UTILIZATION OF CAPTOR SPONGES TO MAINTAIN NITRIFICATION AND DENITRIFICATION IN BNR ACTIVATED SLUDGE AT LOW AEROBIC MCRTS

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(ABSTRACT)

The performance of Captor media integration into the aerobic zone of an activated sludge wastewater treatment system operated at low MCRTs was evaluated using a pilot scale Virginia Initiative Project (VIP) process. Two separate trains were operated, one with Captor media incorporated into the aerobic zone of the system, referred to as an Integrated Fixed Film Activated Sludge (IFAS) system, and the other as a control system, i.e., with no media in the aerobic reactors. The wastewater used for this research was pumped from a main municipal sewer of the Blacksburg-VPI Sanitation Authority Collection System. The TKN of the wastewater was supplemented by the addition of urea to maintain the influent ammonia concentration around 55 mg/L as nitrogen. Sodium acetate was added to maintain the influent COD around 450 mg/L and Sodium bicarbonate was added to maintain the pH in the aerobic zone around 7. The system was operated at MCRTs of 1.7, 1.0 and 0.3 days with the operating temperature around 12 C.

Enhanced nitrification was observed in the IFAS system compared to the control system at all MCRTs. The effluent ammonia concentration difference between the IFAS and the control system is higher than 15 mg/L as nitrogen for the MCRTs selected.

Batch tests were used to determine the nitrification rates of biomass taken from the different sections of the IFAS system. and to compare the rates of the IFAS biomass to the control system biomass. At all three low MCRTs, the majority of the nitrifiers were found to be in the Captor media. Also, the nitrification rate of the biomass in the Captor media was determined to be a function of the soluble COD in the mixed liquor of the reactor when the COD concentration exceeded 10 mg/L.

The total biomass in the IFAS system was 5-25 times more than the total biomass in the control system, but the sludge yield of the mixed liquor was lower, resulting in sludge production lower than that of the control system. This demonstrated that IFAS systems have the potential to achieve good nutrient and COD removal without increasing the biomass solids loads to the secondary clarifier. Thus, modification of a conventional activated sludge plant for biological nitrogen removal can be accomplished using IFAS technology without large increases in reactor or clarifier volume.

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TABLE OF CONTENTS

TABLES OF CONTENTS

(continued)

TABLE OF CONTENTS

(continued)

TABLES OF CONTENTS

(continued)

LIST OF TABLES

LIST OF TABLES

(continued)

LIST OF TABLES

(continued)

LIST OF FIGURES

CHAPTER 1

INTRODUCTION

Nutrient (nitrogen and phosphorus) discharges from wastewater treatment plants have caused more and more concern in recent years. Nutrients can support the growth of algae, other phytoplankton and aquatic plants in receiving waters. This can result in eutrophication, a condition detrimental to preferred aquatic life. Also, free ammonia is toxic to fish, and toxic impacts need to be minimized.

Biological nitrogen removal with simultaneous BOD/COD removal requires higher biomass retention times (MCRTs) than systems removing only BOD/COD, and the required MCRT increases rapidly when the design temperature is below 15 C. Higher MCRT results in higher MLSS concentration, which requires larger reactors and clarifiers, which increases the construction and maintenance costs.

Cost is often the most important concern for upgrading a single sludge BOD/COD removal wastewater treatment plant to achieve simultaneous nutrient and BOD/COD removal. Also the availability of land is frequently a limiting factor for treatment plant upgrading. Consequently, there is a clear need for more compact wastewater treatment plants that accomplish both nutrient and BOD removal. The integration of fixed film media into activated sludge has been suggested as one of the ways to accomplish this objective.

The nutrients discharged into the Chesapeake Bay are a major concern of the USEPA Chesapeake Bay Program and the Maryland Department of the Environment (MDE). Consequently, Anne Arundel County, Maryland, has received a mandate from MDE requiring removal of nitrogen and phosphorus from all of the County's wastewater treatment plant discharges. However, modification of the Annapolis plant by conventional methods was found to be very expensive, and the Cox Creek plant does not

have sufficient space for expansion. Therefore, Anne Arundel County and MDE asked Virginia Tech to evaluate the feasibility of upgrading these treatment plants by incorporating fixed film media directly into the existing reactors. The purpose was to determine if the media addition would enhance nitrification at low temperatures.

This research was started on August 1992 by Dipanker Sen and Pramod R. Mitta. Ringlace and Captor media were tested in a bench scale wastewater treatment plant in Blacksburg, Virginia. Early research using Ringlace media and Fixed Captor media produced uncertain results. In contrast, free floating Captor media showed excellent benefits for enhanced nitrogen removal. The purpose of this research was to continue the study and more fully evaluate the integrated fixed film activated sludge (IFAS) process for both nitrification and denitrification.

The main objective of this research was to evaluate the performance of aerobic activated sludge cells containing integrated Captor media when operated at low MCRTs, i.e., 1.7 days to 0.3 day. The evaluation included determination of:

1. the enhancement of nitrification by Captor media in the aerobic zone of a BNR system.
2. the enhancement of denitrification in both the overall system and in the aerobic zone of the BNR system, by the incorporation of Captor media in the aerobic zone of the system.
3. the enhancement of COD removal by Captor media in the aerobic zone of a BNR system.
4. the optimum location of Captor media in the aerobic zone for the enhancement of nitrogen removal in a BNR system.
5. the potential for the reduction of the aerobic reactor design volume, when incorporating Captor media.
6. the quantity of attached growth on the Captor media relative to the mixed liquor suspended solids biomass quantity.

7. the expected life span of captor media in an IFAS system.

CHAPTER 2

LITERATURE REVIEW

EFFECTS OF NITROGEN IN SURFACE WATERS

Nitrogen forms discharged to receiving waters in wastewater treatment plant effluents can cause serious water quality problems. For example:

* Free Ammonia is toxic to aquatic organisms, especially fish.
* Oxygen is consumed when ammonium is nitrified in receiving waters, and this can result in the loss of habitat and the death of fish and other aquatic life, when low dissolved oxygen(DO) concentration result.
* Nitrogen can stimulate the growth of aquatic plants, algae and other phytoplankton, which eventually die and their remains are consumed by bacteria, resulting in the exertion of a large amount of oxygen and low oxygen concentration.
* High nitrate concentrations in drinking water can cause methemoglobinanemia in infants.
* In summer time, when the receiving streams have lower flow rates and higher temperatures, the toxicity of effluent ammonia is magnified because of lower dilution by receiving waters, and also because algae grow will increase the pH of the water, which rapidly increase the amount of free ammonia relative to the ammonium concentration.

BIOLOGICAL NITROGEN REMOVAL

Biological nitrogen removal is a two step process consisting of nitrification and denitrification. Ammonia is first oxidized to nitrite by *Nitrosomonas spp.*, then the nitrite is converted to nitrate by *Nitrobacter spp.*. Both are autotrophic bacteria.

Nitrification Reactions

The two step nitrification process is expressed as follows:

$$2NH_4^+ + 3O_2 \rightarrow 2NO_2^- + 4H^+ + 2H_2O \qquad (2\text{-}1)$$

$$2NO_2^- + O_2 \rightarrow 2NO_3^- \qquad (2\text{-}2)$$

The equation show that when nitrification occurs, oxygen and alkalinity are consumed. Based on equations 2-1 and 2-2, the oxygen required for complete oxidation of ammonia is 4.57 g/g N oxidized. Equations 2-1 and 2-2 also show that alkalinity is consumed when ammonia is oxidized to nitrite. About 7.14 mg of alkalinity as $CaCO_3$ are consumed per mg ammonia-N oxidized. Because of this, some poorly buffered wastewater treatment plants need to add lime or soda ash to maintain acceptable pH levels for nitrification, and discharge.

Factors That Affect Nitrification

1) Temperature

Temperature is one of the most important factors affecting nitrification. Higher temperatures up to 40 C result in faster rate of nitrification. However, nitrification rates slow down rapidly below 15 C. Downing(1974) reported an equation for the effect of temperature on the maximum specific growth rate of nitrification, as follows:

$$Un_{max} = 0.18 \times e^{0.116(T-15)} \qquad (2\text{-}3)$$

This equation indicates that the maximum specific growth rate doubles with a temperature increase of 7 C.

2) pH

The reports of the effects of pH on nitrification vary for different investigators. Wild et als.(1975) pointed out that from pH 7.0 to 8.0, the maximum specific growth rate doubled. Engle and Alexander(1958) showed pH has no effect on nitrification from 7.2 to 8.0, and a linear decrease of nitrification below pH 7.2. EPA(1975) proposed the following equation to describe the influence of pH on nitrification:

$$U_{n,pH} = U_{n,7.2} \times (1\text{-}0.833 \times (7.2\text{-pH})) \qquad (2\text{-}4)$$

This equation indicates that at pH 6.5, the maximum specific growth rate is about 40% of the rate at pH 7.2. As mentioned before, nitrification destroys alkalinity, which cause low pH in weakly buffered waters. In order to maintain good performance during nitrification, it may be necessary to add soda ash and/or lime to replace the alkalinity destroyed during nitrification.

3) Toxicity

Quantification of the effect of toxic substances on nitrification is difficult because of other factors that may strongly affect nitrification, i.e., pH, temperature, dissolved oxygen and organic loading. Most of the toxicity studies in the literature used batch tests and activated sludge from operating plants.

Skinner and Walker(1961) found that metals are toxic to *Nitrosomonas*, with complete inhibition for the following metals and concentrations: Nickel, 0.25 mg/L; Chromium, 0.25 mg/L and Copper, 0.1-0.5 mg/L.

Table 2.1, 2.2, 2.3 lists the toxicity of some organic compounds.(Randall et als., 1992).

4) Dissolved Oxygen

Dissolved oxygen is necessary for nitrification. However, different minimum mixed liquor DO concentrations have been reported by different researchers. For example, Downing (1954) reported 0.3 mg/L was sufficient, while Boo et als. (1962) reported 1.0 mg/L was required. Sen et als (1992) concluded that the DO concentration required is a function of the organic loading rate, which can be approximately by the MCRT. They concluded that nitrification can be limited by DO concentration in high rate systems because the rate of DO transfer become the limiting factor. However, the complement of nitrification is not likely to be a function of the DO concentration in low rate(high MCRT) system because the rate of DO transfer is not significant.

DENITRIFICATION REACTIONS

The denitrification process is expressed as follows:

$$NO_3^- \text{-->} NO_2^- \text{-->} NO \text{-->} N_2O \text{-->} N_2 \qquad (2\text{-}5)$$

Denitrification is considered to be an anoxic process, occurring in the absence of oxygen, and requires an organic or inorganic electron donor.

Unlike nitrification, which consumes alkalinity, denitrification produces alkalinity and will restore half the alkalinity which was destroyed during nitrification, this equal to 3.57 mg

Table 2.1. Organic Compounds That Inhibit Nitrification.

Compound	Concentration(mg/L) at Approximately 75% Inhibition
Acetone	2000
Allyl alcohol	19.5
Allyl chloride	180
Allyl Isothiocyanate	1.9
Benzothiazole Disulfide	38
Carbon disulfide	35
Chloroform	18
o-Cresol	12.8
Di-allylether	100
Dicyandiamide	250
Diguanide	50
2,4-Dinitrophenol	460
Dithio-oxamide	1.1
Ethanol	2400
Guanidine carbonate	16.5
Hydrazine	58
8-Hydroxyquinoline	72.5
Mercarptobenzothiazole	3.0
Methylamine hydrochloride	1550
Methylisothiocyanate	0.8
Methylthiuronium sulfate	6.5
Phenol	5.6
Potassium thiocyanate	300

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Skatol	7
Sodium dimethyl dithiocarbonate	13.6
Sodium methyl dithiocarbamate	0.9
Tetramethyl thiuram disulfate	30
Thioacetamide	0.53
Thiosemicarbazide	0.18
Thiourea	0.076
Trimethylamine	118

Source: Hockenburg and Grady, 1977

Table 2.2 Organic Compounds That Inhibit Nitrification.

Compound	Inhibiting Concentration
Phenol	100 mg/L
Vitamins riboflavin,	50 mg/L
Thiamine	5 mg/L
2-chloro-6-trichloromethyl-pyridine	10 mg/L
Diethyldithiocarbonate	0.01 mM
Methylene blue	0.1 mM
Tanning and tanin derivatives	0.001 - 0.00001mM

Source: Sharma and Ahlert, 1977

Table 2.3 *Nitrosomonas* Toxicity Due to Organic Compound for IC_{50} Concentrations of 20 mg/L or Less.

Organic Compound	IC_{50} Concentration, mg/L
4-Aminophinol	0 07
3-Chlorophenol	0 20
2 Aminophenol	0 27
2-Bromophenol	0 35
2 3-Dichlorophenol	0 42
2,3 6-Trichlorophenol	0 42
1,3-Dichloropropene	0 48
5-Chloro-1-pentyne	0 59
2 3-Dichlorophenol	0 61
1,3-Dichloropropene	0 67
Chlorobenzene	0 71
4-Chlorophenol	0 73
2 4-Dichlorophenol	0 79
Trichloroethylene	0 81
4 Bromophenol	0 83
1,1 Dichloroethane	0 91
2 3,5,6-Tetrachlorophenol	1 30
1 1,2,2-Tetrachloroethene	1 40
1,1,2 Trichloroethene	1 90
2 2 2-Trichloroethanol	2 00
4 Nitrophenol	2 60
2-Chlorophenol	2 70
3 5-Dichlorophenol	3 00
2 3,5-Trichlorophenol	3 90
2 4,6-Tribromophenol	7 70
Resurcinol	7 80
2 4,6-Trichlorophenol	7 90
Pentachloroethane	7 90
2,6-Dichlorophenol	8 10
1,1,1,2-Tetrachloroethane	8 70
1,2,4 5-Tetrachlorobenzene	9 80
2-Nitrophenol	11 00
Benzene	13.00
1,5-Dichloropentane	13 00
1,2,3 4-Tetrachlorobenzene	20.00

Source Blum and Speece, 1991

(as $CaCO_3$) of alkalinity production per mg of nitrate nitrogen reduced. This is especially beneficial for poorly buffered wastewaters.

Factors that Affect Denitrification

1) Dissolved Oxygen

The presence of DO will inhibit denitrification even in very low concentrations. Skerman(1957) reported that a DO concentration of 0.2 mg/L can inhibit denitrification for a *Pseudomonas* culture. Nelson(1978) found that at a DO concentration of 0.13 mg/L, denitrification ceased.

Researchers believe that to understand the influence of DO on denitrification, one must understand that the DO concentration within the activated sludge floc is typically not the same as the DO in the bulk liquid. Consequently, denitrification can be observed under apparently aerobic condition (Rittman and Langeland, 1985).

2)pH

The influence of pH on denitrification is not as pronounced as it is for nitrification, and reports on this field do varies. Dawson and Murphy(1972) reported that the optimum pH for denitrification is 7.0 and that the rates at 6.0 and 8.0 are only half the optimum rate. Nommik(1956) reported that pH changes between 7.0 and 8.0 have no effect on denitrification, they noted that neutral to alkaline pH conditions favor the conversion of nitrous oxide to di-nitrogen gas.

