.d.	n.d.	n.d.
	p	303.644	301.033	291.888	4.551	4.432	4.234	5.296	12.159	5.602	n.d.	n.d.	n.d.	201.123	186.607	198.010	38.234	34.605	34.135	54.199	55.805	54.785	n.d.	n.d.	n.d.
2	12/03 a	334.849	338.299	334.896	4.116	4.166	4.167	12.954	5.474	7.800	n.d.	n.d.	n.d.	230.808	213.869	237.100	35.205	27.928	36.688	53.996	52.003	50.473	n.d.	n.d.	n.d.
	p	376.778	379.262	399.015	10.044	10.095	10.943	19.758	8.702	20.689	n.d.	n.d.	n.d.	273.009	255.272	351.869	38.816	30.721	9.291	55.098	52.806	35.764	n.d.	n.d.	n.d.
3	12/04 a	431.029	416.090	418.505	9.131	9.067	8.683	22.285	26.117	25.785	n.d.	n.d.	n.d.	326.141	330.699	323.232	35.319	35.911	34.714	25.720	46.589	49.058	n.d.	n.d.	n.d.
	p	422.623	439.720	425.271	10.222	10.844	10.563	26.324	28.473	28.887	n.d.	n.d.	n.d.	376.585	365.245	388.183	32.352	31.352	33.152	45.716	48.027	47.296	n.d.	n.d.	n.d.
4	12/05 a	432.745	422.537	425.795	14.788	14.317	14.182	30.584	31.614	30.753	n.d.	n.d.	n.d.	450.182	459.778	455.468	33.748	34.853	34.482	46.271	45.670	48.045	n.d.	n.d.	n.d.
	p		471.282	472.444		9.705	11.504			25.591	n.d.	n.d.	n.d.	497.502	500.885	488.333	34.401	34.987	33.743	46.593	48.342	45.774	n.d.	n.d.	n.d.
5	12/06 a	457.748	426.880	370.365	13.576	12.385	10.316	24.230	23.840	27.481	n.d.	n.d.	n.d.	557.964	581.266	550.923	34.418	35.911	33.824	47.769	50.552	50.340	n.d.	n.d.	n.d.
	p	406.028	367.817	359.084	6.771	5.863	5.848	22.862	15.182	22.828	n.d.	n.d.	n.d.	568.400	589.071	617.903	20.541	21.000	22.114	46.084	42.149	45.114	n.d.	n.d.	n.d.
6	12/07 a	351.584	338.413	35.796	3.646	3.517	3.750	20.665	16.080	8.119	n.d.	n.d.	n.d.	581.994	560.157	550.858	9.462	8.970	8.445	42.478	35.107	34.301	n.d.	n.d.	n.d.
	p	321.233	340.501	326.934	6.622	6.988	6.794	20.983	9.093	21.237	n.d.	n.d.	n.d.	534.819	578.331	586.692	13.201	14.669	14.898	34.301	25.807	31.939	n.d.	n.d.	n.d.

RUN1 - CONTROL 100/0, TEST 100/0 - AVERAGED VFA DATA (mg/L)

DAY	DATE		ACETIC Unsettled ML	ACETIC Settled ML	ACETIC C Feed	ACETIC T Feed	ACETIC C ATAD	ACETIC T ATAD	PROPRIONIC Unsettled ML	PROPRIONIC Settled ML	PROPRIONIC C Feed	PROPRIONIC T Feed	PROPRIONIC C ATAD	PROPRIONIC T ATAD
1	9/11	a		98	149	153	161	163		37	107	101	3	5
		p			189	166	129	167			143	124	4	3
2	9/12	a	8	84	166	163	135	161	0	29	122	116	2	4
		p			178	184	117	142			126	135	3	2
3	9/13	a	5	72	151	134	126	145	0	13	110	98	3	3
		p			160	152	107	147			125	119	2	4
4	9/14	a	6	60	152	139	135	149	0	13	130	111	5	4
		p			152	155	125	166			119	123	4	6
5	9/15	a	5	64	143	144	144	157	0	13	105	104	4	4
		p			168	152	138	145			117	109	6	3
6	9/16	a	6	54	154	142	143	129	0	10	114	102	7	2
		p			148	138	129	157			111	105	4	5
AVG			6	72	159	152	132	152	0	19	119	112	4	4
STDS			1.51	16.33	13.65	14.01	13.77	11.33	0.00	11.03	11.07	11.25	1.43	1.16
MIN			5	54	143	134	107	129	0	10	105	98	2	2
MAX			8	98	189	184	161	167	0	37	143	135	7	6
MEDIAN			6	68	153	152	132	153	0	13	118	110	4	4

DAY	DATE		ISO-BUTYRIC Unsettled ML	ISO-BUTYRIC Settled ML	ISO-BUTYRIC C Feed	ISO-BUTYRIC T Feed	ISO-BUTYRIC C ATAD	ISO-BUTYRIC T ATAD	BUTYRIC Unsettled ML	BUTYRIC Settled ML	BUTYRIC C Feed	BUTYRIC T Feed	BUTYRIC C ATAD	BUTYRIC T ATAD
1	9/11	a		5	3	2	14	11		0	8	5	0	0
		p			5	3	13	12			12	9	0	0
2	9/12	a	0	3	4	4	12	12	0	0	9	8	0	0
		p			5	5	11	9			10	9	0	0
3	9/13	a	0	0	4	3	11	7	0	0	7	5	0	0
		p			4	4	10	6			10	8	0	0
4	9/14	a	0	0	4	3	12	7	0	0	12	8	0	0
		p			4	4	11	6			11	9	0	0
5	9/15	a	0	0	3	4	12	7	0	0	7	6	0	0
		p			4	3	12	5			7	1	0	0
6	9/16	a	0	0	4	3	13	5	0	0	7	5	0	0
		p			3	3	11	5			7	6	0	0
AVG			0	1	4	3	12	8	0	0	9	7	0	0
STDS			0.00	2.19	0.71	0.73	1.02	2.74	0.00	0.00	1.90	2.36	0.00	0.00
MIN			0	0	3	2	10	5	0	0	7	1	0	0
MAX			0	5	5	5	14	12	0	0	12	9	0	0
MEDIAN			0	0	4	3	12	7	0	0	9	7	0	0

RUN 1 - CONTROL 100/0, TEST 100/0 - TOTAL VFA (mg/L)

DAY	DATE		Unsettled ML	Settled ML	C Feed	T Feed	C ATAD	T ATAD
1	9/11	a		139	267	262	178	178
		p			349	302	145	182
2	9/12	a	8	117	302	290	149	176
		p			319	333	131	153
3	9/13	a	5	85	271	240	140	155
		p			299	283	120	157
4	9/14	a	6	72	298	262	151	159
		p			285	290	140	177
5	9/15	a	5	77	258	257	160	168
		p			296	265	156	153
6	9/16	a	6	64	279	253	163	136
		p			268	252	144	167
AVG			6	92	291	274	148	164
STDS			1.51	29.24	25.52	26.36	15.25	13.75
MIN			5	64	258	240	120	136
MAX			8	139	349	333	178	182
MEDIAN			6	81	291	263	147	163

RUN 2 - CONTROL 100/0, TEST 65/35 - AVERAGED VFA DATA (mg/L)

		ACETIC						PROPRIONIC						ISO-BUTYRIC						BUTYRIC					
DAY	DATE	Unsettled ML	Settled ML	C Feed	T Feed	C ATAD	T ATAD	Unsettled ML	Settled ML	C Feed	T Feed	C ATAD	T ATAD	Unsettled ML	Settled ML	C Feed	T Feed	C ATAD	T ATAD	Unsettled ML	Settled ML	C Feed	T Feed	C ATAD	T ATAD
1	9/27 a	0	75	106	135	217	488	0	9	· 80	81	10	49	0	0	1	3	15	41	0	0	5	6	0	8
	p			138	204	221	477			93	158	11	35			1	4	16	43			6	12	0	9
2	9/28 a	13	60	88	114	221	380	0	9	68	67	12	20	0	0	1	4	14	26	0	0	4	5	0	3
	p			129	153	157	457			107	113	8	41			2	4	13	33			6	7	0	6
3	9/29 a	15	66	121	143	203	506	0	9	102	103	8	44	0	0	2	4	15	36	0	0	6	5	0	4
	p			129	121	232	545			104	86	15	41			2	4	22	33			5	4	0	2
4	9/30 a	10	69	111	138	227	519	0	16	88	87	15	36	0	0	2	5	21	29	0	0	5	6	0	2
	p			143	241	238	556			86	159	13	39			1	9	22	27			6	10	0	0
5	10/01 a	10	78	106	103	226	497	0	22	83	58	22	22	0	0	3	2	20	18	0	0	4	3	0	0
	p			102	147	192	516			71	93	12	26			1	6	18	16			5	4	0	0
6	10/02 a	22	98	108	147	260	562	0	22	83	85	15	21	0	0	2	4	20	13	0	0	4	4	0	0
	p			135	217	241	520			89	148	20	19			1	7	18	12			5	7	0	0
AVG		12	74	118	155	220	502	0	15	88	103	13	33	0	0	2	5	18	27	0	0	5	6	0	3
STDS		7.14	13.23	17.03	42.96	26.19	49.49	0.00	6.39	12.11	34.59	4.38	10.49	0.00	0.00	0.48	1.78	3.30	10.69	0.00	0.00	0.76	2.61	0.00	3.26
MIN		0	60	88	103	157	380	0	9	68	58	8	19	0	0	1	2	13	12	0	0	4	3	0	0
MAX		22	98	143	241	260	562	0	22	107	159	22	49	0	0	3	9	22	43	0	0	6	12	0	9
MEDIAN		12	72	116	145	224	511	0	12	87	90	12	36	0	0	2	4	18	28	0	0	5	6	0	2

RUN 2 - CONTROL 100/0, TEST 65/35 - TOTAL VFA (mg/L)

DAY	DATE	Unsettled ML	Settled ML	C Feed	T Feed	C ATAD	T ATAD
1	9/27 a	0	84	193	225	241	587
	p			238	379	248	564
2	9/28 a	13	69	161	189	247	429
	p			244	277	178	537
3	9/29 a	15	75	230	256	226	591
	p			240	215	268	621
4	9/30 a	10	85	206	235	264	587
	p			237	419	273	621
5	10/01 a	10	101	196	166	268	538
	p			179	250	222	558
6	10/02 a	22	120	197	239	295	596
	p			230	379	279	551
AVG		12	89	213	269	251	565
STDS		7.14	18.56	27.59	80.40	31.30	51.49
MIN		0	69	161	166	178	429
MAX		22	120	244	419	295	621
MEDIAN		12	84	218	245	256	575

RUN 3 - CONTROL 100/0, TEST 35/65 - AVERAGED VFA DATA (mg/L)

DAY	DATE	ACETIC Unsettled ML	ACETIC Settled ML	ACETIC C Feed	ACETIC T Feed	ACETIC C ATAD	ACETIC T ATAD	PROPRIONIC Unsettled ML	PROPRIONIC Settled ML	PROPRIONIC C Feed	PROPRIONIC T Feed	PROPRIONIC C ATAD	PROPRIONIC T ATAD
1	10/12 a	0	142	91	90	194	356	0	20	67	27	5	10
	p			149	131	227	419			131	48	10	19
2	10/13 a	0	114	66	69	233	450	0	9	48	19	10	18
	p			89	84	187	465			71	26	5	12
3	10/14 a	0	75	75	85	222	420	0	1	54	24	5	9
	p	0		104	121	199	381	0		94	46	5	9
4	10/15 a	0	98	59	76	190	338	0	10	41	21	4	7
	p	0		79	147	207	359	0		51	63	3	17
5	10/16 a	0	62	79	76	187	464	0	7	54	33	5	26
	p	0	49	108	119	182	463	0	3	85	59	3	10
6	10/17 a	0	52	90	58	165	433	0	3	69	15	3	14
	p	0	55	112	90	184	427	0	5	97	30	4	8
AVG		0	81	92	96	198	414	0	7	72	34	5	13
STDS		0.00	33.79	24.20	27.48	20.40	45.27	0.00	5.94	26.14	15.98	2.45	5.75
MIN		0	49	59	58	165	338	0	1	41	15	3	7
MAX		0	142	149	147	233	465	0	20	131	63	10	26
MEDIAN		0	69	90	88	192	423	0	6	68	29	5	11

DAY	DATE	ISO-BUTYRIC Unsettled ML	ISO-BUTYRIC Settled ML	ISO-BUTYRIC C Feed	ISO-BUTYRIC T Feed	ISO-BUTYRIC C ATAD	ISO-BUTYRIC T ATAD	BUTYRIC Unsettled ML	BUTYRIC Settled ML	BUTYRIC C Feed	BUTYRIC T Feed	BUTYRIC C ATAD	BUTYRIC T ATAD
1	10/12 a	0	15	2	3	2	5	0	6	3	3	0	0
	p			3	4	3	7			8	2	0	0
2	10/13 a	0	17	0	2	3	8	0	4	2	2	0	0
	p			2	2	2	7			3	1	0	0
3	10/14 a	0	11	1	2	2	5	0	0	3	2	0	0
	p	0		2	2	2	5	0		5	2	0	0
4	10/15 a	0	12	0	1	2	5	0	4	2	2	0	0
	p	0		2	5	1	8	0		2	3	0	0
5	10/16 a	0	1	2	1	1	11	0	0	3	2	0	0
	p	0	0	3	3	1	7	0	0	5	2	0	0
6	10/17 a	0	0	2	1	1	6	0	0	4	2	0	0
	p	0	0	3	2	1	6	0	0	7	2	0	0
AVG		0	7	2	2	2	7	0	2	4	2	0	0
STDS		0.00	7.24	0.82	1.19	0.64	1.72	0.00	2.48	1.78	0.71	0.00	0.00
MIN		0	0	0	1	1	5	0	0	2	1	0	0
MAX		0	17	3	5	3	11	0	6	8	3	0	0
MEDIAN		0	6	2	2	2	6	0	0	3	2	0	0

NOTE: for unsettled mixed liquor samples am = A-side
pm = B-side

RUN 3 - CONTROL100/0, TEST 35/65 - TOTAL VFA (mg/L)

DAY	DATE	Unsettled ML	Settled ML	C Feed	T Feed	C ATAD	T ATAD
1	10/12 a	0	182	163	123	201	370
	p			291	184	240	446
2	10/13 a	0	143	116	91	246	476
	p			166	112	194	483
3	10/14 a	0	86	134	113	229	434
	p	0		207	170	207	395
4	10/15 a	0	124	103	99	195	351
	p	0		134	219	211	383
5	10/16 a	0	71	137	112	193	501
	p	0	52	200	183	187	480
6	10/17 a	0	55	165	75	169	453
	p	0	60	219	124	190	440
AVG		0	97	169	134	205	434
STDS		0.00	47.92	52.56	44.25	22.88	48.86
MIN		0	52	103	75	169	351
MAX		0	182	291	219	246	501
MEDIAN		0	79	164	118	198	443

RUN 4 - CONTROL 100/0, TEST 0/100 - AVERAGED VFA DATA (mg/L)

		ACETIC						PROPRIONIC						ISO-BUTYRIC						BUTYRIC					
DAY	DATE	Unsettled ML	Unsettled ML	C Feed	T Feed	C ATAD	T ATAD	Unsettled ML	Settled ML	C Feed	T Feed	C ATAD	T ATAD	Unsettled ML	Settled ML	C Feed	T Feed	C ATAD	T ATAD	Unsettled ML	Settled ML	C Feed	T Feed	C ATAD	T ATAD
1	10/27 a	0	0	84	15	206	705	0	0	62	5	3	53	0	0	1	0	2	17	0	0	2	0	0	0
	p			120	40	230	756			102	5	4	63			2	0	2	21			4	0	0	0
2	10/28 a	0	0	87	7	272	825	0	0	62	0	7	65	0	0	2	0	3	25	0	0	2	0	0	0
	p			143	1	205	823			119	0	2	75			3	0	2	27			4	0	0	0
3	10/29 a	0	0	74	1	183	838	0	0	51	0	3	76	0	0	2	0	2	30	0	0	2	0	0	0
	p			95	1	176	819			68	0	3	68			2	0	1	29			3	0	0	0
4	10/30 a	0	0	88	2	200	810	0	0	70	0	4	51	0	0	2	0	2	29	0	0	4	0	0	0
	p			103	1	194	750			87	0	5	37			2	0	2	24			4	0	0	0
5	10/31 a	0	0	90	3	204	714	0	0	75	0	4	28	0	0	2	0	2	20	0	0	4	0	0	0
	p			108	2	158	651			99	0	4	25			2	0	2	18			5	0	0	0
6	11/01 a	0	0	79	3	180	612	0	0	69	0	4	19	0	0	1	0	2	18	0	0	4	0	0	0
	p			97	6	164	566			83	0	4	16			2	0	2	17			4	0	0	0
AVG		0	0	97	7	198	739	0	0	79	1	4	48	0	0	2	0	2	23	0	0	4	0	0	0
STDS		0.13	0.00	19.22	11.15	30.68	91.39	0.00	0.00	19.75	2.02	1.42	22.05	0.00	0.00	0.34	0.00	0.43	5.10	0.00	0.00	0.93	0.00	0.00	0.00
MIN		0	0	74	1	158	566	0	0	51	0	2	16	0	0	1	0	1	17	0	0	2	0	0	0
MAX		0	0	143	40	272	838	0	0	119	5	7	76	0	0	3	0	3	30	0	0	5	0	0	0
MEDIAN		0	0	92	2	197	753	0	0	73	0	4	52	0	0	2	0	2	23	0	0	4	0	0	0

NOTE: for unsettled mixed liquor samples left column = A-side
right column = B-side

RUN 4 - CONTROL 100/0, TEST 0/100 - TOTAL VFA (mg/L)

DAY	DATE	Unsettled ML	Unsettled ML	C Feed	T Feed	C ATAD	T ATAD
1	10/27 a	0	0	150	20	211	774
	p			229	45	237	840
2	10/28 a	0	0	153	7	282	915
	p			269	1	208	925
3	10/29 a	0	0	129	1	187	944
	p			169	1	180	916
4	10/30 a	0	0	163	2	206	890
	p			197	1	201	811
5	10/31 a	0	0	170	3	210	763
	p			214	2	163	693
6	11/01 a	0	0	153	3	186	649
	p			186	6	170	599
AVG		0	0	182	8	203	810
STDS		0.13	0.00	39.52	12.99	31.89	116.14
MIN		0	0	129	1	163	599
MAX		0	0	269	45	282	944
MEDIAN		0	0	169	2	203	825

RUN 5 - CONTROL 0/100, TEST 0/100 solubilized - AVERAGED VFA DATA (mg/L)

DAY	DATE	ACETIC Unsettled ML	ACETIC Unsettled ML	ACETIC C Feed	ACETIC T Feed	ACETIC C ATAD	ACETIC T ATAD	PROPRIONIC Unsettled ML	PROPRIONIC Settled ML	PROPRIONIC C Feed	PROPRIONIC T Feed	PROPRIONIC C ATAD	PROPRIONIC T ATAD
1	11/20 a	1	1	1	98	13	4	0	0	0	5	0	0
	p			2	104	13	2			0	14	0	0
2	11/21 a	2	3	4	54	3	3	0	0	0	3	0	0
	p			2	134	3	3			0	16	0	0
3	11/22 a	4	4	5	57	4	4	0	0	0	3	0	0
	p			2	163	7	3			0	22	0	0
4	11/23 a	2	3	4	68	35	3	0	0	0	7	0	0
	p			2	197	62	7			0	35	0	0
5	11/24 a	2	3	3	65	76	4	0	0	0	6	0	0
	p			3	194	73	4			0	37	0	0
6	11/25 a	3	5	5	57	75	6	0	0	0	6	0	0
	11/26 a			3	108	3	3			0	10	0	0
AVG		2	3	3	108	31	4	0	0	0	14	0	0
STDS		0.83	1.31	1.27	52.85	31.43	1.46	0.00	0.00	0.00	11.89	0.00	0.00
MIN		1	1	1	54	3	2	0	0	0	3	0	0
MAX		4	5	5	197	76	7	0	0	0	37	0	0
MEDIAN		2	3	3	101	13	4	0	0	0	9	0	0

DAY	DATE	ISO-BUTYRIC Unsettled ML	ISO-BUTYRIC Settled ML	ISO-BUTYRIC C Feed	ISO-BUTYRIC T Feed	ISO-BUTYRIC C ATAD	ISO-BUTYRIC T ATAD	BUTYRIC Unsettled ML	BUTYRIC Settled ML	BUTYRIC C Feed	BUTYRIC T Feed	BUTYRIC C ATAD	BUTYRIC T ATAD
1	11/20 a	0	0	0	3	0	3	0	0	0	3	0	0
	p			0	4	0	0			0	11	0	0
2	11/21 a	0	0	0	3	0	0	0	0	0	5	0	0
	p			0	4	0	0			0	19	0	0
3	11/22 a	0	0	0	3	0	0	0	0	0	5	0	0
	p			0	6	0	0			0	26	0	0
4	11/23 a	0	0	0	4	0	0	0	0	0	7	0	0
	p			0	9	0	0			0	34	0	0
5	11/24 a	0	0	0	5	0	0	0	0	0	6	0	0
	p			0	9	0	0			0	35	0	0
6	11/25 a	0	0	0	5	0	2	0	0	0	2	0	0
	11/26 a			0	6	0	0			0	9	0	0
AVG		0	0	0	5	0	0	0	0	0	14	0	0
STDS		0.00	0.00	0.00	2.22	0.00	0.90	0.00	0.00	0.00	11.98	0.00	0.00
MIN		0	0	0	3	0	0	0	0	0	2	0	0
MAX		0	0	0	9	0	3	0	0	0	35	0	0
MEDIAN		0	0	0	5	0	0	0	0	0	8	0	0