3) Organic Substrate

Denitrification reaction require an organic substrate. Barth et als,(1968) estimated that 4.0 mg/L of municipal sewage BOD is required to reduce nitrate to nitrogen gas. McCarty et als. (1969) pointed out that methanol was a preferred external carbon source based on a low sludge yield and cost. The following equation was provided by them to relate methanol requirement to nitrate nitrogen removal:

$$M = 2.47(No) + 1.53\ Ni + 0.87\ DOu \qquad (2\text{-}6)$$

where:

M: Methanol required, mg/L

No: Nitrate nitrogen reduced, mg/L

Ni: Nitrite nitrogen reduced, mg/L

DOu: Dissolved Oxygen reduced, mg/L

From this equation, the methanol required to reduce nitrate nitrogen as a ratio of the COD used is 3.71.

In biofilm systems, denitrification can occur in the deep layer where dissolved oxygen is zero, and the denitrifiers can use the dead biomass as the organic supply for denitrification.

Biological Nitrogen Removal Literature Summary

Randall(1991) pointed out that biological nutrient removal is the most economical way to remove nutrients from wastewater. It can eliminate, or at least substantially reduce, the addition of chemicals to remove phosphorus. This saves the costs of chemical addition and also reduces the quantity of waste sludge produced, which reduces the cost of sludge disposal. In addition, the removal of influent wastewater BOD during BPR and

denitrification reduces the energy requirement for oxygen transfer, plus increase the alpha factor of the wastewater, making oxygen transfer more efficient per unit horsepower.

A single sludge system incorporating both an anaerobic zone and an anoxic zone ahead of the aerobic zone is the most energy efficient system.(Randall et als, 1991). It can remove substrate and stabilize some of the organic matter in the anaerobic and anoxic zones. Another advantage of this system is aeration cost reduction, because the oxygen transfer driving force is greater when the mixed liquor entering the aerobic zone has no dissolved oxygen(Randall et als, 1991). Consequently, less power is required to transfer the oxygen.

McClintock et als(1988) stated that incorporation of an anoxic zone for denitrification can reduce the volume required for aerobic nitrification, reduce the sludge generation and generate about one half of the alkalinity destroyed during nitrification. This latter effect can reduce chemical alkalinity addition for poorly buffered waters. Another advantage of incorporating anaerobic and anoxic zones ahead of the aerobic zone is that they discourage the growth of filamentous microorganisms in the activated sludge, thus resulting better sludge settling in the clarifiers.

FIXED FILM BIOLOGICAL PROCESSES

Fixed film biological processes for wastewater treatment were introduced early in the 20th century, but their use decreased sharply during the 1970s because the rock media trickling filters traditionally used were not sufficiently efficient for BOD removal to meet new effluent standards. However, the development of synthetic biomass support material and the need to develop compact and inexpensive plants to meet stringent effluent requirements, has refocused more and more attention on fixed film systems in recent years. Consequently, there has been a lot of research on fixed film biological processes,

including: trickling filters, rotating biological contractors, biofilters, biofilms on granular activated carbon and sand, and anaerobic biofilm systems in recent years.

Broch-Due(1994) used an aerobic moving bed biofilm reactor to treat pulp and paper wastewater. The concentration of influent COD was increased from 10000 mg/L to 65000 mg/L during evaluation. High COD and BOD removal rates were accomplished by this reactor when the influent COD concentration was about 50000 mg/L, i.e, 70% COD and 98% BOD removal was achieved. The reactor also achieved 98% toxicity removal as measured by Microtox, and maintained good performance during shock loading.

Kerrn-Jespersen et als.(1994) investigated biological phosphorus removal by operating a fixed film reactor under alternating anaerobic and anoxic conditions. Biological phosphorus removal was obtained with nitrate as electron acceptor. The phosphorus concentration in the sludge was about 10% of the dry biomass solids.

Edwards et als.(1994) studied the treatment of high COD wastewater with fluidized bed reactors. Two kinds of media, sand and granular activated carbon(GAC) were studied and 99% COD removal was observed in both reactors. Further studies showed that the GAC reactor had better performance than the sand reactor because of its ability to handle rapid increases in COD loads and toxic surges.

R. Pujol et als(1993) reported there were more than 50 biofilter treatment plants in Europe and North American. Experience with this kind of reactor has demonstrated high performance for a broad range of applications, as demonstrated by COD and nutrient removal. The compact and modular design of these units makes biofilters particularly well suited for areas of variable population, i.e., resorts.

Combined activated sludge fixed film media biological treatment systems were introduced in the early 1980's. They consist of the placement of fixed or suspended media in the aeration tank of an activated sludge system to increase the biomass in the system. Several pilot and full-scale studies(Boyle & Wallace, 1986; Heidman et als, 1988; Lessman and Reinmann, 1987; Dipanker et als, 1993) concluded that this system has some advantages over conventional systems. Such as:

Increased total biomass, hence improved substrate removal ability.

Better performance during shock loads.

Better performance of clarifiers.

Enhanced nitrification.

Reduction in sludge production.

Reduced reactor volume requirement.

Better energy and cost efficiency.

Yu et als(1994) studied the suspended carrier biofilm process for treatment of pulp and paper industry wastewaters. The biocarrier had a density close to water and was suspended in the mixed liquor by aeration. Fifty percent to 70% COD removal was achieved here using a total treatment time of 2 to 4 hours, and the treatment proved stable even at the high loading rate of 12 kg BOD/m3/day.

A full scale wastewater treatment plant at Moundsville/Glen Dale, West Virginia, was operated with an aeration tank containing 30% Captor media by volume. The design flow rate was 2.3 MGD, and 95% BOD removal, 70-90% nitrification and 40-60% denitrification was achieved by the Captor process even at temperatures as low as 12 C.

Biofilm Growth

The formation of biofilms on microcarriers(for example, sand and GAC) depends on the characteristics of the selected carriers, the substrate and the microorganisms (Senthilnathan, 1989).

Heijnen et als(1992) hypothesized that the biofilm formation process is a three stage process. First, single cells attach to the surface of the carriers. Next, the attached cells accumulate and form patches of biofilm. Third, the biofilm patches expanded over the majority of the carrier surfaces. The author also mentioned that biofilm growth was positively influenced by the roughness of the carrier surface but negatively influenced by the concentration of the carrier material.

Figure 2.1 is Grady's (1983) model of biofilm structure. The depth of biofilm is a function of nutrient, electron donor and electron acceptor. Materials can be transported from the bulk liquid to the biofilm:liquid interface, then enter the biofilm. The substrate concentration at the biofilm:liquid interface was lower than that of the bulk liquid. Figure 2.2 is a schematic of typical substrate concentration profiles.

Characklis(1981) pointed out that biofilm thickness was less than 1 mm in turbulent flow systems. Studies by Kornegay(1968) and Tomlinson(1966) concluded that the rate of substrate consumption increased as the biofilm depth increased up to a limiting depth of 70-100 um, after which the removal rate was independent of depth. This depth was defined as the active depth. The active depth was determined by substrate transportation limitations within the biofilm.

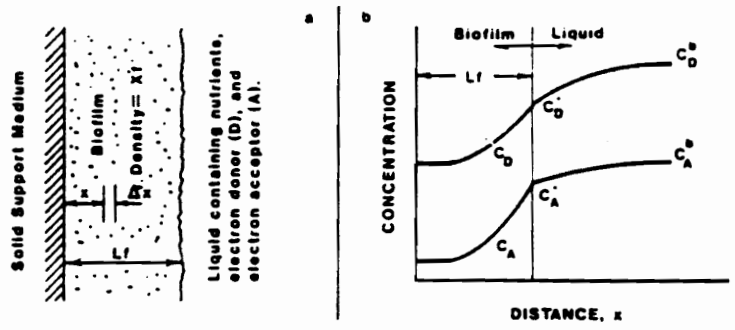

Figure 2.1 Schematic diagram of biofilm.

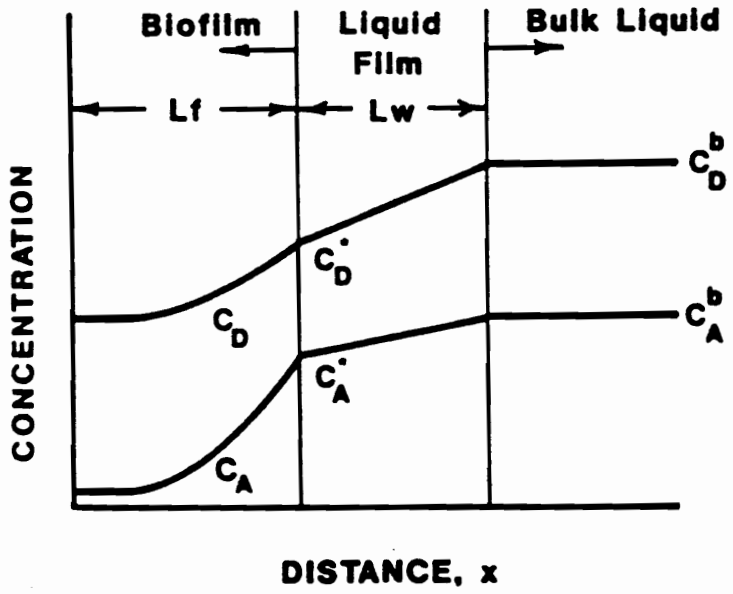

Figure 2.2 Idealized biofilm and stagnant liquid layer illustrating concentration profiles of the electron donor (D) and the electron acceptor (A).

Biofilm Competition

Studies of the biofilm in media (Watanabe, 1992; Masuda, 1991) have demonstrated the coexistence of heterotrophs, nitrifiers and denitrifiers in the biofilm. The composition of the bacteria population is a function of biofilm depth. The activity of nitrifiers and denitrifiers strongly depends on the DO levels in the layers of the biofilm, high DO will increase the activity of nitrifiers while limit the activity of denitrifiers.

Heterotrophic bacteria can grow faster than nitrifiers and when substrate for heterotrophic bacterial growth is present, it permits them to outcompete nitrifiers for space and DO. Unless the growth of heterotrophs is controlled, the growth of nitrifiers in the biofilm is impossible(Rittmann, et als, 1992)

INTEGRATED FIXED FILM ACTIVATED SLUDGE SYSTEM

Some early research on the addition of fixed film media into activated sludge, using materials such as spheres of stainless steel wire(Atkinson, 1984), marble particles (Lewandowski, 1983), and biofilter packing materials(Rogalla, 1989, Haseltine, 1991) resulted in uncertain benefits. This was because either the media could not maintain a high biomass growth and/or the aeration system could not keep the media in suspension in the aeration basin(Heidman, 1988)

The recent development of porous foam biomass support media can overcome these problems. It can provide surface area to support the growth of attached biomass and also can be easily suspended in the activated sludge basin by aeration. Two sizes of porous media have been developed for such systems, Linpor media, manufactured by the Linde

Corporation in Germany, and Captor media, distributed by Simon Waste Solutions of Houston, Texas. The linpor media is a 1 cm cube while Captor media is 12.5mm×25mm×25mm.

Captor media consists of polyurethane foam cuboids with a porosity of approximately 97%, and typically about 30 pores per inch(Boyle and Wallace, 1986). Pilot studies showed that the use of the media resulted in higher BOD removal rates, more stable operation and increased air transfer efficiency(Boyle, 1986). However, the technology is not recognized as fully developed by the US EPA due to limited availability of operational data, especially when it is applied to nitrogen and phosphorus removal(Shin et als, 1991)

Effects on Nitrification

Several studies have shown that activated sludge nitrification can be enhanced by the addition of sponge media. Reimann(1984) used Linpor media to improve nitrification when treating low BOD wastewater. An aeration basin filled with Linpor media was located after a regular activated sludge treatment process and enhanced nitrification resulted. Later, Reimann(1984) added media directly into the original aeration basin and found that enhanced nitrification continued.

Kondo et als (1992) studied the simultaneous removal of BOD and nitrogen with anoxic/oxic porous biomass support systems. The media they used was polyurethane foam. Even for temperatures as low as 13 C and an MCRT as low as 6 hour, the effluent ammonia was less than 1 mg/L for an influent of about 26 mg/L. No control system was used during this experiment.

Louis(1993) added Linpor media to an activated sludge aerobic reactor to treat a high strength, high ammonia industrial wastewater. Nitrification was clearly enhanced by media addition and the author concluded that this was because the addition of media increased the effective MCRT of the system.

Effect on Denitrification

Denitrification can occur in fixed film media even in aerobic reactors due to the presence of anoxic zones in the interior regions of the biofilm(Reimann et als, 1990; Watanabe et als, 1992; Wartchow, 1990). Watanabe(1992) found that the activity of the nitrifiers and denitrifiers depended on the dissolved oxygen in that zone. The ammonia oxidation rate in deep layers of the biofilm was just half that of the surface area. Mausda(1991) used a micro slicer to slice biofilm formed on an RBC and demonstrated the coexistence of heterotrophs, nitrifiers and denitrifiers.

Endogenous denitrification had been reported by many researchers (Ekama, et. al 1984, Chen, et.al, 1992). They concluded that denitrification could occur in a biofilm reactor even when the concentration of organic substrate was very low. The organic substrate used by the denitrifiers was the biomass of the biofilm, therefore, this was called endogenous denitrification. Because the biomass density of the biofilm was very high, the amount of substrate available for endogenous decay was also very high.

Zhang et als(1993) studied microbial competition in biofilms with microelectrode and microslicing techniques. The results of this study showed that heterotrophs can out compete nitrifiers for dissolved oxygen, which results in the inhibition of nitrification. The

competition for substrate in the biofilms resulted in a stratified biofilm structure, where the heterotrophs are concentrated near the surface, and the nitrifiers in the deep layers.

H. Tsuna, et als(1992) studied BOD removal and nitrification by aerobic reactors filled with 10% and 20% by volume polyurethane foam medium. Nitrification started to occur after BOD removal was completed. Heterotrophs were dominate in the first part of the reactor where COD was available, while the nitrifiers were dominate in the later part of the reactor after the completion of BOD removal, but where ammonium was still present.

Effects on COD Removal

Several studies have shown that effluent COD and/or BOD is lower from IFAS systems than from control activated sludge systems(Rogalla, 1989; Morper and Wildmoser, 1989; Hegemann, 1984; Renz, 1985). The development of biofilm within the system increased the actual MCRT of the system, which increased the COD removal ability of the system.

However, Haseltine(1991) reported that the effluent COD did not decrease after media addition. Louis(1993) also found that the addition of fixed film media did not improve COD removal, and he believed that this was because of the lower growth rates and decreased hydraulic retention times of the IFAS system.

Effects on Sludge Settling Properties

Several researches have reported that IFAS system produce activated sludger with lower sludge volume indexes(SVIs) than similar conventional systems. Hegemann reported a

SVI decrease from 485 to about 130 after the addition of 40% Linpor media. Wanner et als(1988) observed a SVI decrease from over 2000 to 200 after the addition of 30% sponge media to an activated sludge system. Haseltine(1991) observed improved settling properties in a study of IFAS treatment of a high acetate wastewater. The SVI decreased from 200 to 50 with the addition of 20% LINPOR-N media. However, he also pointed out that the SVIs for both control and media systems were the same during periods of filamentous bulking. Louis(1993) found that the SVI decreased with an increase in media concentration for systems operated at 2.5 day MCRT, but at 5.0 MCRT he did not find a difference between the IFAS system and the control system.

Lessel(1993) reported a SVI decrease from 180-300 to 50 in an IFAS reactor using Ringlace as the medium. It was believed that this decrease occurred because of the elimination of filamentous organisms. The micro-organisms in the activated sludge shifted from predominantly filamentous organisms to floc-formes ciliates and rotifers, and the higher the ratio of attached media biomass to total biomass, the lower the SVI values.

Effects on Sludge Production

Some research projects have shown that sludge production in biofilm and IFAS systems was less than in conventional activated sludge system (Rogalla, 1989; Wang et als, 1992; Lessel, 1991).

Wang(1992) believed that the lower sludge production was due to the presence of an anaerobic zone where the biomass was degraded. A possible second reason for lower sludge production is that the organisms of higher trophic levels, such as worms, eat the bacteria. This results in a lower cell yield coefficient compared to other organisms usually found in the conventional activated sludge process.

Louis(1993) did not observe a decrease in sludge production with media addition. Haseltine(1991) got the same results as Louis except for his 1 day MCRT experiments, where sludge production did decrease.

PRIOR RESEARCH WITH EXPERIMENTAL SYSTEM

This research was a continuation of an investigation begun by Mitta(1994) and Jensen(1995), under the supervision of Sen(1995).

Mitta's Research

Mitta's research concentrated on Ringlace media and fixed foam media. The operating MCRT varied from 5.3 to 3.1 days, and he was assisted by Jensen with 3.4 and 3.1 day MCRT experiments. From his research, he concluded:

* There was no statistical (95% confidence) demonstration of enhanced nitrogen removal by the IFAS system. This was probably because of the MCRT values used. Even the control achieved good nitrification.
* Denitrification was substantially increased in the integrated fixed film activated sludge(IFAS) systems, compared to the control. Ringlace media achieved more denitrification than the fixed foam media.
* Attached growth is a function of the available COD. Thicker biomass was found in aerobic cell 1 where the soluble COD concentration were the highest.
* Sludge production and observed sludge yield were lower in IFAS system than in the control system.

Jensen's Research

Mitta's research showed that free floating Captor media had much better nutrient removal ability than Ringlace and fixed foam media, so Jensen's research concentrated on free floating Captor media. He conducted experiments at 4 MCRT's, 3.4, 3.1, 2.4 and 1.7 days, Liu joined the research group during the experiment at 2.4 day MCRT.

Jensen's conclusion were:

* IFAS systems with free floating Captor media have better nitrogen remove ability than conventional activated sludge systems. Floating sponge media enhances this ability to a greater degree than rope like Ringlace media does in bench scale system.
* The optimum location for media addition is a function of the COD, in the zone containing the media.
* No statistical conclusion could be made about sludge production and observed sludge yield.

SUMMARY OF LITERATURE REVIEW

The integration of fixed film media into activated sludge processes have been studied by many researchers, and the results have been reasonably consistent. Better COD and nutrient removals were reported by almost all the researchers. IFAS systems are less sensitive to low temperatures and high organic loads than traditional activated sludge systems, and this results in a substantial decrease in the required reactor and clarifier

volumes for nitrogen removal. Endogenous denitrification in the aerobic zone of IFAS system has been reported by some researchers.

The performance of the IFAS systems was not only related to the quantity of the attached biomass, but also to the active part of the biomass in the system. Heterotrophs, nitrifiers and denitrifiers compete in the biofilm for substrate and dissolved oxygen. The activity of the nitrifiers and the denitrifiers is related to the available COD, dissolved oxygen and ammonia.

Overall, biofilm systems are economical for simultaneous BOD and nutrient removal, and if designed and operated properly, can maintain fairly good performance. Integration of Captor media into pilot scale activated sludge wastewater treatment system has resulted in very good nutrient and BOD removal, but most of the studies were short term, single MCRT studies, and no control systems were used. It is hard to obtain accurate kinetic coefficients from these studies, and a detailed study of a Captor media IFAS system is needed to more precisely determine these values.

CHAPTER 3

METHODS AND MATERIALS

This research was performed using a pilot scale plant located at Virginia Polytechnic Institute and State University, Blacksburg, Virginia. The plant design and operation, the materials used and the wastewater characteristics are described in this chapter.

PILOT PLANT DESIGN AND OPERATION

In order to investigate the influence of IFAS media incorporation into the aerobic reactors of activated sludge BNR systems, two treatment trains were used, one as a control system, the other as an IFAS system.

Figure 3.1 is a schematic of the configuration of the pilot plants. Excluding the clarifier, each system had a total reactor volume of 106 L. The wastewater flow rate was 207.4 L/day, for a nominal hydraulic retention time of about 12.2 hours.

All treatment trains were constructed by Dipanker Sen and Pramod R. Mitta in 1992 and were initially described by Mitta (1994). The construction material used was Nalgene high density polyethylene.

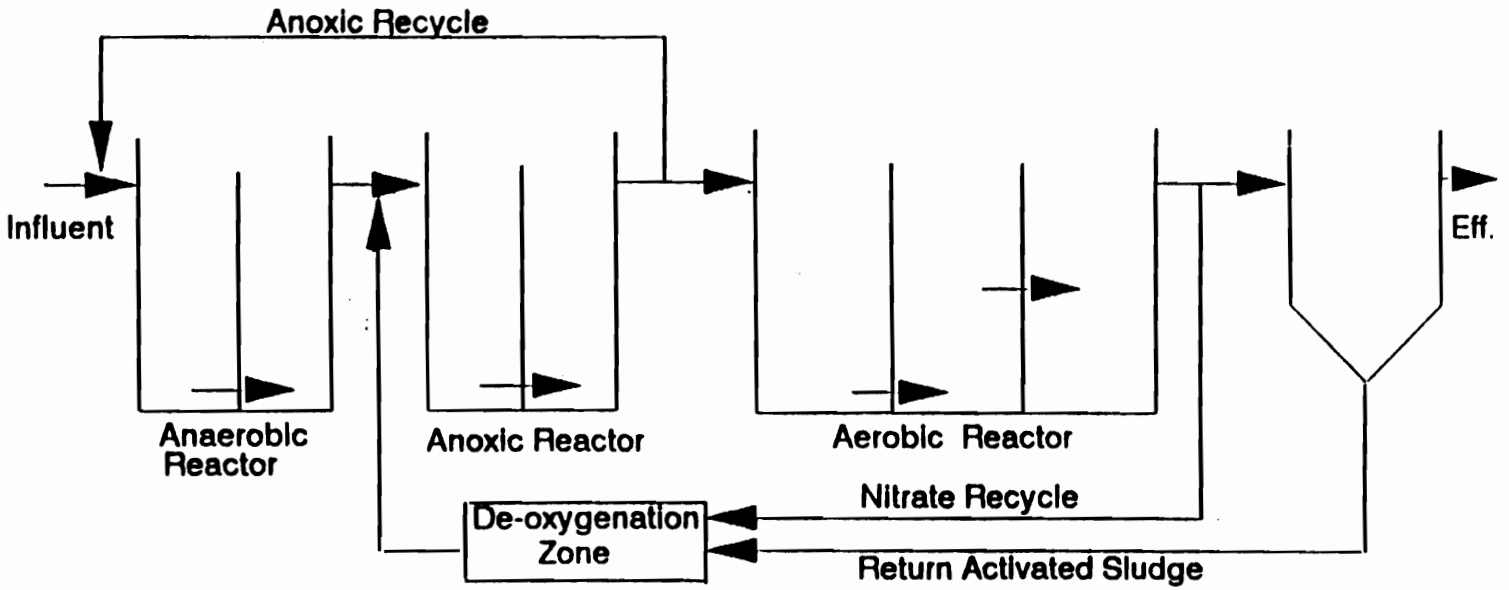

Figure 3.1 Design of a Treatment Train of Bench Scale System - VIP Configuration.

The first two cells of the trains were operated under anaerobic conditions. After the anaerobic reactors were two anoxic reactors, followed by three reactors operated under aerobic conditions. The return activated sludge (RAS) was returned to a de-oxygenation zone before introduction into the anoxic reactor.

The total volume of the anaerobic zone was 17.4 L, and it was divided into two cells by a 3/8" plexiglass plastic baffle, giving each cell a volume of about 8.7 L. The anoxic zone had the same volume as the anaerobic zone, and also was divided into two equal volume cells by a 3/8" plexiglass plastic baffle. The aerobic reactor was divided into three equal size cells with a total volume of 69.3 L. The volume of the deoxygenation reactor was 2 L, and the volume of the clarifier was 15 L. The anaerobic and anoxic zones each comprised one-sixth of the total volume. The aerobic zone comprised two-thirds of the total volume. The reason for this volume ratio was to optimize nitrogen removal by optimizing nitrification.

The anaerobic and anoxic cells of the plant were mixed by subfractional electric gear motors with a mixing speed of 50 RPM. The gear motors were attached to shafts with mixing blades. The electric gear motors were also used to drive scraper blades in the clarifiers at a speed of 1 RPM. Fine bubble stone diffusers were used to aerate the aerobic cells, and the air was supplied by a 1HP Ghast oil-less compressor.

To conform with the UCT/VIP configuration, the mixed liquor was recycled from anoxic cell 2 to anaerobic cell 1 to return biomass to that reactor. This flow will be referred to as the anoxic recycle. Mixed liquor from aerobic 3 cell(nitrate recycle) and RAS from the clarifier were combined in the deoxygenation zone to remove dissolved oxygen before addition into anoxic cell 1. During these experiments, the recycle flow was equal to the influent wastewater flow, Q, which was 207.4 L/day. Thus a flow of 2Q entered the deoxygenation zone while a mixed liquor flow of 1Q was returned to the anaerobic reactor. During the 0.3 day MCRT experiment, there was no return activated sludge recycle.

A small dose of chlorine was added to the RAS line to control filamentous bacterial growth. The SVI was maintained less than 200 mg/L.

Cole Parmer masterflex peristaltic pumps were used to pump all recycle flows and influents.

Table 3.1 lists the actual flows in different lines and reactors for different experiments(in terms of Q, the influent flow rate).

Table 3.1 The Actual Flows in the Lines and Reactors at Different MCRTs.(In terms of Q)

MCRT	RAS	NR	MLR	Anaerobic zone	Anoxic zone	Aerobic zone
1.7	Q	Q	Q	2Q	4Q	3Q
1.0	Q	Q	Q	2Q	4Q	3Q
0.33	0	Q	Q	2Q	3Q	2Q

Q: Influent Flow Rate, 207.4 L/day.

RAS: Return Activated Sludge.

NR: Nitrate Recycle.

MLR: Mixed Liquor Recycle.

WASTEWATER CHARACTERISTICS

Wastewater from the Blacksburg VPI Sanitation Authority main sewer line was pumped to storage tanks 24 hours before it was pumped to the reactors. The major reason for this 24 hour detention time was to maintain the influent wastewater temperature at about 12 C. Sodium acetate, urea, sodium phosphate and sodium bicarbonate were added to the storage tank at the same time the wastewater was pumped to the storage tank. The chemical addition was to maintain the influent COD around 450 mg/l, the TKN around 55 mg/l, and the alkalinity sufficient to buffer the acid produced by nitrification to maintain a pH around 7.

The chemical addition was administered according to the sewage strength. During heavy rains and holidays when few students were on campus, the sewage strength was much lower than normal. Higher chemical doses were added during these times. The influent concentration of the wastewater were checked regularly to maintain relatively uniform COD and TKN concentrations.

Dissolved Oxygen (D.O.) and Temperature was measured in situ during each sample profile to make sure the D.O. in the aerobic cells was larger than 6 mg/L, and the mixed liquor temperature was 12 C.

Table 3.2 describes the characteristics of the wastewater in this research.

Table 3.2 Influent Characteristics

Influent Characteristics	Raw Influent	Primary Effluent	Primary effluent for spiked profile
TKN (mg/L)	150	55	55
Temperature (C)	N/A	12	12
COD (mg/L)	150	450	450
TP (mg/L)	2	6	350

MEDIA ADDITION AND THE INFLUENCE OF REACTOR VOLUME

About 880 Captor sponges (12.5 mm×25mm×25mm) were added to each aerobic cell of the IFAS system. The media dry volume was about 30% of the total aerobic reactor volume. The media were kept in suspension during operation by the turbulence produced by coarse bubble air aeration.

The liquid volume displaced by the media was very small, but media addition reduced the liquid HRT of the aerobic zone of the IFAS system because the media retained water which was not displaced by the forward flow. To quantify this effect, 5 to 6 sponges were taken from each aerobic cell and placed in a plastic net which was then shaken by hand and weighed. This was the wet weight. After that, the media were dried at 105 C for 24 hours and reweighed to determine the dry weight. The difference in the wet weight and the dry weight was the volume of water entrained in the porous media of the biofilm. After that, the sponges was squeezed and washed in clean water to wash the biomass out of the sponges and dried again at 105 C for another 24 hours and weighed. The difference of the two dry weights was the attached growth on the sponges.

The total volume displaced by the porous media was the sum of the liquid volumes displaced by the clean media, the entrapped liquid and the biosolids growing on the media. The volume displaced by the clean media was obtained from the manufacturer and checked by immersing clean sponges in water. It was found that the volume displaced by

the clean media was less than 10% of the volume of water and biomass solids entrapped in the media during operation.

$$\text{Biofilm volume fraction, BVF} = \frac{V_w}{V_m} \times MVF \qquad (3\text{-}1)$$

V_w: Volume of water and solids retained in the media

V_m: Volume of media

MVF: Media Volume Fraction (30% in this study).

The derivation of this equation is in Appendix A.

MCRT MONITORING

1.7 Day MCRT

The operating MCRT of each train was maintained by measuring the MLSS of both Aerobic cell 3 and the effluent twice every week. The sludge wasting rate was calculated using the following formula.

$$Qw = \frac{V(1 - BVF)X - \theta cXeQ}{\theta cX - \theta cXe} \qquad (3\text{-}2)$$

Where:

Qw: sludge wasting rate

V: total volume of the system

X: mixed liquor suspended solids

θc: total sludge age of the system

Xe: effluent suspended solids

Q: influent flow rate

BVF: fraction of volume replaced by the media

For the control system, the BVF was zero. Derivation of the above formula is shown in Appendix A. Sludge wasting was accomplished by pumping mixed liquor from aerobic cell 3 at a rate slightly lower than the calculated rate plus manually wasting everyday to maintain the total wasting rate at the calculated rate.

1.0 Day Aerobic MCRT

For operation at 1.0 day MCRT, the sludge was wasted from the return activated sludge line because the calculated rate for wasting from aerobic 3 cell was about 40-50 L/day, and it was very difficult to accomplish this. By wasting from the return activated sludge, the wasting rate decreased to about 20 L.

The wasting rate for this MCRT was calculated using the following formula:

$$Qw = \frac{Va \times (1 - BVF) \times X - Q \times Xe \times \theta_c}{\theta_c \times Xr} \qquad (3\text{-}3)$$

Where:

Xr = (548.6 × Xe-Vt × Xe)/341

Qw: Sludge Wasting Rate (L/day)

Q: Flow rate of the system (207.36 L/day)

Va: Total volume of the aerobic zone

BVF: Fraction of volume occupied by the media.