NOTE: for unsettled mixed liquor samples left column = A-side
right column = B-side

RUN 5 - CONTROL 0/100, TEST 0/100 solubilized - TOTAL VFA (mg/L)

DAY	DATE	Unsettled ML	Unsettled ML	C Feed	T Feed	C ATAD	T ATAD
1	11/20 a	1	1	1	109	13	7
	p			2	133	13	2
2	11/21 a	2	3	4	65	3	3
	p			2	173	3	3
3	11/22 a	4	4	5	68	4	4
	p			2	217	7	3
4	11/23 a	2	3	4	86	35	3
	p			2	276	62	7
5	11/24 a	2	3	3	82	76	4
	p			3	276	73	4
6	11/25 a	3	5	5	70	75	7
	11/26 a			3	133	3	3
AVG		2	3	3	141	31	4
STDS		0.83	1.31	1.27	77.90	31.43	1.98
MIN		1	1	1	65	3	2
MAX		4	5	5	276	76	7
MEDIAN		2	3	3	121	13	4

RUN 6 - CONTROL 35/65, TEST 35/65 solubilized - AVERAGED VFA DATA (mg/L)

		ACETIC					
DAY	DATE	Primary Sludge	Settled ML	C Feed	T Feed	C ATAD	T ATAD
1	12/02 a	38	3	16	40	248	187
	p			15	126	299	195
2	12/03 a	42	1	15	44	336	227
	p			17	142	385	293
3	12/04 a	42	0	18	44	422	327
	p			34	134	429	377
4	12/05 a	39	1	20	44	427	455
	p			24	127	472	496
5	12/06 a	40	2	14	31	418	563
	p			26	95	378	592
6	12/07 a	37	0	13	40	242	564
	p			13	115	330	567
AVG		40	1	19	82	365	404
STDS		2.18	1.13	6.24	44.68	74.62	155.11
MIN		37	0	13	31	242	187
MAX		42	3	34	142	472	592
MEDIAN		40	1	17	70	381	416

		PROPRIONIC					
DAY	DATE	Primary Sludge	Settled ML	C Feed	T Feed	C ATAD	T ATAD
1	12/02 a	23	0	2	12	3	39
	p			3	39	4	36
2	12/03 a	27	0	2	9	4	33
	p			9	52	10	26
3	12/04 a	25	0	3	8	9	35
	p			13	46	11	32
4	12/05 a	21	0	2	9	14	34
	p			7	50	11	34
5	12/06 a	21	0	2	4	12	35
	p			6	23	6	21
6	12/07 a	19	0	0	5	4	9
	p			4	38	7	14
AVG		23	0	4	25	8	29
STDS		2.88	0.00	3.62	18.90	3.76	9.48
MIN		19	0	0	4	3	9
MAX		27	0	13	52	14	39
MEDIAN		22	0	3	18	8	34

		ISO-BUTYRIC					
DAY	DATE	Primary Sludge	Settled ML	C Feed	T Feed	C ATAD	T ATAD
1	12/02 a	0	0	0	2	3	48
	p			0	7	8	55
2	12/03 a	0	0	0	2	9	52
	p			0	8	16	48
3	12/04 a	0	0	0	3	25	40
	p			0	8	28	47
4	12/05 a	0	0	0	2	31	47
	p			0	6	26	47
5	12/06 a	0	0	0	1	25	50
	p			0	3	20	44
6	12/07 a	0	0	0	2	15	37
	p			0	5	17	31
AVG		0	0	0	4	19	45
STDS		0.00	0.00	0.00	2.56	8.84	6.60
MIN		0	0	0	1	3	31
MAX		0	0	0	8	31	55
MEDIAN		0	0	0	3	19	47

		BUTYRIC					
DAY	DATE	Primary Sludge	Settled ML	C Feed	T Feed	C ATAD	T ATAD
1	12/02 a	0	0	0	0	0	0
	p			0	9	0	0
2	12/03 a	0	0	0	0	0	0
	p			0	11	0	0
3	12/04 a	0	0	0	0	0	0
	p			0	9	0	0
4	12/05 a	0	0	0	0	0	0
	p			0	9	0	0
5	12/06 a	0	0	0	0	0	0
	p			0	7	0	0
6	12/07 a	0	0	0	0	0	0
	p			0	10	0	0
AVG		0	0	0	5	0	0
STDS		0.00	0.00	0.00	4.78	0.00	0.00
MIN		0	0	0	0	0	0
MAX		0	0	0	11	0	0
MEDIAN		0	0	0	3	0	0

RUN 6 - CONTROL 35/65, TEST 35/65 solubilized - TOTAL VFA (mg/L)

DAY	DATE	Primary Sludge	Settled ML	C Feed	T Feed	C ATAD	T ATAD
1	12/02 a	60	3	19	54	254	274
	p			18	181	311	286
2	12/03 a	69	1	17	56	349	313
	p			26	212	412	368
3	12/04 a	67	0	21	55	456	402
	p			47	198	468	456
4	12/05 a	60	1	21	55	472	536
	p			31	193	508	577
5	12/06 a	62	2	17	36	456	648
	p			31	128	404	657
6	12/07 a	56	0	14	48	261	611
	p			17	168	353	612
AVG		62	1	23	115	392	478
STDS		4.84	1.15	9.38	70.52	85.56	145.84
MIN		56	0	14	36	254	274
MAX		69	3	47	212	508	657
MEDIAN		61	1	20	92	408	496

APPENDIX G: NUTRIENT DATA

RUN 1 - CONTROL 100/0, TEST 100/0 - NUTRIENT DATA (mg/L as N or P)

		UNSETTLED MIXED LIQUOR (A-side)					SETTLED MIXED LIQUOR (Secondary Sludge)				
DAY	DATE	TP	PO4	TKN	NOx	NH4	TP	PO4	TKN	NOx	NH4
1	9/11 a						435.68	67.67	914.76	0.129	36.57
	p										
2	9/12 a	120.74	0.097	146.70	5.054	0.000	209.29	78.93	314.21	1.028	37.99
	p										
3	9/13 a	148.96	0.020	212.30	4.173	0.000	220.28	138.38	357.75	0.046	37.11
	p										
4	9/14 a	140.66	0.528	249.29	5.269	1.416	238.50	148.63	415.24	0.047	34.11
	p										
5	9/15 a	117.54	0.000	192.72	5.905	0.000	237.45	149.74	431.89	0.547	39.28
	p										
6	9/16 a	128.16	0.138	226.47	5.738	0.000	207.94	133.00	375.45	0.097	37.77
	p										
AVG		131.21	0.157	205.49	5.228	0.283	258.19	119.39	468.22	0.316	37.14
STDS		13.32	0.215	38.81	0.683	0.633	87.95	36.43	222.73	0.397	1.75
MIN		117.54	0.000	146.70	4.173	0.000	207.94	67.67	314.21	0.046	34.11
MAX		148.96	0.528	249.29	5.905	1.416	435.68	149.74	914.76	1.028	39.28
MEDIAN		128.16	0.097	212.30	5.269	0	228.86	135.69	395.34	0.113	37.44

lost sample
below detection limit (for PO4, NOx, NH4)
detection limit = 0.05 mg/L (for PO4, NOx, NH4)

RUN 1 - CONTROL 100/0, TEST 100/0 - NUTRIENT DATA (mg/L as N or P)

		CONTROL REACTOR FEED, 100/0					TEST REACTOR FEED, 100/0				
DAY	DATE	TP	PO4	TKN	NOx	NH4	TP	PO4	TKN	NOx	NH4
1	9/11 a	34.38	5.403	207.86	0.117	26.30	35.13	5.836	245.55	1.162	26.60
	p	39.63	6.276	240.30	1.044	29.56	32.22	6.642	203.60	0.874	29.32
2	9/12 a	30.30	5.689	176.39	0.845	27.65	30.89	6.067	190.20	0.727	27.27
	p	30.12	3.467	185.48	0.673	27.81	32.84	4.177	203.01	0.548	30.40
3	9/13 a	31.43	3.251	205.79	0.052	25.28	36.00	3.131	213.20	0.025	26.38
	p	44.18	3.694	260.27	0.638	25.54	37.53	3.230	245.60	0.624	23.68
4	9/14 a	22.70	5.628	155.61	0.066	25.62	37.74	5.541	173.03	0.068	24.51
	p	26.21	5.717	157.40	0.045	26.39	25.67	4.888	135.93	0.038	26.27
5	9/15 a	25.82	4.800	173.10	0.545	24.50	29.34	4.666	180.05	0.610	22.93
	p	27.03	4.562	173.58	0.096	23.58	30.54	4.567	177.27	0.055	21.53
6	9/16 a	26.63	4.312	172.25	0.059	20.94	32.06	4.238	185.19	0.058	20.41
	p	31.94	4.145	188.91	0.104	19.43	34.97	4.348	214.20	0.099	19.47
AVG		30.86	4.745	191.41	0.357	25.21	32.91	4.778	197.23	0.407	24.90
STDS		6.14	0.998	32.10	0.367	2.85	3.56	1.081	30.93	0.397	3.42
MIN		22.70	3.251	155.61	0.045	19.43	25.67	3.131	135.93	0.025	19.47
MAX		44.18	6.276	260.27	1.044	29.56	37.74	6.642	245.60	1.162	30.40
MEDIAN		30.21	4.681	180.93	0.1105	25.58	32.53	4.6165	196.61	0.3235	25.39

RUN 1 - CONTROL 100/0, TEST 100/0 - NUTRIENT DATA (mg/L as N or P)

		CONTROL ATAD REACTOR, 100/0					TEST ATAD REACTOR, 100/0				
DAY	DATE	TP	PO4	TKN	NOx	NH4	TP	PO4	TKN	NOx	NH4
1	9/11 a	42.38	1.644	196.00	0.994	28.00	34.23	3.381	141.68	0.927	26.61
	p	39.32	2.899	180.15	1.107	28.22	38.09	3.371	173.39	1.241	27.31
2	9/12 a	38.71	2.992	174.76	1.204	28.23	39.15	3.531	177.31	1.269	28.03
	p	38.63	2.058	178.44	1.160	26.39	39.45	2.263	179.76	0.815	25.28
3	9/13 a	39.03	2.195	179.88	0.982	27.01	40.18	2.794	183.14	1.245	25.63
	p	36.11	2.723	168.04	1.186	25.85	40.52	3.280	183.88	1.020	26.74
4	9/14 a	30.60	4.567	153.72	0.071	28.29	29.87	5.644	165.81	0.067	28.66
	p	31.89	4.189	181.94	0.066	17.82	34.95	5.211	195.86	0.075	30.55
5	9/15 a	28.85	3.180	166.34	0.808	27.94	30.32	3.511	168.57	0.785	26.60
	p	30.08	2.574	171.02	0.251	26.89	30.54	2.861	176.91	0.861	26.16
6	9/16 a	30.15	2.447	151.49	0.281	26.68	31.82	2.853	175.92	0.332	24.10
	p	25.40	2.513	146.00	0.309	25.14	29.60	3.080	169.22	1.180	23.98
AVG		34.26	2.832	170.64	0.702	26.37	34.89	3.482	174.29	0.818	26.64
STDS		5.38	0.839	14.49	0.464	2.88	4.39	0.983	13.07	0.437	1.87
MIN		25.40	1.644	146.00	0.066	17.82	29.60	2.263	141.68	0.067	23.98
MAX		42.38	4.567	196.00	1.204	28.29	40.52	5.644	195.86	1.269	30.55
MEDIAN		34.00	2.6485	172.89	0.895	26.95	34.59	3.3255	176.42	0.894	26.61