X: MLSS concentration in the system

Xe: MLSS concentration in the effluent water

θc: Aerobic sludge age

The derivation of the equation is given in Appendix A.

The difference between the calculated sludge wasting rate and the actual wasting rate of the activated sludge was calculated for each train, and the appropriate amount wasted manually every day from aerobic cell 3. The volume for manual wasting was calculated by equation 3-4.

$$Qm = 1.6 \times (Qw-Qp) \qquad (3\text{-}4)$$

Qm : manual wasting rate of each train

Qw : calculated wasting rate of each train

Qp : pumped wasting rate from return activated sludge

The parameter 1.6 is the average ratio of the MLSS concentration in the return activated sludge to the MLSS concentration in aerobic cell 3 at this MCRT.

0.3 Day Aerobic MCRT

For operation at 0.3 day MCRT, there was no return activated sludge recycle in the system, and also no wasting from the system, except from the clarifier, i.e., either in the clarifier effluent or sludge pumped from the bottom of the clarifier. That is to say, the system was operated as a flow - through chemostat.

STEADY STATE DETERMINATION

In this research, each system was allowed to acclimate to the operating conditions for at least 21 days before any steady state samples were taken. After that, samples were collected regularly for at least 8 days for steady state analysis. Another five samples were collected after the profile test for steady state analysis. The systems were considered to be at steady state if the effluent ammonia and aerobic MLSS concentration remained fairly constant over a period of days before profile sampling. The nitrification rates of the five samples collected after profile sampling and the five samples collected during profile testing were used for steady state analysis. Only when these ten nitrification rates were fairly constant was the system considered to be at steady state.

It took longer for the IFAS system to reach steady state than the control system, therefore the control system was believed at steady state when the IFAS system was at steady state.

If a mixed liquor spill occurred, the system was allowed to stabilize for a additional period of time before any steady state sampling. This time was usually about two extra days, depending on the magnitude of the spill.

ANALYTICAL PROCEDURES

During each MCRT experiment, at least five profile sample sets were collected. At 1.7 day MCRT, ten profile sets, five regular profiles and five spiked profiles, were collected. For spiked tests, the urea addition to the raw influent was doubled.

At least one long profile was conducted for each MCRT, i.e. samples were collected from every cell plus the influent and effluent. For medium profiles, samples were collected from the influent, anaerobic cell 2, anoxic cell 2, aerobic cells 1,2,3 and the effluent. For short profiles, samples were collected from only the influent, anoxic cell 2, aerobic cells 1,2 ,3 and the effluent.

All the samples collected from each reactor cell and effluent were filtered through Whatman 403 H glass fiber filter papers (average pore size of 1.3 um). Ammonia nitrogen, soluble Kjeldahl nitrogen (SKN), soluble COD (SCOD), ortho phosphorus (OP), nitrate and nitrite were measured for all samples after filtering. For the influent and aerobic cell 3 samples, unfiltered samples were analyzed for total COD, TKN and total phosphorus (TP).

MLSS and MLVSS concentrations were measured for samples from the effluent, the aerobic zones, and, during some phases, the second anaerobic and anoxic zones.

Table 3.3 outlines the analytical procedures used.

A paired t-test was used to compare the performance of the IFAS system with the control system.

BATCH TEST FOR NITRIFICATION RATES

Nitrification batch tests were conducted twice at each MCRT(usually after profile sampling) to determine the ammonia utilization rates of the mixed liquor and the biofilm on the Captor media. At 1.7 day MCRT, Captor media from each aerobic cell in the IFAS system and the mixed liquor from both systems were removed and tested. For 1.0 and 0.3

day MCRTs, by profile measurement, no nitrification was accomplished by the control system, so no batch test for the mixed liquor in the control system was conducted.

For each batch test, about 100 mL ammonia chloride solution(1000 mg/L ammonia as nitrogen) and 100 mL sodium bicarbonate solution (7000 mg/L alkalinity as $CaCO_3$) were added to each flask to make the initial ammonia concentration around 50 mg/L, and the alkalinity around 350 mg/L. The total liquid volume of each flask about 2 L. Filtered samples were taken every hour for about 6 hours to measure the ammonia, nitrite and nitrate concentration.

Table 3.3. Analytical Procedures

Test	Procedure*
COD	Closed Reflux, Titrimetric Method (5220 C)
TKN	Semi-micro-Kjeldahl Method(4500-Norg C) followed by Titration (4500-NH3 E)
TP	Persulfate Digestion(4500-P.B.5) followed by Ascorbic Acid Method (4500-PE)
NH3-N	Ammonia-Selective Electrode Method (4500-NH3 F)
NO3-N	Ion Chromatography with Chemical Suppression of Eluant Conductivity
NO2-N,OP	Dionex 2010I (4110B)
Alkalinity	Alkalinity (2320B). Potentiometric Titration to Preselected pH
MLSS	Total Suspended Solids Dried at 103-105 C (2540 D)
MLVSS	Fixed and Volatile Solids Ignited at 550 C (2540 E)
pH	Measured with a Fisher Accument pH Meter Model 610 A (4500-H)
DO	Measured with YSI model 54A Membrane Electrode Oxygen Meter (4500-O G)
Temperature	Field Measurement with a Mercury-Filled Celsius Thermometer(2550 B)

*Reference: Standard Methods for the Examination of Water and Wastewater(18th edition)

CHAPTER 4

RESULTS

This chapter presents the results of the experiments performed during this study. Steady state analysis, the efficiency of nitrification, denitrification and COD removal for both IFAS and control systems, plus the extent of attached growth and liquid retained in the biofilm of the IFAS system were studied for each MCRT. The results of the nitrification batch tests performed for each MCRT are also included in this chapter.

MCRT 1.7 DAY EXPERIMENTS

The raw data for the 1.7 day MCRT experiment are presented in Appendix B, 1.7 day MCRT data. Train 2 was the IFAS system, while train 4 was the control system.

Steady State Analysis

The total nitrification results from the IFAS system during regular profile sampling and the measurements taken after profile sampling are presented in Table 4.1. A grouped t-test was conducted and the observed t value was less than the critical t value (95% confidence). This demonstrates that during this MCRT, steady state was achieved and maintained throughout this experiment.

Table 4.1 Steady State Analysis for 1.7 day MCRT. Total Nitrification Results (g/day as nitrogen) from Regular Profile sampling and Measurements After Profile Sampling (g/day as nitrogen) in the IFAS System.

DATE	Nitrification (g/day)	Group
6/2/94	8.07	1
6/7/94	7.93	1
6/9/94	8.01	1
6/17/94	6.93	1
8/15/94	7.4	2
8/16/94	7.45	2
8/18/94	7.01	2
8/19/94	7.22	2
8/20/94	7.38	2
DF	7	
t-critical	1.895	
t-observed	1.745	

DF: Degrees of Freedom

Group 1: Regular Profile Results

Group 2: Measurements Taken after Profile Sampling

t critical is for 95% confidence with 7 degrees of freedom.

Nitrification Analysis

The results listed in Appendix B, 1.7 day MCRT data, show that during regular long profile determination of the IFAS system, the ammonia concentration decreased from 50.2 mg/L as nitrogen to 0.79 mg/L in the IFAS system, while in the control system it decreased from 46.4 mg/L to 20 mg/L. During the spiked long profile experiment, ammonia decreased from 82.5 mg/L to 23.9 mg/L in the IFAS system, but decreased from 85.7 mg/L to only 51.3 mg/L in the control system. The table also shows that in the IFAS system the effluent nitrate concentration increased from 0 to 7.3 mg/L during the regular test and from 0 to 10.3 mg/L during spiked test. But in the control system, the nitrate increase was from 0 to only 1.3 mg/L during both the regular and the spiked test. All of these results demonstrate that better nitrification was occurring in IFAS system.

Table 4.2 presents the nitrification results for both the IFAS and the control systems. The difference between the IFAS system and the control system was so large, it was easily concluded that the IFAS system had a higher nitrification rate than the control system at this MCRT. Paired t test was conducted to evaluate the enhancement of nitrification by the IFAS system. For the normal profile experiment, the observed t value was 109, and for the ammonia spiked experiment, the observed t value was 26.2, while the critical t value for 3 degrees of freedom is 2.353, much less than the observed t values. Clearly, better nitrification was achieved in the IFAS system.

Table 4.2. Comparison of Total Nitrification in the IFAS and Control Systems at 1.7 day MCRT(g/day). During Regular and Spiked Testing.

	Total Nitrification (g/day)		Influent TKN	Effluent Ammonia (mg/L)		
DATE	IFAS	CONTROL	(mg/L)	EFF NH4 (IFAS)	EFF NH4 (Control)	DATA SET
6/2/94	8.07	2.51	66.8	6.3	36.3	regular
6/7/94	7.93	2.4	63.6	3.6	31.6	regular
6/9/94	8.01	1.45	62.0	1.6	29.7	regular
6/17/94	6.93	2.69	55.1	0.79	30.0	regular
6/25/94	8.57	2.09	83.5	15.2	51.3	spiked
6/28/94	9.77	3.83	90.2	21.3	44.6	spiked
7/5/94	8.71	1.73	82.9	20.7	50	spiked
7/8/94	8.94	2.94	81.8	11.5	53.8	spiked

In the IFAS system, nitrification was limited by ammonia during regular testing on 6/7, 6/9 and 6/17, because the effluent ammonia was lower than 5 mg/L.

Denitrification

Nitrification-Denitrification mass balance calculations in Table 4.3 show that total denitrification in the IFAS system was higher than in the control system. However, further analysis showed that the aerobic denitrification in both systems was almost the same. Paired t-testing showed that there was no significant difference in aerobic denitrification between the IFAS and control systems at an 80% confidence level(Tcritical=1.397, Tobs=0.86). The difference in total denitrification in these two systems was in the anoxic zone.

Anoxic denitrification in the IFAS system was much higher than in the control system, and the anoxic denitrification in the IFAS system was about 70% of the total denitrification. One reasonable assumption of this result was that denitrification in the control system was nitrification limited at this low MCRT, considering that very limited nitrification occurred in the control system.

COD Removal

All the profile tests showed that the effluent soluble COD from the IFAS system was less than from the control system. Paired t-test showed that for a 95% confidence level, the effluent COD in IFAS system was less than the effluent COD of the control system. The

Table 4.3. Comparision of Denitrification in the IFAS and Control Systems(g/day as nitrogen).

DATE	TOTAL DENIT.		AEROBIC DENIT.		ANOXIC DENIT.		DATA SET
	IFAS	CONTR.	IFAS	CONTR.	IFAS	CONTR.	
6/2/94	6.18	2.09	1.2	1.43	4.99	0.66	regular
6/7/94	6.04	2.09	1.08	1.49	4.96	0.6	regular
6/9/94	6.1	1.16	0.97	0.54	5.13	0.61	regular
6/17/94	5.35	2.28	1.31	1.54	4.04	0.74	regular
6/25/94	5.93	1.57	-0.89*	0.66	6.82	0.91	spiked
6/28/94	7.53	3.4	2.08	2.61	5.45	0.79	spiked
7/5/94	6.96	1.33	2.14	0.82	4.82	0.51	spiked
7/8/94	6.69	2.55	0.95	1.82	5.74	0.73	spiked

* Measurement variation

Table 4.4. Influent Total and Effluent Soluble COD During 1.7 day MCRT Experiment (mg/L).

	IFAS	IFAS	CONTROL	CONTROL	ΔCOD	ΔCOD	DATA
DAT	INF	EFF	INF	EFF	IFAS	CONTROL	
6/2/9	404	34	437	37	370	370	regular
6/5/9	N/A	35	440	44	N/A	396	regular
6/7/9	435	34	438	39	401	399	regular
6/9/9	417	27	411	36	390	375	regular
6/17/	495	32	495	40	463	455	regular
6/22/	463	45	451	59	418	392	spiked
6/25/	491	30	499	54	461	445	spiked
6/28/	463	24	460	36	439	424	spiked
Aver.	453	32.6	454	43.1	420.4	410.9	

observed t value for normal test was 3.12, for ammonia spiked tests was 3.16, while the critical t value was 2.132(for 4 degrees of freedom).

Although the IFAS system increased COD removal, the effluent COD difference between the two systems was very small compared to the influent COD concentration. At this MCRT, both systems were capable of good COD removal and the difference in COD removal between the IFAS and control systems was not statistically significant at a confidence level of 95%. Spiked COD tests were not performed in this series of experiments because it was very difficult to maintain the same DO in the aerobic reactor while increasing the COD, because the compressor could not supply enough air. Also, increasing the COD would have increased the MLSS at the same time, and it would have taken another several days to wash out the extra biomass. Table 4.4 lists the influent and effluent COD concentrations for all the profile tests.

Attached Growth and Liquid Retained in Captor Media

The quantity of attached growth on the Captor media at 1.7 day MCRT was determined and the results are presented in Tables 4.5 and 4.6. The units for Table 4.5 are mg attached growth/mg sponge. The reason for this unit is that the weight(volume) of clean sponge decreased with its wear over the duration of the experiment. As for Table 4.6, the units are mg attached growth/sponge. The attached growth increases from cell 1 to cell

Table 4.5. The Quantity of Attached Growth at 1.7 Day MCRT, the Units are mg biomass/ mg sponge

DATE	Cell 1	Cell 2	Cell 3*
6/21/94	0.374	0.443	0.734
6/26/94	0.369	0.413	0.609
7/9/94	0.384	0.413	0.475
7/16/94	0.423	0.448	0.558
8/15/94	0.384	0.437	0.479
Average	0.387	0.431	0.571

* Cell 3 did not squeezed at the beginning, after several measurement cell 3 also squeezed, this makes the attached growth in cell 3 steady decreased.

Table 4.6 Attached Growth of Biofilm in Captor Media at 1.7 Day MCRT, mg biomass/ mg sponge.

Time	Cell 1	Cell 2	Cell 3
6/21/94	74	94	164
6/26/94	71	88	139
7/9/94	76	86	104
7/16/94	85	94	120
8/15/94	72	87	106
Average	75	90	127

3,, and the attached growth in aerobic cell 3, were much higher than that in the other two aerobic cells. This was because at 3.1 and 2.4 day MCRT the attached growth in the sponges of aerobic cell 3 was very low, so the sponges were not squeezed during the experiment, while the sponges in other two aerobic cells were squeezed regularly. Sponges in aerobic cell 3 at 1.7 day also were not squeezed at the beginning, but after several measurements, the sponges were squeezed regularly and the attached growth in the sponges decreased throughout this MCRT. Steady state for the attached growth in cell 3 at this MCRT was not achieved.

The data for the liquid entrained into the biofilm are presented in Table 4.7. The liquid retained in the biofilm of cell 1 was the lowest while that in cell 3 was the highest, the same trend as with the attached growth. However, the liquid entrained in cell 3 was just 10% higher than that of aerobic cell 1. Therefore, it appears that squeezing the sponges did not affect the liquid entrained in the sponges.

The entrained liquid results presented in Table 4.7 show that in each cell at different times, the data was variable. This was because this measurement is experimenter related and is difficult for the same experimenter to get precise results. It is hard to decide when it's the right time to determine the wet weight. Only the average is meaningful.

Table 4.7 Liquid Entrained in the Captor Media in Each Aerobic Cell at 1.7 Day MCRT. The units are g/sponge.

Date	Cell 1	Cell 2	Cell 3
5/30/94	2.355	2.566	2.402
6/7/94	2.712	2.487	3.816
6/21/94	2.886	2.989	3.533
6/26/94	2.857	2.980	3.101
7/9/94	2.622	3.322	2.460
7/16/94	3.054	3.054	2.609
7/21/94	2.567	2.963	3.201
Average	2.733	2.909	3.017

Batch Test for Maximum Nitrification in Mixed Liquor and Biofilm Media

Table 4.8 presents the nitrification batch test results for the 1.7 day MCRT biomass, measured on July 21, 1994. The results show that at 1.7 day MCRT, the combined attached biomass and MLSS in the IFAS system had greater nitrification capacity than the MLSS in the control system and that the attached biomass in IFAS system aerobic cell 2 had greater nitrification capacity than attached biomass from the other two cells. The mixed liquor from both systems indicated no big difference in nitrification, although the MLSS of the IFAS system had a smaller rate than the MLSS of the control system. Figure 4.1 is the graph for this table.

MCRT 1.0 DAY EXPERIMENT

The 1.0 day MCRT experiment was started on August 21, 1994. The five influent and effluent steady state analysis samples were started on September 21, 1994. These five samples showed that effluent ammonia maintained a fairly constant value, indicating that steady state had been achieved, so profile testing started on October 7, 1994.

Unlike the 1.7 day MCRT when both regular and spiked test were performed, only regular testing was conducted at this MCRT. Related data are tabulated in Appendix B, 1.0 day MCRT data.

Table 4.8. Batch Nitrification Rate Test Results: 1.7 day MCRT Experiment. Ammonia Concentration as Nitrogen(mg/l).

TIME(h)	CMLSS	IMLSS	Aer1sp+IMLSS	Aer2sp+IMLSS	Aer3sp+IMLSS
Initial	30.8	20.0	20.8	20.8	21.6
T0	51.4	45.6	67.6	65	67.6
T1	47.5	42.2	60.1	55.6	60.1
T2	43.9	39.0	53.4	47.5	53.4
T3	42.2	37.5	52.4	45.6	51.4
T4	40.5	34.6	49.4	39	45.6
T6	36	32	43.9	32	43.9
Nitrification Rate (mg/L/h)	2.57	2.27	3.95	5.5	3.95

CMLSS: Mixed liquor from control system

IMLSS: Mixed liquor from IFAS system

Aersp1+IMLSS: IFAS system mixed liquor plus sponges from aerobic cell 1.

Aersp2+IMLSS: IFAS system mixed liquor plus sponges from aerobic cell 2.

Aersp3+IMLSS: IFAS system mixed liquor plus sponges from aerobic cell 3.

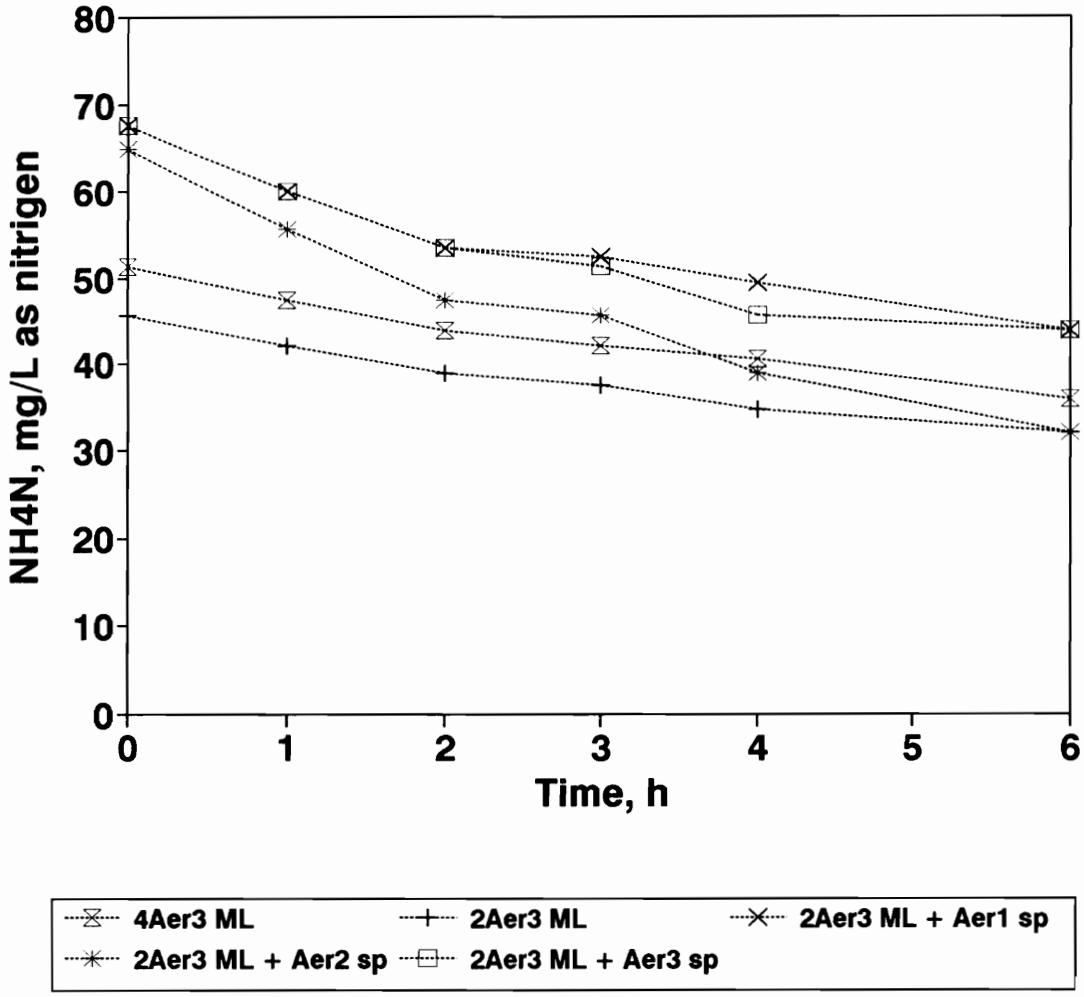

Figure 4.1. Batch Test for Sponges
Nitrification Rate, 1.7 day MCRT.

Steady State Analysis

Table 4.9 presents the total nitrification in the IFAS system during profile sampling plus measurements made after profile sampling. Statistical analysis yield an observed t value of 1.743, which was less than the critical t value for 95% confidence of 1.895. Steady state was believed to have been achieved and maintained throughout the experiment at this MCRT.

Nitrification Analysis

The effluent ammonia difference between the IFAS and control systems was very significant. Paired t test to evaluate the difference of effluent ammonia from these two systems was conducted and the observed t value of 20.22 was much higher than the critical t value of 2.132.. Table 4.10 presents the influent and effluent ammonia concentrations in the IFAS and control systems at this MCRT. The effluent ammonia concentrations from the IFAS system were about 25 mg/L less than the effluent ammonia from the control system. It was easily concluded that the IFAS system had better ammonia removal capacity than the control system. All the effluent ammonia concentrations in both systems were higher than 5 mg/L, so no spiked testing was needed at this MCRT because ammonia clearly was not a factor limiting nitrification.

Table 4.9 IFAS System Steady State Analysis for 1.0 Day MCRT. Nitrification during the Regular Profile Sampling Plus Measurements after Profile Sampling(g/day as nitrogen)

Date	Nitrification	Group
10/7/94	6.44	1
10/9/94	6.47	1
10/11/94	6.57	1
10/15/94	6.38	1
10/18/94	5.27	1
11/5/94	5.88	2
11/9/94	5.93	2
11/15/94	5.81	2
11/17/94	5.54	2
11/19/94	5.79	2
T observed	1.743	
T critical, 95% confidence	1.86	

Group 1: Regular Profile Samples.

Group 2: Tests after Profile Sampling.

Table 4.10. The Influent TKN and Effluent Ammonia Concentrations (mg/L) at 1.0 day MCRT.

	IFAS	IFAS	CONTROL	CONTROL	IFAS	CONTROL
DATE	INF	EFF	INF	EFF	ΔNH3	ΔNH3
10/7/94	57.1	15.4	57.1	44.7	41.7	12.4
10/9/94	54.2	17.5	54.2	45.8	36.7	10.4
10/11/94	57.3	17	55	43.1	40.3	11.9
10/15/94	61.8	14.6	64.3	37.7	47.2	26.6
10/18/94	53.2	18.9	55.3	42	34.3	13.3
Average	56.7	16.7	57.2	42.7	40	14.5

Table 4.11 presents total nitrification by the IFAS and control systems. A paired t test to evaluate the enhancement of nitrification in the IFAS system was conducted. The observed t value was 26.9, which was much higher than the critical t value at the 95% confidence level. The results show that nitrification in the IFAS system was around 6 g/day when there was no nitrification occurring in the control system.

Denitrification

The results in Table 4.12 shows that no denitrification occurred in the control system, as expected, because the system achieved no nitrification. The majority of the total denitrification in the IFAS system was anoxic denitrification. A paired t-test for aerobic denitrification in both systems showed no difference at the 80% confidence level (Tcritical=1.533, Tobs=1.45). Clearly, denitrification was limited by nitrification in the control system, but very little denitrification occurred in the aerobic zone of the IFAS system, possibly because good denitrification occurred in the anoxic zone of the IFAS system.

COD REMOVAL

Table 4.13 compares the influent and effluent COD of the IFAS and control systems. This table shows that the effluent COD from the control system was higher than that from the IFAS system. Paired t-test to evaluate the difference of the effluent COD from the

Table 4.11. Total Nitrification(g/day as nitrogen) in the IFAS and Control Systems: 1.0 day MCRT.

	Total Nitrification(g/d)			Effluent Ammonia (mg/L)	
DATE	IFAS	CONTROL	INFLUENT TKN(mg/L)	EFF ammonia (IFAS) mg/L	EFF ammonia (Control) mg/L
10/7/94	6.44	0	57.1	15.4	44.7
10/9/94	6.47	0	54.2	17.5	45.8
10/11/94	6.57	0	57.3	17	43.1
10/15/94	6.38	0	61.8	14.6	37.7
10/18/94	5.27	0	53.2	18.9	42
Average	6.23	0	56.7	16.7	42.7

Table 4.12. Denitrification in the IFAS and Control Systems(g/day as nitrogen): 1.0 day MCRT.

DATE	TOTAL DENIT(g/d)		ANOXIC DENIT. (g/d)		AEROBIC DENIT. (g/d)	
	IFAS	CONTROL	IFAS	CONTROL	IFAS	CONTROL
10/7/94	4.61	0	3.21	0	1.4	0
10/9/94	3.67	0	3.67	0	0	0
10/11/94	3.76	0	3.76	0	0	0
10/15/94	4.15	0	3.56	0	0.59	0
10/18/94	2.84	0	2.84	0	0	0
Average	3.81	0	3.41	0	0.40	0

Table 4.13. Influent and Effluent COD of IFAS and Control Systems(mg/L): 1.0 day MCRT

	Influent COD (mg/L)		Effluent COD (mg/L)		COD Removal (mg/L)	
DATE	IFAS	CONTROL	IFAS	CONTROL	ΔIFAS	ΔCONTROL
10/7/94	426	435	46	60	380	315
10/9/94	570	576	36	73	534	503
10/11/94	451	451	38	69	413	382
10/15/94	653	659	40	58	613	601
10/18/94	512	512	28	57	484	455
Average	522.4	526.6	37.6	63.4	484.8	463.2

IFAS and control systems showed that the effluent COD from the IFAS system was less than the effluent COD from control system at the 95% confidence level. The observed t value was 6.26, while the critical t value was 2.132.

Although statistically there were some difference for effluent COD between the IFAS and control systems, the difference was small compared with the influent. The advantage of media addition for total COD removal was not significant. No spiked COD tests were performed at this MCRT.

Attached Growth and Liquid Retained in the Captor Media

Tables 4.14 and 4.15 present the attached growth of biomass in the Captor media at the 1.0 day MCRT. The units for Table 4.14 are mg attached growth/ mg sponge, and for Table 4.15 are mg attached growth/ sponge. Both tables show that the attached growth in aerobic cells 1 and 2 was very similar, but the attached growth in cell 3 was much higher than the attached growth in the other two cells.

The results for the liquid retained in the Captor media at 1.0 day MCRT are presented in Table 4.16. The average liquid retained in the media increased from cell 1 to cell 3, but the increase rate was low. Liquid retained in the media of cell 3 was about 10% more than in the cell 1.

Table 4.14. Quantity of attached growth at 1.0 day MCRT, mg attached growth/mg sponge.

DATE	Aerobic cell 1	Aerobic cell 2	Aerobic cell 3
9/17/94	0.453	0.431	0.513
10/8/94	0.384	0.428	0.478
10/13/94	0.376	0.377	0.45
10/27/94	0.39	0.37	0.419
11/19/94	0.419	0.393	0.438
Average	0.40	0.40	0.46

Table 4.15 Attached Biomass Growth in Captor Media at 1.0 day MCRT, mg biomass / mg sponge.

Time	Cell 1	Cell 2	Cell 3
9/17/94	86	87	113
10/8/94	72	86	99
10/13/94	69	71	99
10/27/94	74	72	86
11/19/94	74	77	85
Average	75	78.6	96

Table 4.16. Quantity of Liquid Retained in Captor Media at 1.0 Day MCRT, g/sponge.

Date	Cell 1	Cell 2	Cell 3
9/8/94	3.035	3.1161	3.3683
9/17/94	2.893	2.9708	3.5954
10/18/94	2.987	3.2853	3.5284
10/13/94	3.093	3.1669	3.0891
10/27/94	3.109	3.1676	2.9451
11/19/94	2.7396	3.0001	3.0299
Average	2.9760	3.1178	3.2594

Batch Test for Maximum Nitrification Rates of Mixed Liquor and Biomass in Captor Media

The nitrification batch test results for the 1.0 day MCRT (October 25, 1994) are presented in Table 4.17. The combined attached biomass and MLSS in the IFAS system had greater nitrification capacity than the MLSS in the system. Most of the nitrification in the IFAS system was achieved by attached biomass. The nitrification rate in the sponges of aerobic cell 3 was just a little higher than that of the sponges in aerobic cell 2. Figure 4.2 is the graph for the Table 4.17 data. All the mixed liquor in this batch test came from IFAS aerobic cell 3.

MCRT 0.3 DAY EXPERIMENT

The 0.3 day MCRT experiment was started on November 22, 1994. Five influent and effluent samples were collected beginning on December 16, 1994. These 5 samples showed that the effluent ammonia concentrations were fairly constant, and profile testing was started on December 25, 1994. Like the 1.0 day MCRT experiment, only regular testing was conducted, i.e., no spiked testing was performed. The data obtained are presented in Appendix B 0.3 day MCRT data.