RUN 2 - CONTROL 100/0, TEST 65/35 - NUTRIENT DATA (mg/L as N or P)

		UNSETTLED MIXED LIQUOR (A-side)					SETTLED MIXED LIQUOR (Secondary Sludge)				
DAY	DATE	TP	PO4	TKN	NOx	NH4	TP	PO4	TKN	NOx	NH4
1	9/27 a	137.40	0.061	213.41	6.089	0.041	229.01	132.91	423.00	1.618	37.35
	p										
2	9/28 a	99.03	0.037	139.23	7.082	0.111	258.00	136.06	503.89	1.183	36.14
	p										
3	9/29 a	101.73	0.028	155.12	7.466	0.140	216.86	136.77	407.44	0.658	36.11
	p										
4	9/30 a	92.55	0.044	143.79	7.150	0.054	223.80	129.71	421.05	0.552	36.35
	p										
5	10/01 a	95.36	0.083	149.33	7.954	0.012	202.31	129.87	354.30	0.593	36.19
	p										
6	10/02 a	94.13	0.000	134.87	7.568	0.024	280.05	131.57	512.66	0.599	36.67
	p										
AVG		103.37	0.042	155.96	7.218	0.064	235.01	132.82	437.06	0.867	36.47
STDS		17.01	0.028	29.04	0.636	0.051	28.70	3.03	60.60	0.437	0.48
MIN		92.55	0.000	134.87	6.089	0.012	202.31	129.71	354.30	0.552	36.11
MAX		137.40	0.083	213.41	7.954	0.140	280.05	136.77	512.66	1.618	37.35
MEDIAN		97.19	0.0405	146.56	7.308	0.0475	226.41	132.24	422.03	0.6285	36.27

lost sample
below detection limit (for PO4, NOx, NH4)
detection limit = 0.05 mg/L (for PO4, NOx, NH4)

RUN 2 - CONTROL 100/0, TEST 65/35 - NUTRIENT DATA (mg/L as N or P)

		CONTROL REACTOR FEED, 100/0 (Primary Sludge)					TEST REACTOR FEED, 65/35				
DAY	DATE	TP	PO4	TKN	NOx	NH4	TP	PO4	TKN	NOx	NH4
1	9/27 a	29.63	7.912	164.87	0.786	16.30	149.50	43.70	412.18	0.123	29.89
	p	42.72	5.257	209.91	0.128	21.62	134.33	48.28	423.70	0.195	34.91
2	9/28 a	31.67	3.915	165.87	0.058	18.33	153.03	56.78	400.50	0.552	30.70
	p	35.34	5.132	181.64	0.113	21.69	147.48	79.48	387.50	0.552	33.58
3	9/29 a	45.53	4.400	245.43	0.579	20.21	145.03	50.61	414.60	0.482	29.51
	p	38.90	5.020	226.77		21.45	164.88	47.88	491.88	0.375	29.36
4	9/30 a	36.87	4.346	203.01	0.067	19.57	162.95	57.27	446.20	0.410	31.45
	p	30.84	4.489	179.37	0.072	21.04	158.00	60.46	442.55	0.527	35.63
5	10/01 a	35.63	4.410	185.33	0.188	21.16	163.60	46.63	438.13	0.450	28.73
	p	42.26	4.445	205.65	0.690	21.78	157.03	49.47	429.00	0.327	29.40
6	10/02 a	37.94	4.443	198.20	0.618	21.23	158.50	48.55	457.25	0.367	28.91
	p	41.64	4.674	232.70	0.684	23.00	156.85	53.99	444.65	0.445	35.47
AVG		37.41	4.870	199.89	0.362	20.61	154.26	53.59	432.34	0.400	31.46
STDS		5.07	1.030	25.88	0.302	1.81	8.92	9.53	27.76	0.135	2.69
MIN		29.63	3.915	164.87	0.058	16.30	134.33	43.70	387.50	0.123	28.73
MAX		45.53	7.912	245.43	0.786	23.00	164.88	79.48	491.88	0.552	35.63
MEDIAN		37.40	4.467	200.60	0.1205	21.19	156.94	50.04	433.56	0.4275	30.30

RUN 2 - CONTROL 100/0, TEST 65/35 - NUTRIENT DATA (mg/L as N or P)

		CONTROL ATAD REACTOR, 100/0					TEST ATAD REACTOR, 65/35				
DAY	DATE	TP	PO4	TKN	NOx	NH4	TP	PO4	TKN	NOx	NH4
1	9/27 a	52.46	8.380	205.43	2.331	56.85	151.45	63.61	438.48	0.524	145.24
	p	46.19	6.230	256.80	0.180	51.95	132.33	60.67	381.58	0.297	142.43
2	9/28 a	43.35	6.251	237.51	0.178	56.28	104.05	42.45	337.95	0.440	109.24
	p	46.67	5.173	236.21	0.726	52.86	154.88	63.84	445.95	0.291	143.61
3	9/29 a	43.49	5.521	228.99	0.330	52.26	172.90	66.31	488.63	0.505	146.02
	p	51.95	8.844	239.10	0.219	60.55	180.08	64.45	512.10	0.222	143.28
4	9/30 a	54.62	5.200	257.42	0.261	52.47	159.63	62.59	463.98	0.509	144.76
	p	49.55	5.717	258.26	0.242	52.19	150.30	56.22	420.40	0.402	146.73
5	10/01 a	43.38	5.678	217.55	1.076	50.90	151.85	68.40	404.13	0.470	139.16
	p	43.64	5.717	226.89	1.039	48.80		70.43		0.549	145.17
6	10/02 a	38.64	6.721	204.98	1.317	56.23	166.83	73.01	443.40	0.440	156.22
	p	38.52	5.430	200.40	1.098	49.43	146.83		388.23	0.236	148.70
AVG		46.04	6.239	230.79	0.750	53.40	151.92	62.90	429.53	0.407	142.55
STDS		5.22	1.200	20.69	0.656	3.42	20.56	8.20	50.16	0.116	11.27
MIN		38.52	5.173	200.40	0.178	48.80	104.05	42.45	337.95	0.222	109.24
MAX		54.62	8.844	258.26	2.331	60.55	180.08	73.01	512.10	0.549	156.22
MEDIAN		44.91	5.717	232.60	0.528	52.37	151.85	63.72	438.48	0.44	144.97

RUN 3 - CONTROL 100/0, TEST 35/65 - NUTRIENT DATA (mg/L as N or P)

DAY	DATE	UNSETTLED MIXED LIQUOR (am, a-Side & pm, B-side) TP	PO4	TKN	NOx	NH4	SETTLED MIXED LIQUOR (Secondary Sludge) TP	PO4	TKN	NOx	NH4
1	10/12 a	107.93	0.057	187.52	7.707	0.011	229.69	139.98	469.09	0.112	36.65
	p										
2	10/13 a	98.46	0.000	159.17	6.039	0.007	171.34	125.11	311.33	0.155	32.51
	p										
3	10/14 a	115.97	0.000	196.05	7.009	0.101	328.05	122.77	705.79	0.152	29.39
	p	49.41	0.034	141.03	0.202	13.327					
4	10/15 a	115.61	0.004	189.20	8.595	0.113	305.85	149.42	761.06	0.095	34.71
	p	59.85	0.047	157.40	0.803	13.591					
5	10/16 a	119.00	0.000	191.25	5.866	0.000	263.89	129.26	487.84	0.117	30.15
	p	70.31	0.002	172.80	0.928	12.503	182.06	127.82	326.25	0.162	30.77
6	10/17 a	131.31	0.000	213.92	7.108	0.038	218.44	135.54	426.34	0.131	29.38
	p	76.95	0.060	181.34	1.058	12.792	250.01	137.77	478.65	0.112	33.45
AVG		94.48	0.020	178.97	4.532	5.248	243.67	133.46	495.79	0.130	32.13
STDS		28.25	0.026	21.56	3.352	6.724	55.16	8.89	161.75	0.024	2.67
MIN		49.41	0.000	141.03	0.202	0.000	171.34	122.77	311.33	0.095	29.38
MAX		131.31	0.060	213.92	8.595	13.591	328.05	149.42	761.06	0.162	36.65
MEDIAN		103.19	0.003	184.43	5.9525	0.107	239.85	132.40	473.87	0.124	31.64

lost sample
below detection limit (for PO4, NOx, NH4)
detection limit = 0.05 mg/L (for PO4, NOx, NH4)

RUN 3 - CONTROL 100/0, TEST 35/65 - NUTRIENT DATA (mg/L as N or P)

DAY	DATE	CONTROL REACTOR FEED, 100/0 (Primary Sludge) TP	PO4	TKN	NOx	NH4	TEST REACTOR FEED, 35/65 TP	PO4	TKN	NOx	NH4
1	10/12 a	37.73	4.993	240.48	0.763	18.81	307.84	93.41	777.00	0.091	32.27
	p	48.62	8.180	284.88	0.872	24.73	311.36	98.67	800.63	0.207	36.52
2	10/13 a	31.53	4.042	187.37	0.936	16.98	232.95	80.30	593.33	0.127	28.74
	p	40.94	4.691	233.24	0.798	18.16	164.40	83.10	410.44	0.118	28.79
3	10/14 a	36.29	4.447	199.47	0.058	17.31	197.74	84.81	435.00	0.147	27.41
	p	38.82	6.932	214.83	0.797	22.41	202.39	84.72	490.69	0.164	29.62
4	10/15 a	31.77	4.276	190.56	0.728	18.09	349.65	105.93	855.56	0.115	31.66
	p	38.91	5.068	224.18	0.930	19.36	334.76	115.38	837.30	0.125	36.22
5	10/16 a	52.91	4.558	266.43	0.707	18.97	201.15	72.08	543.56	0.083	25.94
	p	48.35	5.925	268.73	0.560	21.54	192.04	72.76	535.50	0.124	28.65
6	10/17 a	44.90	5.568	267.29	0.037	20.69	287.89	92.22	717.04	0.154	28.82
	p	44.27	4.675	233.15	0.066	22.50	236.81	103.44	530.25	0.087	31.30
AVG		41.25	5.280	234.22	0.604	19.96	251.58	90.57	627.19	0.129	30.49
STDS		6.71	1.215	32.63	0.347	2.40	63.37	13.42	161.07	0.036	3.27
MIN		31.53	4.042	187.37	0.037	16.98	164.40	72.08	410.44	0.083	25.94
MAX		52.91	8.180	284.88	0.936	24.73	349.65	115.38	855.56	0.207	36.52
MEDIAN		39.92	4.842	233.19	0.7455	19.17	234.88	88.52	568.44	0.1245	29.22