Table 4.17. Batch Test Nitrification Rate Results: 1.0 day MCRT Experiment, Ammonia Concentration (mg/L as nitrogen)

TIME(h)	IMLSS	Aer1sp+IMLSS	Aer2sp+IMLSS	Aer3sp+IMLSS
Initial	12.3	17	15.7	15.7
T0	38.2	60.5	54.9	53.9
T1	36.7	57.2	50.7	48.7
T2	35.2	53.9	44.9	44
T3	33.8	50.7	42.3	39.8
T4	33.2	48.7	38.2	36.7
T6	33.0	45	34.5	33.2
Nitrification Rate (mg/L/h)	0.87	2.58	3.4	3.45

IMLSS: IFAS system mixed liquor.

Aersp1+IMLSS: IFAS system mixed liquor plus sponges from aerobic cell 1.

Aersp2+IMLSS: IFAS system mixed liquor plus sponges from aerobic cell 2.

Aersp3+IMLSS: IFAS system mixed liquor plus sponges from aerobic cell 3.

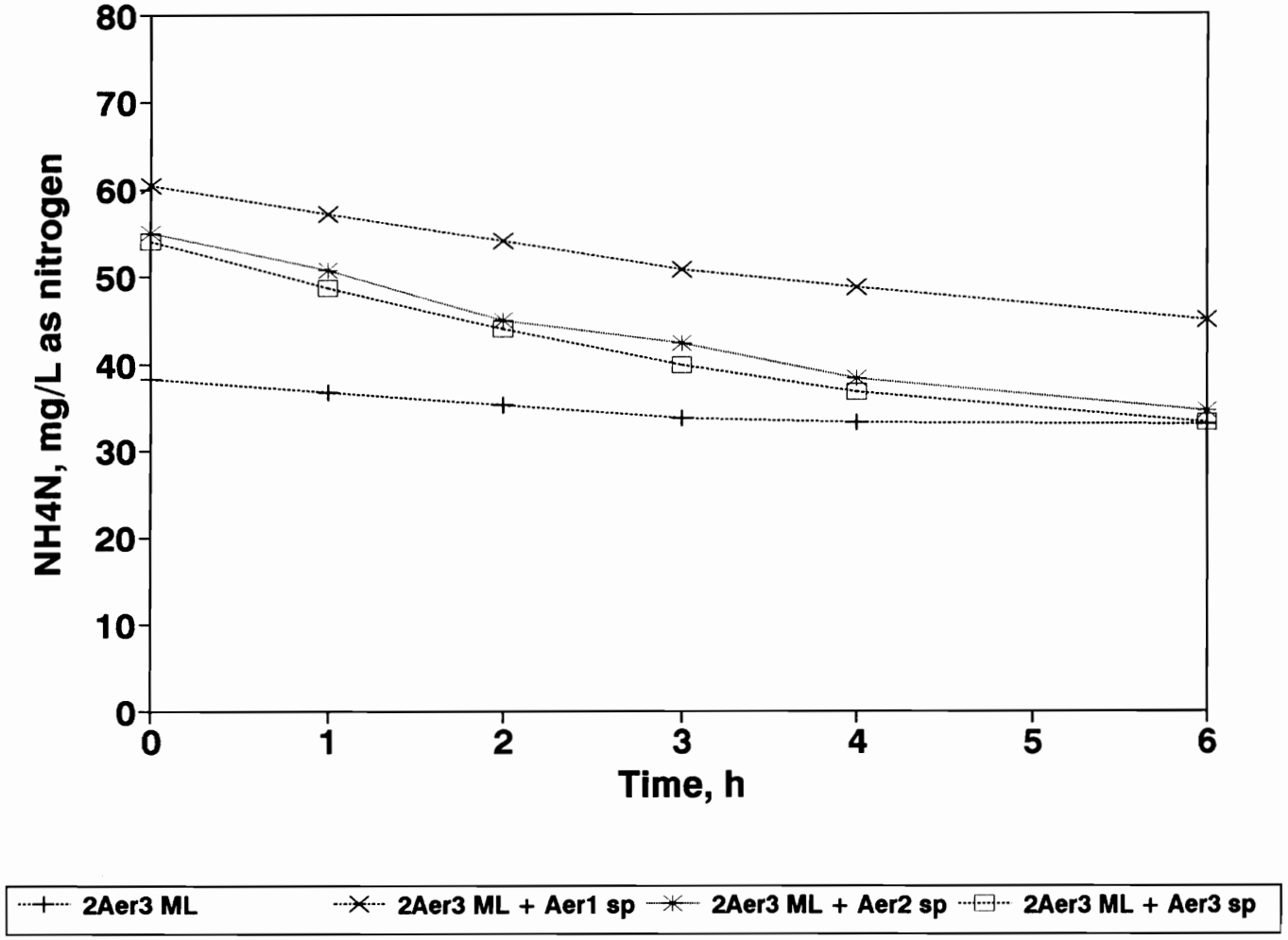

Figure 4.2. Batch Test for Sponges
Nitrification Rate, 1.0 Day MCRT.

Steady State Analysis

Table 4.18 presents the nitrification results from the IFAS system during the regular profile sampling period and the 5 samples analyzed after profile sampling. Statistical analysis shows that there was no difference between these two groups of data, thus demonstrating that steady state had been achieved and was maintained throughout experimentation at this MCRT.

Nitrification

The influent and effluent ammonia concentrations from the IFAS and control systems are presented in Table 4.19. At this MCRT, the control effluent ammonia was numerically close to those observed during the 1.0 day MCRT experiment. This was because at these small MCRTs, no nitrification occurred in the control system. However the IFAS system effluent ammonia concentrations were much higher at the 0.3 day MCRT than at the 1.0 day MCRT, showing that a lot of nitrifiers were lost from the IFAS system when the MCRT was decreased. Although the effluent ammonia concentrations from the IFAS system increased greatly in this MCRT, paired t-test for the effluent ammonia from the IFAS and control systems showed that at a 95% confidence level, the ammonia effluent concentrations from the IFAS system were less than the effluent ammonia concentrations from the control system. The observed t value was 7.89 while the critical t value was 2.132.

Table 4.18 IFAS System Steady State Analysis for 0.3 Day MCRT. Nitrification during the Regular Profile Sampling and Tests After Profile Sampling (g/day as nitrogen) in the IFAS System.

Date	Total Nitrification	Data Group
12/25/94	2.53	1
12/27/94	2.36	1
12/29/94	2.37	1
12/31/94	3.28	1
1/2/95	2.72	1
1/8/95	3.83	2
1/10/95	2.11	2
1/12/95	2.45	2
1/14/95	2.84	2
1/16/95	3.42	2
T observed	1.205	
T critical, 95% confidence	1.86	

Group 1: Regular Profile Samples

Group 2: Samples Collected after Profile Sampling

Table 4.19. Influent TKN and Effluent Soluble Ammonia Concentrations (mg/L as nitrogen) in IFAS and Control Systems: 0.3 day MCRT

	Influent TKN (mg/L)		Eff. Ammonia (mg/L)		N Removal. (mg/L)	
DATE	IFAS	CONTROL	IFAS	CONTR	ΔIFAS	ΔCONTROL
12/25/	52.4	53.4	32.0	37.5	20.4	15.9
12/27/	49.4	49.4	27.4	35.3	22.0	14.1
12/29/	49.4	49.4	28.5	37.5	20.9	11.9
12/31/	46.5	46.5	23.4	34	23.1	12.5
1/2/95	50.8	51.4	23.8	36	27	15.4
Avg.	49.7	50.0	27.0	36.1	22.7	13.9

The total nitrification results from the two systems at the 0.3 day MCRT are given in Table 4.20. There was no nitrification in the control system and the nitrification rate in the IFAS system was greatly decreased compared to performance at an MCRT of 1.0 day.

Denitrification

Because the nitrification rate was very low in both systems, the denitrification in both systems was also very low. Almost no aerobic denitrification was measured in the two systems, and nearly all of the denitrification in the IFAS system was anoxic denitrification. Table 4.21 presents denitrification results in the anoxic zone, the aerobic zone and total denitrification.

COD Removal

Table 4.22 presents the influent and effluent COD concentrations observed at 0.3 day MCRT. Paired t-test on the effluent COD concentrations from the IFAS and control systems at this MCRT showed that for a 95% confidence level, the effluent COD from the IFAS system was lower than from the control system.(Tcritical=2.132, Tobs=8.81)

Attached Growth

The quantities of attached growth measured at 0.3 day MCRT are presented in Table 4.23 and Table 4.24. The attached growth increased from cell 1 to cell 3.

Table 4.20. Total Nitrification (g/day as nitrogen) in the IFAS and Control Systems: 0.3 day MCRT. The Units for Influent TKN and Effluent Ammonia are mg/L.

	Total Nitrification			Effluent Ammonia (mg/L as nitrogen)	
DATE	IFAS (g/day)	CONTROL (g/day)	INF TKN	EFF Ammonia(IFAS)	EFF Ammonia (Control)
12/25/94	2.53	0	52.4	32	37.5
12/27/94	2.36	0.08	49.4	27.4	35.3
12/29/94	2.37	0	49.4	28.5	37.5
12/31/94	3.28	0	46.5	23.4	34
1/2/95	2.72	0	50.8	23.8	36
Average	2.65	0.02	49.7	27.0	36.1

Table 4.21. Denitrification in the IFAS and Control systems for 0.3 day MCRT(g/day as nitrogen).

DATE	TOTAL DENIT.		ANOXIC DENIT.		AEROBIC DENIT.	
	IFAS	CONTROL	IFAS	CONTROL	IFAS	CONTROL
12/25/94	0.49	0	0.49	0	0	0
12/27/94	1.12	0	1.06	0	0.06	0
12/29/94	0.87	0	0.87	0	0	0
12/31/94	1.01	0	1	0	0.01	0
1/2/95	1.83	0	1.13	0	0.7	0
Average	1.06	0	0.91	0	0.15	0

Table 4.22 Influent and Effluent COD Concentrations (mg/L) During the 0.3 day MCRT Experiment.

	Influent		Effluent		COD Removal	
DATE	IFAS	CONTROL	IFAS	CONTROL	ΔIFAS	ΔCONTROL
12/25/94	491	472	52	72	439	400
12/27/94	386	398	46	71	340	327
12/29/94	455	433	54.9	78	400	355
12/31/94	447	399	35	61	412	338
1/2/95	467	474	45	83	422	391
Average	449	435	46.6	73	402.4	362

Regarding the liquid entrained in the media, the results presented in Table 4.25 shown that, unlike the 1.7 day and 1.0 day MCRT results, the liquid entrained in the Captor media increased from cell 1 to cell 3. At this MCRT, the liquid entrained in the sponges of cell 2 contained the least while cell 3 had the highest amount. This may be attributed to the small data set at this MCRT(only 4 observation), and the inherent variability of this measurement.

Batch Test for Maximum Nitrification

The nitrification batch test results for the 0.3 day MCRT biomass are presented in Table 4.26. At this MCRT, the attached biomass in aerobic cell 3 had better nitrification capacity than those from aerobic cells 1 and 2. Almost no nitrification was accomplished by the mixed liquor. Figure 4.3 is a graph for this data.

Table 4.23. Quantity of attached growth at 0.3 day MCRT, mg attached growth/mg sponge.

DATE	Aerobic cell 1	Aerobic cell 2	Aerobic cell 3
12/26/94	0.422	0.441	0.467
1/2/95	0.395	0.425	0.432
1/8/95	0.45	0.452	0.498
1/13/95	0.456	0.485	0.572
Average	0.43	0.45	0.49

Table 4.24. Attached Growth in Captor Media at 0.3 Day MCRT. mg attached growth/sponge.

Date	Aerobic cell 1	Aerobic cell 2	Aerobic cell 3
12/26/94	81	88	96
1/2/95	79	81	90
1/8/95	88	87	104
1/13/95	85	93	119
Average	83	87	102

Table 4.25. Quantity of Liquid Retained by Captor Media at 0.3 Day MCRT, g/sponge.

Date	Cell 1	Cell 2	Cell 3
12/26/94	3.1863	3.0206	3.3388
1/2/95	2.5426	2.6876	3.0917
1/8/95	3.1931	2.7107	3.1122
1/13/95	2.9603	2.9239	3.1256
Average	2.9706	2.8357	3.1671

Table 4.26. Batch Test Nitrification Rate Results: 0.3 Day MCRT, Ammonia Concentration (mg/L as nitrogen).

TIME(h)	IMLSS	Aersp1+IMLSS	Aersp2+IMLSS	Aersp3+IMLSS
T0	30.9	31.8	28.8	25.8
T1	30.5	31.4	26.8	23.3
T2	30.3	30.3	25.8	21.1
T3	29.4	27.9	24.8	18.3
T4	28.5	26.8	23.3	15.6
T5	27.9	25.8	22	12.1
Nitification Rate (mg/L/h)	0.6	1.2	1.24	2.74

IMLSS: IFAS system mixed liquor.

Aersp1+IMLSS: IFAS system mixed liquor plus sponges from aerobic cell 1.

Aersp2+IMLSS: IFAS system mixed liquor plus sponges from aerobic cell 2.

Aersp3+IMLSS: IFAS system mixed liquor plus sponges from aerobic cell 3.