RUN 3 - CONTROL 100/0, TEST 35/65 - NUTRIENT DATA (mg/L as N or P)

DAY	DATE	CONTROL ATAD REACTOR, 100/0 TP	PO4	TKN	NOx	NH4	TEST ATAD REACTOR, 35/65 TP	PO4	TKN	NOx	NH4
1	10/12 a	40.53	7.844	221.76	0.930	55.20	184.20	103.01	434.59	0.159	130.85
	p	46.80	9.247	241.59	0.811	61.44	265.80	113.06	660.64	0.184	138.05
2	10/13 a	58.52	15.262	272.40	0.970	72.22	243.86	115.61	630.04	0.200	125.21
	p	50.73	11.200	283.89	0.151	72.79	223.39	120.42	594.49	0.221	158.42
3	10/14 a	62.21	16.850	292.83	0.196	77.04	205.95	118.45	535.43	0.232	139.62
	p	49.77	10.727	272.15	0.801	70.08	205.88	107.08	516.60	0.229	137.54
4	10/15 a	47.36	10.906	262.25	0.853	72.16	257.93	111.27	661.16	0.236	132.01
	p	47.72	11.199	255.83	0.186	68.43	227.85	118.63	590.81	0.246	138.53
5	10/16 a	51.32	12.638	243.63	0.913	68.84	318.64	125.46	776.86	0.217	149.77
	p	58.44	10.231	271.41	0.199	92.63	294.38	127.13	747.23	0.298	150.43
6	10/17 a	65.57	11.719	299.34	0.848	68.00	309.98	119.63	777.53	0.210	149.83
	p	58.31	9.528	287.27	0.863	80.31	225.68	124.43	591.86	0.364	150.67
AVG		53.10	11.446	267.03	0.643	71.60	246.96	117.02	626.44	0.233	141.74
STDS		7.40	2.507	23.10	0.343	9.32	43.20	7.37	105.77	0.053	9.98
MIN		40.53	7.844	221.76	0.151	55.20	184.20	103.01	434.59	0.159	125.21
MAX		65.57	16.850	299.34	0.970	92.63	318.64	127.13	777.53	0.364	158.42
MEDIAN		51.02	11.0525	271.78	0.8295	71.12	235.86	118.54	612.26	0.225	139.08

RUN 4 - CONTROL 100/0, TEST 0/100 - NUTRIENT DATA (mg/L as N or P)

		UNSETTLED MIXED LIQUOR (A-side)					UNSETTLED MIXED LIQUOR (B-side)				
DAY	DATE	TP	PO4	TKN	NOx	NH4	TP	PO4	TKN	NOx	NH4
1	10/27 a	136.59	0.060	215.45	8.697	0.036	67.29	0.246	162.80	1.342	14.633
	p										
2	10/28 a	125.81	0.000	200.79	7.846	0.027	104.66	0.003	257.42	1.617	14.438
	p										
3	10/29 a	152.55	0.075	251.52	9.801	0.000	100.64	0.008	237.00	1.985	15.545
	p										
4	10/30 a	148.91	0.084	240.72	8.705	0.000	116.46	0.000	262.74	1.256	13.517
	p										
5	10/31 a	129.65	0.017	209.45	7.071	0.025	117.32	0.000	262.98	2.008	12.210
	p										
6	1101 a	143.81	0.072	236.27	7.920	0.000	117.59	0.000	252.03	1.795	11.660
	p										
AVG		139.55	0.051	225.70	8.340	0.013	103.99	0.043	239.16	1.667	9.111
STDS		10.68	0.034	19.97	0.941	0.016	19.37	0.100	38.62	0.320	6.936
MIN		125.81	0.000	200.79	7.071	0.000	67.29	0.000	162.80	1.256	0.000
MAX		152.55	0.084	251.52	9.801	0.036	117.59	0.246	262.98	2.008	15.545
MEDIAN		140.20	0.066	225.86	8.3085	0.0125	110.56	0.0015	254.72	1.706	13.9775

lost sample
below detection limit (for PO4, NOx, NH4)
detection limit = 0.05 mg/L (for PO4, NOx, NH4)

RUN 4 - CONTROL 100/0, TEST 0/100 - NUTRIENT DATA (mg/L as N or P)

		CONTROL REACTOR FEED, 100/0					TEST REACTOR FEED, 0/100				
DAY	DATE	TP	PO4	TKN	NOx	NH4	TP	PO4	TKN	NOx	NH4
1	10/27 a	39.66	4.430	221.55	1.014	20.16	355.95	150.18	746.80	0.051	35.07
	p	37.07	5.881	212.58	0.831	24.82	433.55	166.54	914.70	0.146	38.53
2	10/28 a	42.51	4.680	244.47	0.901	20.43	328.35	132.40	657.10	0.091	32.40
	p	41.51	7.683	238.53	0.960	26.07	400.15	170.51	859.85	0.098	35.00
3	10/29 a	36.86	4.180	210.66	0.923	20.66	262.55	122.90	477.25	0.086	28.08
	p		5.261		0.899	22.83	309.80	137.78	591.00	0.199	30.09
4	10/30 a	51.02	4.465	261.75	0.971	21.74	314.90	127.82	582.55	0.096	27.54
	p	41.01	5.682	230.67	1.027	23.72	340.00	160.83	671.45	0.114	30.82
5	10/31 a	41.55	4.595	225.24	0.985	21.91	318.55	130.72	618.55	0.105	26.55
	p	39.35	5.374	223.85	0.764	23.59	294.40	157.11	562.10	0.146	30.39
6	1101 a	46.59	4.258	247.82	0.879	20.85	310.15	125.21	627.95	0.128	26.63
	p	57.14	5.192	290.42	0.805	22.94	284.35	51.62	567.25	0.175	30.42
AVG		43.11	5.140	237.05	0.913	22.48	329.39	136.14	656.38	0.120	30.96
STDS		6.19	0.979	23.50	0.083	1.86	48.13	31.49	127.00	0.041	3.72
MIN		36.86	4.180	210.66	0.764	20.16	262.55	51.62	477.25	0.051	26.55
MAX		57.14	7.683	290.42	1.027	26.07	433.55	170.51	914.70	0.199	38.53
MEDIAN		41.51	4.936	230.67	0.912	22.37	316.73	135.09	623.25	0.1095	30.40

RUN 4 - CONTROL 100/0, TEST 0/100 - NUTRIENT DATA (mg/L as N or P)

		CONTROL ATAD REACTOR, 100/0					TEST ATAD REACTOR, 0/100				
DAY	DATE	TP	PO4	TKN	NOx	NH4	TP	PO4	TKN	NOx	NH4
1	10/27 a	50.97	8.687	264.60	1.104	82.77	342.75	225.34	801.00	0.608	247.32
	p	56.60	15.060	243.87	0.968	84.77	293.40	218.44	653.25	0.746	252.41
2	10/28 a	79.73	20.675	310.77	0.960	93.02	365.35	217.99	819.55	0.552	252.32
	p	49.01	11.027	264.77	0.966	75.99	373.35	207.79	875.30	0.325	260.61
3	10/29 a	53.84	11.966	255.84	0.967	75.81	433.85	214.79	942.70	0.516	269.32
	p	55.55	9.650	272.27	1.124	76.26	434.85	216.61	976.85	0.568	275.80
4	10/30 a	65.51	13.680	298.73	0.941	77.94	330.15	210.39	744.80	0.401	263.06
	p	64.02	15.490	281.66	0.924	81.15	365.55	205.99	841.55	0.515	264.38
5	10/31 a	53.19	13.048	255.08	0.915	79.64	360.80	208.94	812.20	0.526	254.78
	p	53.22	11.539	263.21	0.206	75.66	337.15	207.59	769.15	0.449	246.79
6	1101 a	66.41	16.314	286.20	0.926	83.07	266.55	208.51	553.80	0.412	24.53
	p	60.24	15.065	268.77	1.030	80.18	356.65	209.28	762.05	0.464	248.03
AVG		59.02	13.517	272.15	0.919	80.52	355.03	212.64	796.02	0.507	238.28
STDS		8.68	3.286	19.18	0.235	5.03	48.51	5.91	115.59	0.110	67.94
MIN		49.01	8.687	243.87	0.206	75.66	266.55	205.99	553.80	0.325	24.53
MAX		79.73	20.675	310.77	1.124	93.02	434.85	225.34	976.85	0.746	275.80
MEDIAN		56.07	13.364	266.77	0.963	79.91	358.73	209.84	806.60	0.5155	253.60

RUN 5 - CONTROL 0/100, TEST 0/100 solubilized - NUTRIENT DATA (mg/L as N or P)

		UNSETTLED MIXED LIQUOR (A-side)					UNSETTLED MIXED LIQUOR (B-side)				
DAY	DATE	TP	PO4	TKN	NOx	NH4	TP	PO4	TKN	NOx	NH4
1	11/20 a	144.29	0.083	236.04	8.025	0.000	99.27	0.072	222.51	10.082	0.076
	p										
2	11/21 a	158.97	0.006	256.22	7.263	0.047	104.82	0.232	234.00	4.730	0.006
	p										
3	11/22 a	141.86	0.068	229.47	7.772	0.059	116.03	0.038	257.31	7.506	0.075
	p										
4	11/23 a	152.34	0.089	247.53	7.973	0.015	100.50	0.034	209.19	7.675	0.056
	p										
5	11/24 a	171.98	0.000	251.99	7.742	0.030	105.36	0.026	227.01	5.316	0.035
	p										
6	11/25 a	175.41	0.053	281.16	6.672	0.001	131.48	0.071	259.59	3.313	0.002
	11/26 a										
AVG		157.47	0.050	250.40	7.575	0.025	109.58	0.079	234.94	6.437	0.042
STDS		13.99	0.038	18.08	0.518	0.024	12.25	0.078	19.95	2.445	0.033
MIN		141.86	0.000	229.47	6.672	0.000	99.27	0.026	209.19	3.313	0.002
MAX		175.41	0.089	281.16	8.025	0.059	131.48	0.232	259.59	10.082	0.076
MEDIAN		155.66	0.0605	249.76	7.757	0.0225	105.09	0.0545	230.51	6.411	0.0455

lost sample
below detection limit (for PO4, NOx, NH4)
detection limit = 0.05 mg/L (for PO4, NOx, NH4)

RUN 5 - CONTROL 0/100, TEST 0/100 solubilized - NUTRIENT DATA (mg/L as N or P)

		CONTROL REACTOR FEED, 0/100							TEST REACTOR FEED, 0/100 solubilized						
DAY	DATE	TP	solubleTP	PO4	TKN	solubleTKN	NOx	NH4	TP	solubleTP	PO4	TKN	solubleTKN	NOx	NH4
1	11/20 a	241.50	41.00	42.08	536.00	7.48	0.182	5.450	247.45	78.60	76.22	536.70	79.58	0.293	14.93
	p	305.45	53.03	53.34	668.00	11.04	0.102	7.750	234.45	122.44	128.07	502.20	130.91	0.237	32.30
2	11/21 a	313.15	40.07	42.02	679.10	7.53	0.143	4.770	250.50	75.41	73.80	541.10	65.14	0.307	16.04
	p	217.70	49.43	53.72	451.45	11.75	0.154	6.040	207.05	130.43	121.81	465.55	117.45	0.162	37.15
3	11/22 a	223.45	38.63	42.34	465.10	5.58	0.184	5.420	253.15	82.09	84.77	554.75	71.44	0.218	15.29
	p	281.25	56.67	65.99	581.15	10.30	0.147	6.840	258.90	141.75	140.12	538.05	120.26	0.173	46.55
4	11/23 a	237.75	46.49	47.47	460.15	5.52	0.200	5.690	244.20	95.55	87.66	550.95	64.05	0.234	16.74
	p	284.75	66.39	59.48	626.00	6.18	0.143	7.100	263.25	137.44	145.40	596.70	109.43	0.282	56.49
5	11/24 a	299.05	59.07	61.94	667.45	8.45	0.171	7.110	296.35	101.36	98.62	703.95	66.45	0.379	19.49
	p	296.95	71.70	78.39	616.45	10.79	0.171	10.850	282.70	140.44	143.25	637.65	111.71	0.231	53.41
6	11/25 a	76.30	41.03	45.64	100.65	8.32	0.161	6.970	137.30	60.15	62.05	200.40	52.69	0.148	19.69
	11/26 a	179.10	62.88	63.38	402.30	17.28	0.571	13.580	110.85	89.10	80.34	205.25	81.53	0.487	25.18
AVG		246.37	52.20	54.65	521.15	9.18	0.194	7.298	232.18	104.56	103.51	502.77	89.22	0.263	29.44
STDS		68.00	11.22	11.48	163.62	3.33	0.121	2.526	55.48	28.72	30.33	153.06	26.88	0.097	15.46
MIN		76.30	38.63	42.02	100.65	5.52	0.102	4.770	110.85	60.15	62.05	200.40	52.69	0.148	14.93
MAX		313.15	71.70	78.39	679.10	17.28	0.571	13.580	296.35	141.75	145.40	703.95	130.91	0.487	56.49
MEDIAN		261.38	51.23	53.53	558.58	8.39	0.166	6.905	248.98	98.46	93.14	539.58	80.55	0.2355	22.44

RUN 5 - CONTROL 0/100, TEST 0/100 solubilized - NUTRIENT DATA (mg/L as N or P)

		CONTROL ATAD REACTOR, 0/100							TEST ATAD REACTOR, 0/100 solubilized						
DAY	DATE	TP	solubleTP	PO4	TKN	solubleTKN	NOx	NH4	TP	solubleTP	PO4	TKN	solubleTKN	NOx	NH4
1	11/20 a	311.55	167.07	154.85	763.80	254.64	0.256	182.02	310.55	187.35	166.00	747.35	301.05	0.229	202.79
	p	274.00	174.80	154.84	672.95	284.33	0.229	174.54	277.65	165.66	165.41	643.80	264.77	0.272	193.80
2	11/21 a	343.55	169.25	154.52	837.25	274.17	0.260	166.83	266.30	176.01	159.16	620.20	266.36	0.265	185.30
	p	272.85	169.41	149.30	680.75	265.46	0.239	155.12	295.40	181.91	157.63	670.35	267.84	0.249	179.36
3	11/22 a	297.80	166.62	148.45	699.40	262.98	0.260	151.09	262.55	169.56	155.79	609.45	259.67	0.256	173.72
	p	313.45	168.86	149.74	700.75	272.52	0.335	149.64	262.10	165.69	150.54	569.45	230.67	0.309	173.73
4	11/23 a	226.60	176.04	156.66	504.90	266.66	0.390	153.62	195.20	166.08	148.66	457.25	255.69	0.255	170.75
	p	294.85	162.92	152.37	650.70	242.31	0.488	138.98	239.55	160.77	134.19	490.20	215.72	0.378	169.74
5	11/24 a	289.65	177.08	155.58	648.75	267.30	0.536	150.77	239.20	164.81	152.07	421.10	217.46	0.394	171.06
	p	228.50	172.20	156.29	496.75	255.92	0.485	146.53	259.95	167.09	149.73	539.15	244.40	0.361	175.50
6	11/25 a	231.55	173.96	155.97	543.35	258.62	0.435	154.36	297.00	173.57	156.10	590.70	255.69	0.386	190.70
	11/26 a	277.90	152.72	143.57	645.70	225.96	0.474	140.62	237.35	141.20	131.54	520.05	192.12	0.557	174.46
AVG		280.19	169.24	152.68	653.75	260.90	0.366	155.34	261.90	168.31	152.24	573.25	247.62	0.326	180.08
STDS		36.59	6.70	4.07	100.12	15.36	0.115	12.97	31.71	11.52	10.63	93.44	29.37	0.094	10.67
MIN		226.60	152.72	143.57	496.75	225.96	0.229	138.98	195.20	141.20	131.54	421.10	192.12	0.229	169.74
MAX		343.55	177.08	156.66	837.25	284.33	0.536	182.02	310.55	187.35	166.00	747.35	301.05	0.557	202.79
MEDIAN		283.78	169.33	154.68	661.83	264.22	0.3625	152.36	262.33	166.58	153.93	580.08	255.69	0.2905	174.98

RUN 6 - CONTROL 35/65, TEST 35/65 solubilized - NUTRIENT DATA (mg/L as N or P)

		PRIMARY SLUDGE					SETTLED MIXED LIQUOR (Secondary Sludge)				
DAY	DATE	TP	PO4	TKN	NOx	NH4	TP	PO4	TKN	NOx	NH4
1	12/02 a	37.76	3.711	205.46	0.675	28.83	165.90	81.17	288.38	0.960	16.116
	p										
2	12/03 a	31.58	3.256	191.66	0.750	31.68	530.40	98.54	1153.31	1.200	17.013
	p										
3	12/04 a	31.04	3.375	194.63	0.729	30.77	498.68	128.22	1094.85	0.880	18.669
	p										
4	12/05 a	27.56	3.131	181.02	0.853	31.00	684.90	108.67	1512.53	1.110	18.393
	p										
5	12/06 a	24.75	3.011	153.54	0.818	34.37	360.38		715.05		14.186
	p										
6	12/07 a	22.02	2.963	143.45	0.710	27.74	665.63	127.43	1428.98	0.850	19.281
	p										
AVG		29.12	3.241	178.29	0.756	30.73	484.31	90.67	1032.18	0.833	14.808
STDS		5.59	0.276	24.57	0.067	2.31	196.05	47.87	460.56	0.430	6.758
MIN		22.02	2.963	143.45	0.675	27.74	165.90	0.00	288.38	0.000	0.000
MAX		37.76	3.711	205.46	0.853	34.37	684.90	128.22	1512.53	1.200	19.281
MEDIAN		29.30	3.1935	186.34	0.7395	30.88	514.54	108.67	1124.08	0.96	17.703

lost sample
below detection limit (for PO4, NOx, NH4)
detection limit = 0.05 mg/L (for PO4, NOx, NH4)

RUN 6 - CONTROL 35/65, TEST 35/65 solubilized - NUTRIENT DATA (mg/L as N or P)

		CONTROL REACTOR FEED, 35/65							TEST REACTOR FEED, 35/65 solubilized						
DAY	DATE	TP	solubleTP	PO4	TKN	solubleTKN	NOx	NH4	TP	solubleTP	PO4	TKN	solubleTKN	NOx	NH4
1	12/02 a	314.80	78.65	79.37	729.40	17.03	0.740	23.39	338.20		90.05	742.80		1.050	27.55
	p	314.40	125.39	131.05	734.60	20.45	0.980	27.11	293.55	129.33	133.73	665.65	68.93	1.190	72.66
2	12/03 a	283.10	81.92	85.14	645.25	17.09	0.700	21.15	272.85	84.45	91.84	628.65	46.65	1.200	30.15
	p	277.40	130.88	136.29	637.40	22.02	0.820	31.89	283.80	130.79	139.09	649.05	73.83	1.000	84.07
3	12/04 a	257.85	82.83	90.61	574.15	17.99	0.080	25.04	285.20	99.74	104.12	628.85	64.16	1.070	41.05
	p	256.60	116.66	135.67	597.05	26.63	1.050	31.43	396.70	138.03	145.37	906.60	65.76	1.150	92.41
4	12/05 a	351.25	76.53	84.58	850.80	18.72	1.010	22.31	322.20	96.66	95.94	724.55	38.52	1.030	29.84
	p	329.45	122.94	126.62	921.20	26.96	0.910	29.13	219.40	142.26	147.32	507.10	68.00	0.950	82.23
5	12/06 a	152.05	69.63	72.98	327.25	15.20	0.820	22.50	179.00	72.06	78.99	366.35	31.23	0.700	26.85
	p	187.65	91.86	95.10	429.80	23.52	1.070	23.52	168.55	107.54	111.76	347.70	71.70	1.040	72.60
6	12/07 a	339.40	89.16	90.65	814.60	17.91	0.720	24.66	297.20	103.04	105.31	656.70	46.29	0.980	36.10
	p	334.00	136.58	139.40	776.50	23.36	0.910	32.77	259.70	146.31	155.69	599.05	77.49	1.100	97.47
AVG		283.16	100.25	105.62	669.83	20.57	0.818	26.24	276.36	113.65	116.60	618.59	59.32	1.038	57.75
STDS		61.93	24.26	25.67	172.44	3.89	0.265	4.11	64.60	24.97	26.22	154.99	15.74	0.133	28.07
MIN		152.05	69.63	72.98	327.25	15.20	0.080	21.15	168.55	72.06	78.99	347.70	31.23	0.700	26.85
MAX		351.25	136.58	139.40	921.20	26.96	1.070	32.77	396.70	146.31	155.69	906.60	77.49	1.200	97.47
MEDIAN		298.75	90.51	92.88	687.33	19.58	0.865	24.85	284.50	107.54	108.54	638.95	65.76	1.045	56.83

RUN 6 - CONTROL 35/65, TEST 35/65 solubilized - NUTRIENT DATA (mg/L as N or P)