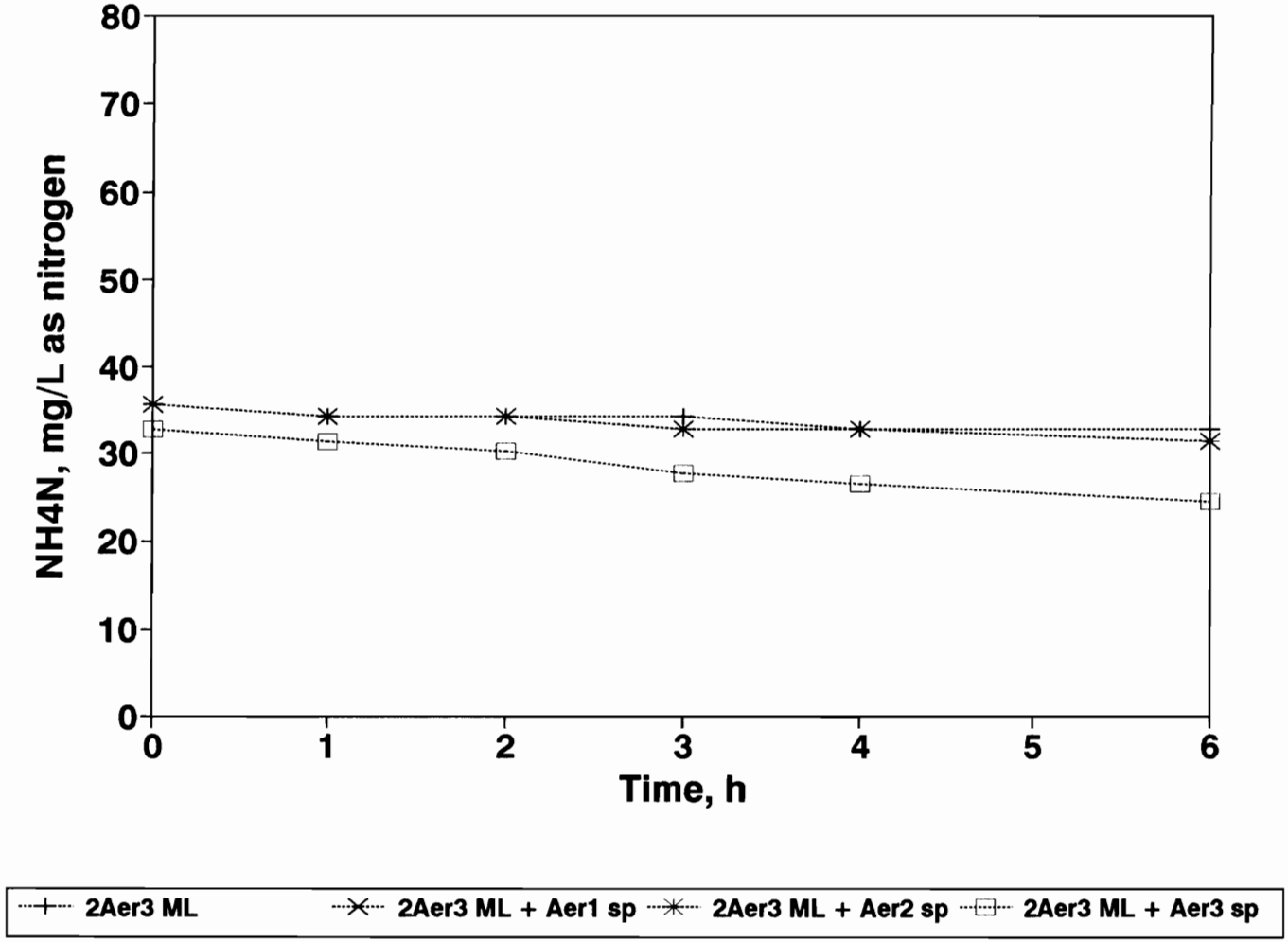

Figure 4.3. Batch Test for Sponges
Nitrification Rate, 0.3 Day MCRT.

CHAPTER 5

DISCUSSION

The results presented in Chapter 4 demonstrated that the integration of Captor media into activated sludge can substantially improve nitrification even at very small MCRTs. Further analysis and discussion of the experimental results, and their significance for biological nutrient removal(BNR) wastewater treatment, will be presented in this chapter.

Effect of Soluble COD on the Maximum Nitrification Rate of Fixed Film Biomass

Figure 5.1 indicates that the nitrification rate of the biomass on the sponges was a function of the SCOD concentration for all the batch nitrification tests(from 3.1 day to 0.3 day MCRT). The figure shows that when the SCOD concentration was larger than 10 mg/L, the maximum nitrification rate decreased as the SCOD concentration increased. Other data indicates that the maximum nitrification rate was a linear function of ammonia when the SCOD concentration was less than 10 mg/L, as shown by Figure 5.2.

SYSTAT nonlinear regression was used to fit equations for these two conditions. For SCOD concentrations larger than 10 mg/L, the following equation was obtained:

$$\mathrm{Qm} = \frac{A \times K_s}{K_s + SCOD - 10} \qquad (5\text{-}1)$$

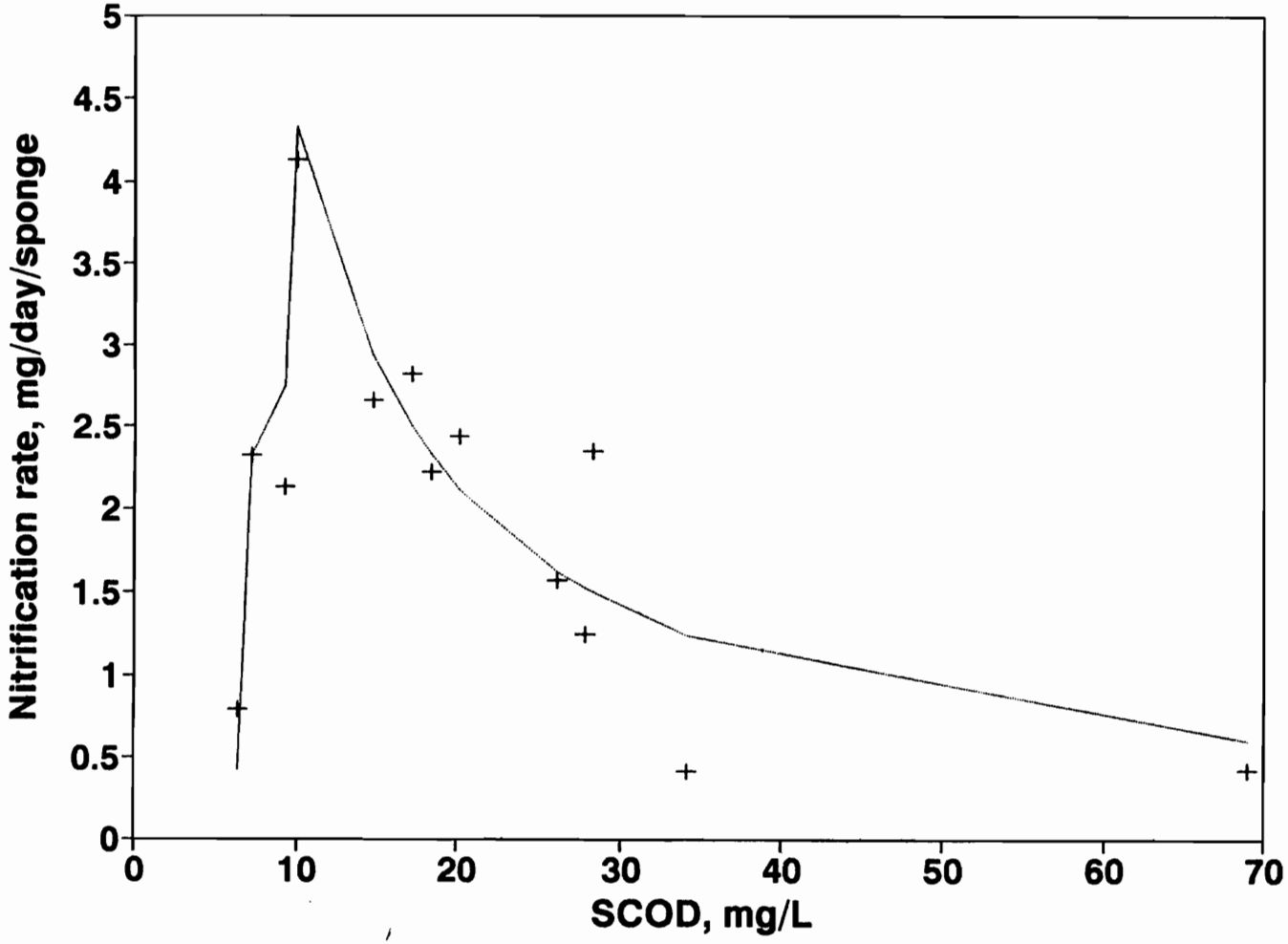

Figure 5.1. Nitrification Rate on Sponges.

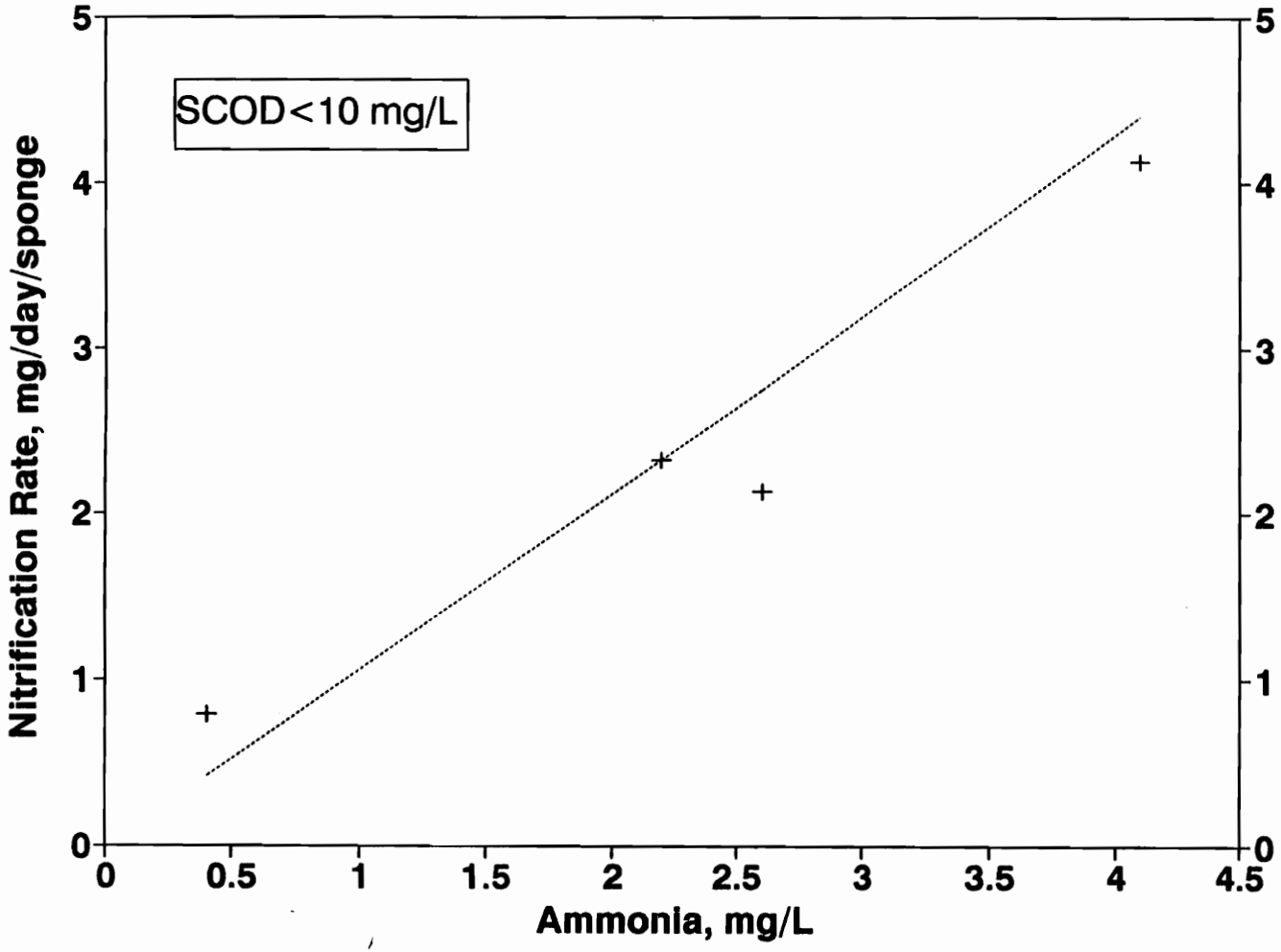

Figure 5.2. Nitrification Rates on Sponges.

where: Qm : Maximum Nitrification Rate on Sponges

A : 4.4 mg ammonia nitrified/sponge/day.

Ks : 9.4 mg/L SCOD.

The r^2 of the observations was 0.97, and the corrected r^2 was 0.90. The high value of r^2 indicated that this equation fit the data very well. For SCOD concentration less than 10 mg/L, the equation of best fit was found to be:

$$Qm = 1.055 \times \text{ammonia concentration} \qquad (5\text{-}2)$$

The r^2 for this equation was 0.98.

From equations 5-1 and 5-2, it can be deduced that the optimum location for media addition to enhance nitrification was a function of available COD and ammonia within the aerobic zone. High concentrations of COD apparently caused conditions that inhibited the growth of nitrifiers by promoting the growth of heterotrophic bacteria. Available ammonia was also a factor which influenced the competition between the nitrifiers and the heterotrophs, but it was the dominant factor only when the SCOD concentration was less than 10 mg/L.

IFAS System: An Economic Choice for Wastewater Treatment Plant Upgrading

Effluent Ammonia and Nitrification

Most of the full scale waste water treatment plants in the United States have good performance for COD removal, but the majority of them were not designed for nitrogen removal when they were built and consequently have insufficient volume and/or setting capacity for complete nitrification and nitrogen removal. If these plants can be upgraded without additional construction, or minimize construction, using IFAS technology, then the technology become the upgrading methodology of choice, based on economical considerations..

Simultaneous nutrient and COD removal in traditional activated sludge systems generally requires higher biomass retention times, which must be obtained either by higher MLSS concentrations and/or by larger reactor volume. The latter option is common and it requires substantial capital cost. Furthermore, in some plants where space is limited, it is not a feasible option.

Utilization of IFAS technology potentially can reduce or eliminate the need for building new reactors and/or clarifiers. The technology permits an increase in the total biomass in the system by promoting biomass growth on media which does not leave the reactor.

Thus, the amount of biomass in the aerobic zone is increased, which increases the aerobic and total MCRTs thereby promoting nitrification, but the solids load to the clarifiers increases very little or not at all. Throughout this research, the total biomass in the IFAS system is 5 to 25 times more than the total biomass in the control system and the solids load to the clarifiers of IFAS system was less than the solids load to the clarifiers in control system.

As noted in Chapter 4, effluent ammonia from the IFAS system was significantly lower than from the control system. Paired t tests were conducted to analyze the difference of effluent ammonia from the IFAS system and control system. The difference was clearly statistically significant, as shown in Table 5.1. The results presents in Chapter 4 here and Jensen's thesis show that complete nitrification could not be maintained in a conventional BNR activated sludge system at an MCRT of 3.1 day , but could be maintained in an IFAS Captor system down to an MCRT of only 1.7 days.

Paired t tests also were conducted to evaluate the enhancement of nitrification by the IFAS system compared to the control system. The results are presented in Table 5.2 . The observed t value is much higher than the critical t value which demonstrates the significant difference of nitrification between the IFAS and control systems. Overall, the Captor media IFAS system greatly increased the nitrogen removal capacity of the traditional activated sludge system in low MCRTs. At 1.7 day MCRT, the total nitrification in the IFAS system was about 4 times the total nitrification in the control system. At 1.0 day

Table 5.1. Statistical Evaluation of Effluent Ammonia from the IFAS and Control Systems.

MCRT	Degrees of Freedom	t values (Normal)	t values (Spiked)
1.7	3	60.38	9.5
1.0	4	20.22	NA
0.3	4	7.89	NA

NA: Not available

Null Hypothesis Hi = Hc
Alternative Hypothesis Hi > Hc

Critical t value for 95% confidence

$t_{3,0.05} = 2.353$ $t_{4,0.05} = 2.132$

If observed t value larger than critical t value, choose alternative hypothesis, else choose null hypothesis.

Table 5.2 Statistical Evaluation of Nitrification in the IFAS and Control Systems.

MCRT	Degrees of Freedom	t value (Normal)	t value (Spiked)
1.7	3	109	26.2
1.0	4	26.9	NA
0.33	4	6.41	NA

NA: Not available
t values for one sided t test:

$t_{3,0.05} = 2.353$ $t_{4,0.05} = 2.132$

and 0.3 day MCRT, almost no nitrification found in control system but the IFAS system still maintain some nitrification.