		CONTROL ATAD REACTOR, 35/65							TEST ATAD REACTOR, 35/65 solubilized						
DAY	DATE	TP	solubleTP	PO4	TKN	solubleTKN	NOx	NH4	TP	solubleTP	PO4	TKN	solubleTKN	NOx	NH4
1	12/02 a	237.20	169.05	139.17	559.00	259.37	1.630	194.53	265.50	196.62	152.78	621.60	279.96	1.220	300.59
	p	287.40	177.77	143.34	672.10	266.16	1.610	209.93	236.70	188.51	152.00	568.70	271.64	1.430	321.84
2	12/03 a	240.65	184.68	145.56	558.60	280.64	1.480	197.19	246.90	195.59	150.86	584.30	288.75	1.310	315.00
	p	226.35	196.86	145.48	527.70	251.88	1.350	312.49	246.00	191.69	151.76	559.90	286.01	1.260	380.61
3	12/04 a	245.00	204.26	151.67	568.75	264.57	1.390	308.26	238.00	191.09	152.69	494.12	280.28	1.210	349.33
	p	278.80	203.09	153.36	633.25	265.22	1.290	350.52	249.60	182.57	153.57	560.30	279.81	1.110	304.14
4	12/05 a	242.20	195.74	162.87	556.80	285.48	1.450	308.76	244.10	189.50	165.73	558.50	285.44	1.460	283.05
	p	253.95	212.91	157.85	574.05	263.70	1.490	262.92	235.05	194.09	158.59	556.80	275.54	1.540	242.06
5	12/06 a	249.05	200.25	158.61	577.10	265.73	1.310	258.95	207.15	188.24	157.97	485.25	271.02	1.500	310.84
	p	265.45	202.31	155.70	620.45	285.81	1.360	375.73	229.65	194.99	157.19	498.40	289.37	1.220	338.61
6	12/07 a	234.00	193.56	149.54	566.70	198.11	0.700	338.96	224.80	198.11	153.10	510.40	287.69	1.460	324.31
	p	254.20	202.97	158.32	594.10	281.31	1.590	339.68	184.10	188.01	154.37	399.25	281.31	1.290	292.14
AVG		251.19	195.29	151.79	584.05	264.00	1.388	288.16	233.96	191.58	155.05	533.13	281.40	1.334	313.54
STDS		18.18	12.43	7.27	39.86	23.42	0.245	62.42	21.29	4.48	4.21	58.64	6.31	0.138	34.84
MIN		226.35	169.05	139.17	527.70	198.11	0.700	194.53	184.10	182.57	150.86	399.25	271.02	1.110	242.06
MAX		287.40	212.91	162.87	672.10	285.81	1.630	375.73	265.50	198.11	165.73	621.60	289.37	1.540	380.61
MEDIAN		247.03	198.56	152.52	571.40	265.47	1.42	308.51	237.35	191.39	153.34	557.65	280.79	1.3	312.92

APPENDIX H: TOC DATA

RUN 1 - CONTROL 100/0, TEST 100/.0 - TOC DATA (mg/L)

DAY	DATE	Control Feed	Test Feed	Control ATAD	Test ATAD
1	9/11 a	591	591	615	615
	p	570	570	622	622
2	9/12 a				
	p				
3	9/13 a	538	538	588	588
	p	555	555	550	550
4	9/14 a				
	p				
5	9/15 a	603	603	678	678
	p	563	563	714	714
6	9/16 a				
	p				

	Control Feed	Test Feed	Control ATAD	Test ATAD
AVG	570	570	11928	628
STDS	24	24	59	59
MIN	538	538	550	550
MAX	603	603	714	714
MEDIAN	566	566	619	619

NOTE : One set of samples was used for both the control and test data.

RUN 2 - CONTROL 100/0, TEST 65/35 - TOC DATA (mg/L)

DAY	DATE	Control Feed	Test Feed	Control ATAD	Test ATAD
1	9/27 a	795	777	691	1042
	p	749	771	682	1021
2	9/28 a				
	p				
3	9/29 a	623	707	680	1008
	p	829	834	759	984
4	9/30 a				
	p				
5	10/01 a	708	802	681	939
	p	685	886	684	975
6	10/02 a				
	p				

	Control Feed	Test Feed	Control ATAD	Test ATAD
AVG	731	796	696	995
STDS	75	61	31	37
MIN	623	707	680	939
MAX	829	886	759	1042
MEDIAN	728	789	683	996

RUN 3 - CONTROL 100/0, TEST 35/65 - TOC DATA (mg/L)

DAY	DATE	Control Feed	Test Feed	Control ATAD	Test ATAD
1	10/12 a				
	p				
2	10/13 a	524	778	590	938
	p	570	760	560	966
3	10/14 a				
	p				
4	10/15 a	484	1076	530	865
	p	564	1184	525	898
5	10/16 a				
	p	594	820	608	975
6	10/17 a	580	864	506	1013
	p				

	Control Feed	Test Feed	Control ATAD	Test ATAD
AVG	553	914	553	943
STDS	41	175	40	54
MIN	484	760	506	865
MAX	594	1184	608	1013
MEDIAN	544	821	528	918

RUN 4 - CONTROL 100/0, TEST 0/100 - TOC DATA (mg/L)

DAY	DATE	Control Feed	Test Feed	Control ATAD	Test ATAD
1	10/27 a	547	1352	543	1531
	p	565	1185	542	1335
2	10/28 a				
	p				
3	10/29 a	602	741	507	1559
	p	659	720	542	1454
4	10/30 a				
	p				
5	10/31 a	656	1023	584	1252
	p	613	943	542	1229
6	11/01 a				
	p				

	Control Feed	Test Feed	Control ATAD	Test ATAD
AVG	520	994	543	1393
STDS	233	248	24	142
MIN	0	720	507	1229
MAX	659	1352	584	1559
MEDIAN	608	983	542	1395

RUN 5 - CONTROL 0/100, TEST 0/ 100 solubilized- TOC DATA (mg/L)

DAY	DATE	Control Feed	Test Feed	Control ATAD	Test ATAD
1	11/20 a	49	320	472	502
	p	52	568	522	468
2	11/21 a	50	298	512	426
	p	44	517	508	422
3	11/22 a	45	306	478	465
	p	45	519	572	325
4	11/23 a	45	346	496	363
	p	41	527	562	352
5	11/24 a	43	273	687	377
	p	42	500	573	381
6	11/25 a	45	231	608	363
	11/26 a	46	342	455	357

	Control Feed	Test Feed	Control ATAD	Test ATAD
AVG	46	396	537	400
STDS	3	120	66	55
MIN	41	231	455	325
MAX	52	568	687	502
MEDIAN	45	344	517	379

RUN 6 - CONTROL 35/65, TEST 35/65 solubilized - TOC DATA (mg/L)

DAY	DATE	Control Feed	Test Feed	Control ATAD	Test ATAD
1	10/02 a	60	186	792	761
	p	112	417	1124	828
2	12/03 a	56	202	1685	848
	p	94	319	1052	746
3	12/04 a	61	186	1205	1960
	p	102	300	1108	887
4	12/05 a	64	200	1690	1105
	p	114	338	1687	894
5	12/06 a	50	163	1693	1023
	p	79	430	1071	1055
6	12/07 a	60	241	888	961
	p	100	438	1246	1052

	Control Feed	Test Feed	Control ATAD	Test ATAD
AVG	79	285	1270	1010
STDS	24	103	332	322
MIN	50	163	792	746
MAX	114	438	1693	1960
MEDIAN	72	271	1165	928

APPENDIX J: FORMULAS & SAMPLE CALCULATIONS

TOTAL SOLIDS

$$TS = \frac{(mass_{dried\ sample}) - (mass_{dish})}{volume_{sample}} \quad \frac{mg}{L}$$

Note: 10 000 mg/L = 10 g/L = 1% TS

SLUDGE VOLUMES FOR FEED RATIOS

L_o = volume of sludge remaining from previous day
L_1 = volume of primary sludge
L_2 = volume of secondary sludge
L_w = volume of distilled water

g_o/L = consistency of sludge remaining
g_1/L = consistency of primary sludge
g_2/L = consistency of secondary sludge

control feed tank:

$$(L_o)*(\frac{g_o}{L}) = g_o$$

$$(L_1)*(\frac{g_1}{L}) = g_1 \rightarrow \frac{g_o+g_1}{L_o+L_1} = g/L_{control}$$

test feed tank:

$$(L_o)*(g_o/L) = g_o$$

$$(L_1)*(g_1/L) = g_1 \rightarrow g_1*(mix\ ratio,\ ie.\ \frac{35}{65}) = g_2\ required$$

$$\rightarrow \frac{g_2}{g_2/L} = L_2\ required$$

$$\rightarrow g/L_{test} = \frac{g_o+g_1+g_2}{L_o+L_1+L_2}$$

if $g/L_{test} > g/L_{control}$:

$$\rightarrow \frac{g_o+g_1+g_2}{g/L_{control}} = L_{total}\ required$$

$$\rightarrow L_{total} - (L_o+L_1+L_2) = L_w\ required$$

Note: if $g/L_{test} < g/L_{control}$, then g/L_{test} was used and L_w was calculated for control feed tank.

TOTAL SOLIDS DESTRUCTION

$$\% \text{ destruction} = \frac{avg\ TS_{feed} - TS_{ATAD}}{avg\ TS_{feed}} \; x\ 100\%$$

$$\text{where for day}_i: \; avg\ TS_{feed} = \frac{TS_{feed_{i-1}} + TS_{feed_{i-2}} + TS_{feed_{i-3}}}{3}$$

$$TS_{ATAD} = TS_{ATAD_i}$$

QUATTRO PRO EQUATIONS

$$\text{AVG} = \bar{x} = \frac{\Sigma x_i}{n}$$

$$\text{STDS} = \sigma = \sqrt{\frac{\Sigma(\bar{x}-x_i)^2}{n-1}}$$

MEDIAN = the middle value for an odd number of values
= the average of the two middle values for an even number of values

APPENDIX K: STATISTICS TABLES

T-Test Results for ATAD Temperature (5% significance)

t-Test: Paired Two-Sample for Means

RUN 1 TEMPERATURE	CONTROL	TEST
Mean	49.075	46.6
Variance	0.7529545	1.0145455
Observations	12	12
Pearson Correlation	0.992283	
Pooled Variance	0.88375	
Hypothesized Mean Difference	0	
df	11	
t	47.228936	
P(T<=t) one-tail	2.354E-14	
t Critical one-tail	1.7958848	
P(T<=t) two-tail	4.696E-14	
t Critical two-tail	2.2009852	

t-Test: Paired Two-Sample for Means

RUN 2 TEMPERATURE	CONTROL	TEST
Mean	48.791667	44.541667
Variance	1.497197	0.2317424
Observations	12	12
Pearson Correlation	0.7568857	
Pooled Variance	0.8644697	
Hypothesized Mean Difference	0	
df	11	
t	16.089631	
P(T<=t) one-tail	2.718E-09	
t Critical one-tail	1.7958848	
P(T<=t) two-tail	5.436E-09	
t Critical two-tail	2.2009852	

t-Test: Paired Two-Sample for Means

RUN 3 TEMPERATURE	CONTROL	TEST
Mean	45.008333	43.858333
Variance	1.4935606	0.4517424
Observations	12	12
Pearson Correlation	0.8349524	
Pooled Variance	0.9726515	
Hypothesized Mean Difference	0	
df	11	
t	5.2598108	
P(T<=t) one-tail	0.0001342	
t Critical one-tail	1.7958848	
P(T<=t) two-tail	0.0002685	
t Critical two-tail	2.2009852	

t-Test: Paired Two-Sample for Means

RUN 4 TEMPERATURE	CONTROL	TEST
Mean	44.158333	42.076667
Variance	0.7244697	0.8167152
Observations	12	12
Pearson Correlation	0.9102993	
Pooled Variance	0.7705924	
Hypothesized Mean Difference	0	
df	11	
t	19.220348	
P(T<=t) one-tail	4.092E-10	
t Critical one-tail	1.7958848	
P(T<=t) two-tail	8.184E-10	
t Critical two-tail	2.2009852	

t-Test: Paired Two-Sample for Means

RUN 5 TEMPERATURE	CONTROL	TEST
Mean	44.166667	43.125
Variance	1.1787879	2.3493182
Observations	12	12
Pearson Correlation	0.972932	
Pooled Variance	1.764053	
Hypothesized Mean Difference	0	
df	11	
t	6.7015787	
P(T<=t) one-tail	1.684E-05	
t Critical one-tail	1.7958848	
P(T<=t) two-tail	3.369E-05	
t Critical two-tail	2.2009852	

t-Test: Paired Two-Sample for Means

RUN 6 TEMPERATURE	CONTROL	TEST
Mean	44.1	42.775
Variance	0.5363636	0.3802273
Observations	12	12
Pearson Correlation	0.7830791	
Pooled Variance	0.4582955	
Hypothesized Mean Difference	0	
df	11	
t	10.032358	
P(T<=t) one-tail	3.579E-07	
t Critical one-tail	1.7958848	
P(T<=t) two-tail	7.158E-07	
t Critical two-tail	2.2009852	

Note: if |t| > t critical, a significant difference exists between means

T-Test Results for ATAD ORP (5% significance)

t-Test: Paired Two-Sample for Means

RUN 1 ORP	CONTROL	TEST
Mean	-242.66667	-318.75
Variance	14.606061	43.659091
Observations	12	12
Pearson Correlation	0.6516014	
Pooled Variance	29.132576	
Hypothesized Mean Difference	0	
df	11	
t	52.340668	
P(T<=t) one-tail	7.661E-15	
t Critical one-tail	1.7958848	
P(T<=t) two-tail	1.521E-14	
t Critical two-tail	2.2009852	

t-Test: Paired Two-Sample for Means

RUN 2 ORP	CONTROL	TEST
Mean	-254.75	-373.75
Variance	35.295455	42.386364
Observations	12	12
Pearson Correlation	0.2708793	
Pooled Variance	38.840909	
Hypothesized Mean Difference	0	
df	11	
t	54.73204	
P(T<=t) one-tail	4.663E-15	
t Critical one-tail	1.7958848	
P(T<=t) two-tail	9.326E-15	
t Critical two-tail	2.2009852	

t-Test: Paired Two-Sample for Means

RUN 3 ORP	CONTROL	TEST
Mean	-261.91667	-393.33333
Variance	139.7197	21.69697
Observations	12	12
Pearson Correlation	0.6098141	
Pooled Variance	80.708333	
Hypothesized Mean Difference	0	
df	11	
t	46.888408	
P(T<=t) one-tail	2.542E-14	
t Critical one-tail	1.7958848	
P(T<=t) two-tail	5.085E-14	
t Critical two-tail	2.2009852	

t-Test: Paired Two-Sample for Means

RUN 4 ORP	CONTROL	TEST
Mean	-274.41667	-421.33333
Variance	126.44697	8.2424242
Observations	12	12
Pearson Correlation	0.2346629	
Pooled Variance	67.344697	
Hypothesized Mean Difference	0	
df	11	
t	46.548846	
P(T<=t) one-tail	2.753E-14	
t Critical one-tail	1.7958848	
P(T<=t) two-tail	5.507E-14	
t Critical two-tail	2.2009852	

t-Test: Paired Two-Sample for Means

RUN 5 ORP	CONTROL	TEST
Mean	-330.41667	-282.83333
Variance	694.08333	15638.515
Observations	12	12
Pearson Correlation	0.2723413	
Pooled Variance	8166.2992	
Hypothesized Mean Difference	0	
df	11	
t	-1.3670736	
P(T<=t) one-tail	0.0994445	
t Critical one-tail	1.7958848	
P(T<=t) two-tail	0.198889	
t Critical two-tail	2.2009852	

t-Test: Paired Two-Sample for Means

RUN 6 ORP	CONTROL	TEST
Mean	-354.41667	-433.25
Variance	134.08333	47.840909
Observations	12	12
Pearson Correlation	0.4730378	
Pooled Variance	90.962121	
Hypothesized Mean Difference	0	
df	11	
t	26.505586	
P(T<=t) one-tail	1.28E-11	
t Critical one-tail	1.7958848	
P(T<=t) two-tail	2.559E-11	
t Critical two-tail	2.2009852	

Note: if |t| > t critical, a significant difference exists between means

T-Test Results for VFA Levels in Sludge Feed (5% significance)

t-Test: Paired Two-Sample for Means

RUN 1 FEED TOTAL VFA	CONTROL	TEST
Mean	290.90647	274.08419
Variance	651.33341	694.99115
Observations	12	12
Pearson Correlation	0.7564154	
Pooled Variance	673.16228	
Hypothesized Mean Difference	0	
df	11	
t	3.2152984	
P(T<=t) one-tail	0.0041138	
t Critical one-tail	1.7958848	
P(T<=t) two-tail	0.0082276	
t Critical two-tail	2.2009852	

t-Test: Paired Two-Sample for Means

RUN 4 FEED TOTAL VFA	CONTROL	TEST
Mean	181.76775	7.5846389
Variance	1561.5804	168.69527
Observations	12	12
Pearson Correlation	0.2295492	
Pooled Variance	865.13784	
Hypothesized Mean Difference	0	
df	11	
t	15.607317	
P(T<=t) one-tail	3.75E-09	
t Critical one-tail	1.7958848	
P(T<=t) two-tail	7.499E-09	
t Critical two-tail	2.2009852	

t-Test: Paired Two-Sample for Means

RUN 2 FEED TOTAL VFA	CONTROL	TEST
Mean	212.71006	269.2175
Variance	761.31298	6463.4023
Observations	12	12
Pearson Correlation	0.6128691	
Pooled Variance	3612.3576	
Hypothesized Mean Difference	0	
df	11	
t	-2.9161821	
P(T<=t) one-tail	0.0070165	
t Critical one-tail	1.7958848	
P(T<=t) two-tail	0.014033	
t Critical two-tail	2.2009852	

t-Test: Paired Two-Sample for Means

RUN 5 FEED TOTAL VFA	CONTROL	TEST
Mean	3.0578333	140.72901
Variance	1.6109287	6067.9746
Observations	12	12
Pearson Correlation	-0.4810779	
Pooled Variance	3034.7928	
Hypothesized Mean Difference	0	
df	11	
t	-6.0740338	
P(T<=t) one-tail	4.014E-05	
t Critical one-tail	1.7958848	
P(T<=t) two-tail	8.029E-05	
t Critical two-tail	2.2009852	

t-Test: Paired Two-Sample for Means

RUN 3 FEED TOTAL VFA	CONTROL	TEST
Mean	169.48767	133.70211
Variance	2762.1445	1957.857
Observations	12	12
Pearson Correlation	0.4631107	
Pooled Variance	2360.0008	
Hypothesized Mean Difference	0	
df	11	
t	2.447162	
P(T<=t) one-tail	0.0162043	
t Critical one-tail	1.7958848	
P(T<=t) two-tail	0.0324085	
t Critical two-tail	2.2009852	

t-Test: Paired Two-Sample for Means

RUN 6 FEED TOTAL VFA	CONTROL	TEST
Mean	23.195639	115.33892
Variance	88.046499	4972.6411
Observations	12	12
Pearson Correlation	0.5915625	
Pooled Variance	2530.3438	
Hypothesized Mean Difference	0	
df	11	
t	-4.8802527	
P(T<=t) one-tail	0.0002433	
t Critical one-tail	1.7958848	
P(T<=t) two-tail	0.0004867	
t Critical two-tail	2.2009852	

NOTE: if |t| > t critical, a significant difference exists between means

T-Test Results for VFA Levels in ATAD (5% significance)

t-Test: Paired Two-Sample for Means

RUN 1 ATAD TOTAL VFA	CONTROL	TEST
Mean	148.05689	163.53594
Variance	232.6638	189.182
Observations	12	12
Pearson Correlation	0.1244804	
Pooled Variance	210.9229	
Hypothesized Mean Difference	0	
df	11	
t	-2.7890795	
P(T<=t) one-tail	0.0088078	
t Critical one-tail	1.7958848	
P(T<=t) two-tail	0.0176155	
t Critical two-tail	2.2009852	

t-Test: Paired Two-Sample for Means

RUN 2 ATAD TOTAL VFA	CONTROL	TEST
Mean	250.73333	565.04675
Variance	979.91615	2651.6129
Observations	12	12
Pearson Correlation	0.2840417	
Pooled Variance	1815.7645	
Hypothesized Mean Difference	0	
df	11	
t	-20.893141	
P(T<=t) one-tail	1.671E-10	
t Critical one-tail	1.7958848	
P(T<=t) two-tail	3.343E-10	
t Critical two-tail	2.2009852	

t-Test: Paired Two-Sample for Means

RUN 3 ATAD TOTAL VFA	CONTROL	TEST
Mean	205.05625	434.42964
Variance	523.51304	2387.644
Observations	12	12
Pearson Correlation	-0.0101268	
Pooled Variance	1455.5785	
Hypothesized Mean Difference	0	
df	11	
t	-14.669602	
P(T<=t) one-tail	7.202E-09	
t Critical one-tail	1.7958848	
P(T<=t) two-tail	1.44E-08	
t Critical two-tail	2.2009852	

t-Test: Paired Two-Sample for Means

RUN 4 ATAD TOTAL VFA	CONTROL	TEST
Mean	203.48983	809.90064
Variance	1017.215	13489.478
Observations	12	12
Pearson Correlation	0.4739458	
Pooled Variance	7253.3465	
Hypothesized Mean Difference	0	
df	11	
t	-20.033246	
P(T<=t) one-tail	2.625E-10	
t Critical one-tail	1.7958848	
P(T<=t) two-tail	5.25E-10	
t Critical two-tail	2.2009852	

t-Test: Paired Two-Sample for Means

RUN 5 ATAD TOTAL VFA	CONTROL	TEST
Mean	30.503889	4.1485
Variance	987.90338	3.9078355
Observations	12	12
Pearson Correlation	0.4812847	
Pooled Variance	495.90561	
Hypothesized Mean Difference	0	
df	11	
t	2.9905515	
P(T<=t) one-tail	0.0061428	
t Critical one-tail	1.7958848	
P(T<=t) two-tail	0.0122856	
t Critical two-tail	2.2009852	

t-Test: Paired Two-Sample for Means

RUN 6 ATAD TOTAL VFA	CONTROL	TEST
Mean	391.91654	478.20478
Variance	7320.7628	21268.485
Observations	12	12
Pearson Correlation	0.3553911	
Pooled Variance	14294.624	
Hypothesized Mean Difference	0	
df	11	
t	-2.1285699	
P(T<=t) one-tail	0.0283601	
t Critical one-tail	1.7958848	
P(T<=t) two-tail	0.0567202	
t Critical two-tail	2.2009852	

NOTE: if |t| > t critical, a significant difference exists between means