COD Removal

A Paired t test was conducted to evaluate the enhancement of COD removal by the IFAS system. The results are presented in Table 5.3

Data presented in Table 5.3 demonstrate that the IFAS system increased the SCOD removal capacity of the traditional activated sludge system. Throughout this research, the effluent SCOD from IFAS system was about 20 mg/L less than the effluent ammonia from the control system. The lower the MCRT, the higher the difference. This result is believed to occur because, there is an increase of total biomass in the IFAS system relative to the control system, which increases the effective total MCRT. It is generally accepted that an increase in MCRT result in greater removal of COD, i.e., a lower effluent COD concentration.

Denitrification

With domestic sewage, denitrification can occur only when nitrification has occurred first. The results given in Chapter 4 showed that total denitrification in the IFAS system was

Table 5.3 Statistical Evaluation of Effluent SCOD from IFAS and Control Systems.

MCRT	Degrees of Freedom	t value (Normal)	t value (Spiked)
1.7	3	3.12	3.16
1.0	4	6.26	NA
0.3	4	8.81	NA

NA: Not available

Null Hypothesis $H_i = H_c$
Alternative Hypothesis $H_i > H_c$

Critical t value for 95% confidence

$t_{3,0.05} = 2.353$ $t_{4,0.05} = 2.132$

If observed t value larger than critical t value, choose alternative hypothesis, else choose null hypothesis.

higher than total denitrification in the control system, but there was not a significant difference between the aerobic denitrification in the two systems.

From data listed in Appendix B, it can be seen that the NOx-N concentrations in both anoxic cells for the IFAS and control systems were less than 0.3 mg/L, indicating that complete denitrification had occurred in the first anoxic cell of both systems. Thus, the failure of the control system to achieve denitrification could only be attributed to its failure to achieve nitrification in the first place, not because denitrification was less efficient in the control system.

Sludge Production and Sludge Yield

Another potential advantage of the IFAS systems is that they can increase the total biomass in the system without significantly increasing the sludge load to the second clarifiers. This is possible because the higher effective MCRT results in a lower observed sludge yield. Table 5.4 presents the results of sludge production and yield data in the IFAS and control systems for each MCRT. This table shows that sludge production and sludge yield in the IFAS system was lower than in the control system at every MCRT. This may contribute to two factors(Sen, 1995):

1: an increase in the quantity of COD stabilized by the attached growth, as demonstrated by the low effluent COD in the IFAS system.

2: an additional COD stabilization in the anoxic zones with an increase in the difference

Table 5.4. Comparision of Sludge Production and Yield in the IFAS and Control Systems. units for sludge production is g/day, for sludge yield is g biomass produced/g COD consumed.

MCRT (day)	sludge prod (IFAS)	sludge yield (IFAS)	sludge prod. (control)	sludge yield (control)	sludge prod. difference	sludge yield difference
1.7	34.48	0.36	39.16	0.37	13.6%	2.8%
1.0	36.29	0.354	41.66	0.38	12.9%	7.3%
0.3	28.35	0.32	30.46	0.4	7.9%	25.0%

in nitrification between the two systems.

Mixed Liquor Suspended Solids(MLSS)

Table 5.5 presents the average MLSS and MLVSS concentrations in the aerobic zones of the IFAS and control systems at different MCRTs. The MLSS and MLVSS concentrations in the control system were larger than those in the IFAS system, the difference is from 1% to 17.6%. This means that an IFAS system can improve the performance of an activated sludge system by increasing the total biomass in the reactor without increasing the MLSS concentration of the mixed liquor. Therefore, the load to the clarifiers will not increase even though the effective MCRT has been increased.

Discussion about Captor Media

The results in Chapter 4 and previous discussion have demonstrated that Captor media is a potentially good choice for upgrading a traditional single sludge BOD removal activated sludge system to a simultaneous BOD, nutrient removal system. The purpose of the subsequent discussion highlight important Captor media characteristics such as: the quantity of attached growth, the amount of water retained by Captor media, the influence of media addition on reactor volume, and the life span of Captor media in a BNR reactor.

Table 5.5 Comparision of IFAS and Control Aerobic Zone MLSS and MLVSS Concentrations at Different MCRTs.

MCRT	MLSS (IFAS)	MLSS (CONTROL)	MLSS Differen.	MLVSS (IFAS)	MLVSS (CONTROL)	MLVSS Difference
1.7	945	1024	8.4%	870	979.4	12.6%
1.0	596	602	1.0%	500	512	2.4%
0.3	136	160	17.6%	114	134	17.5%

Attached Biomass Vs Suspended Biomass

Results presented in Chapter 4 showed that the amount of attached growth biomass on the Captor media was substantial. Additional data presented in Table 5.6 shows that the attached growth biomass was from 5 to 25 times the suspended biomass. Thus, the suspended biomass was just a small fraction of the total biomass in the IFAS Captor media system.

Table 5.6 also shows that the attached biomass in the system from 1.7 day MCRT to 0.3 day MCRT do not change very much, the performance of the system changed a lot. The effluent ammonia at 0.3 day MCRT was almost 10 times the effluent ammonia observed at 1.7 day MCRT. This demonstrates that the quantity of biomass in the system is not the only parameter which determines the performance of the system. The activity and composition of the biomass in the system is more important. The composition of bacteria in the biomass is related to COD and DO, as is the activity of the biomass.

As mentioned in the literature review, the declining use of fixed film systems in the 60-70's and the uncertainty of results from early research on IFAS systems was because the media used at that time could not support enough biomass growth. In contrast, it has been shown that Captor media can support large amount of biomass, but this huge biomass growth also can cause some trouble. It increases the weight of the media in the reactors,

Table 5.6 Concentrations of Attached Biomass and Suspended Biomass at Each MCRT.

mg/L

MCRT	Attached	Suspended	Total	Suspended/Total(%)
1.7 day	3800	945	4745	20%
1.0 day	3150	596	3746	16%
0.3 day	3800	136	3936	4%

which requires more air supply or turbulence to keep the media suspended in the reactor. Throughout this research, hand squeezing of the Captor media in the IFAS system was performed to remove excess biomass from the media, and mechanical squeezing would be necessary in full scale applications to prevent the biomass from becoming too heavy. Mitta(1994) pointed out that the amount of attached growth on Ringlace media was a function of the available SCOD. The higher the SCOD concentration, the more the attached growth. This was not true for Captor media. Table 5.7 presents the attached growth in each cell at each MCRT. From cell 1 to cell 3, the attached growth increased while the SCOD concentration decreased.

Throughout this experiment, the air supply decreased from cell 1 to cell 3, and this can explain why the attached growth increased from cell 1 to cell 3. A physical factor, the turbulence of the mixed liquor, is the major factor which decides the amount of attached growth on the media, but the activity of the attached biomass is related to the substrate concentrations in the mixed liquor; i.e., DO, SCOD, and ammonia.

The Life Span of Captor Media in IFAS System

The clean weight of the sponges decreased throughout the test. Table 5.8 presents the weight of the clean sponges at each MCRT. The decrease of the clean weight of the sponges was not significant throughout the test. Possibly because of the short test time, about 8 months, or because of the replacement of square sponges with round sponges,

Table 5.7 The average of the attached growth in each cell at every MCRT(mg/sponge).

MCRT(day)	Cell 1	Cell 2	Cell 3*	Average
1.7	75	90	127	98
1.0	75	78	96	83
0.33	83	87	102	91
Average	77.7	85	108.3	90.7**

* Did not routinely squeeze sponges

** Overall average

Table 5.8 Clean Weight of Sponges Throughout the Test. g/sponge

MCRT	Cell 1	Cell 2	Cell 3	Average
1.7	0.1947	0.2088	0.2244	0.2090
1.0	0.1836	0.1946	0.2094	0.1958
0.3	0.1934	0.1937	0.2069	0.1977
Average	0.1906	0.1990	0.2135	0.2006*

* Overall average

which decreased the propensity to wear. Captor media demonstrated a good potential life span in the experimental IFAS system. The life span data in this research is not sufficient to make general conclusion because of the short experiment time and also the inaccurate of the measurement of the weight of the Captor media.

Volume Replaced by Media Addition

The addition of Captor media into the aerobic zone of an IFAS system will reduce the liquid HRT of the aerobic zone, because the media retains water which is not displaced by the forward flow during operation. Table 5.9 presents the average liquid retained by Captor media at each MCRT. The value here is much higher than the actual solid volume of the Captor media, which is just 0.223 g/sponge. The volume displaced by the media can be mainly contributed to the liquid retained in the media, not the solid volume of the sponges. Table 5.10 presents the results of the volume replaced by media addition, which is : volume displaced by media/total aerobic volume. The results were very consistent. The actual aerobic volume is about 88% of the total aerobic volume, and this value is not related to the MCRT.

Table 5.9 The Average Liquid Retained by Each Cell at Each MCRT. g/sponge.

MCRT	Cell 1	Cell 2	Cell 3	Average
1.7	2.733	2.909	3.017	2.886
1.0	2.976	3.118	3.259	3.118
0.3	2.971	2.836	3.167	2.991
Avg.	2.898	2.955	3.147	2.998

Table 5.10 Volume Replaced by the Media Addition. media volume/total aerobic volume.

MCRT	Cell 1	Cell 2	Cell 3	Average
1.7	0.105	0.112	0.116	0.111
1.0	0.114	0.120	0.125	0.120
0.3	0.114	0.109	0.122	0.115
Average	0.111	0.114	0.121	*0.115

* Overall Average

CHAPTER 6

CONCLUSIONS

1. The integration of Captor media into the aerobic zone of a single sludge BNR activated sludge system can enhance nitrification, and the enhancement increases with decreases in MCRT below the critical MCRT for nitrifiers.

2. The nitrification rate in the Captor media integrated fixed film activated sludge aerobic reactors (IFAS) was a function of the ammonium concentration when the soluble COD (SCOD) concentration was less than 10 mg/L, however, when the soluble COD concentration higher than 10 mg/L, the nitrification rate was a function of the SCOD concentration in the IFAS zone. Mathematical equations were developed to describe both of these relationships.

3. Denitrification in the IFAS system was greater than in the control system because of greater nitrification, but there was little difference in denitrification in the IFAS aerobic zones of the two systems.

4. The amount of attached growth on the Captor media was not strongly related to the SCOD in the aerobic IFAS zone, but strongly related to the turbulence of the mixed liquor.

5. The reactor volume occupied by the Captor media which affected the HRT in the reactor was about 10 times greater than the water physically displaced by the sponges. This is because the sponges retain water that is not displaced by the forward flow during operation.

6. The total biomass in the IFAS system was 5 - 25 times the total biomass in the control system, because of the biomass growing on the media, yet the mixed liquor MLSS concentration in the IFAS system was less than the MLSS concentration in the control system.

7. Lower sludge production and sludge yield were observed in the IFAS system, as one would expect because of the higher effective MCRTs.

8. The effluent COD from the IFAS system was about 20 mg/L less than the effluent COD from the control system at all MCRTs for an influent COD of around 450 mg/L.

9. The clean sponge weight decreased throughout the test, but the rate of decrease was low, about 6% in 8 months. This calculates to a 9% replacement rate per year, i.e., complete replacement in slightly eleven years. It was observed that sponges with rounded corner undergo less wear than sponges with square corner, at least during the early stage of wear.

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Appendix 1

Derivation of the Formula Used to Calculate Suspended Growth Mean Cell Residence Time(MCRT) for 1.7 day MCRT

θc = Mass of Cells in the Reactor/Mass of Cells Wasted per day

$$= \frac{VX}{QwX + (Q - Qw)Xe} \qquad (1)$$

Where:

V: Volume of the Mixed Liquor in the Reactor.

For IFAS system: V=Vo(1-BVF)

For control system: V=Vo

Vo is the volume of the aerobic reactor.

X: MLSS in the aerobic cell

Qw: Sludge wasting rate

Q: Flow rate of the influent

Xe: Effluent Suspended solids concentration

Solve equation (1) for Qw, which is

$$Qw = \frac{VX - \vartheta_c \times Q \times X_e}{\vartheta_c X - \vartheta_c X_e}$$

One assumption for this equation is that the MLSS concentration in the reactor at different cell is exactly the same. Unfortunately, this is not the case, the retutn activated sludge is returned to anoxic zone in this VIP system. The MLSS in anaerobic zone is less than the MLSS at other cells. But the anaerobic volume is just 17% of the total volume, and it is impossible for exact hand waste, this equation can be used for this experiment.

A.2 Derivation of the Formula for Calculating the Wasting Rate at 1.0 day MCRT.

At 1.0 day MCRT, sludge was waste from return activated sludge(RAS) line, so first calculate the MLSS at RAS line.

Some simple assumptions:

Qw = 30 L/day

Qr = 216ml/min = 311 L/day

Qinf = 207.6 L/day

where Qw is the wasting rate from RAS line, it is believed that the overall waste volume is higher than this. Qr is the flow rate of the return activated sludge. Qinf is the influent flow rate. The MLSS of the RAS is:

$$Xr = \frac{(Qw + Qr + Q\text{inf}) \times X - Q\text{inf} \times Xe}{Qw + Qr} \qquad (3)$$

Where:

X: MLSS in the reactor.

Xe: MLSS in the effluent.

The actual volume of water to be wasted from RAS line is:

$$Qwr = \frac{69.2 \times (1 - mediafraction) \times X - Q\text{inf} \times Xe \times \theta_c}{Xr \times \theta_c} \qquad (4)$$

Where:

θ_c: Aerobic bacteria retention time

The effluent water MLSS is much smaller than the mixed liquor in the reactor. The ratio of MLSS at RAS and reactor Xr/X is around 1.6. The actual hand waste from reactor is:

$$Qhw = (Qwr - 30) \times 1.6 \qquad (5)$$

A.3 Procedure for Calculating Nitrification in Aerobic Cells

$$\textbf{Nitrification} = (TKN_{in} - TKN_{out}) \times \textbf{FlowRate/1000.} \quad (6)$$

The unit for this nitrification is g/day. This is not a exact equation, because we have some TKN in waste sludge, but this is very small compare with the total nitrification.

A.4. Procedure for Denitrification Calculation

NOx-N concentration in the nitrate recycle(mg/L) = NO_3-N + NO_2-N in aerobic cell 3.

NOx-N concentration in the return activated sludge recycle = NO_3-N + NO_2-N in effluent.

NOx-N entering the anoxic zone (g/day) = NOx-N concentration in the nitrate recycle×Flow rate of nitrate recycle + NOx-N in the return activated sludge recycle×Flow rate of return activated sludge.

NOx-N leaving the anoxic zone(g/day) = NOx-N in the anoxic zone 2 × Flow rate in anoxic zone.

Denitrification in the anoxic zone(g/day) = NOx-N entering the anoxic zone - NOx-N leaving the anoxic zone.

Total denitrification in the system(g/day) = Total nitrification - NOx-N in the effluent.

Denitrification in the aerobic zone(g/day) = Total denitrification - Denitrification in anoxic zone.

A.5. Sludge Production and Sludge Yield.

Sludge production(g/day) = Sludge waste.

COD consumed every day = Influent COD×Flow rate - Effluent COD×Flow rate.

Sludge yield = Sludge production/COD consumed.

1.7 DAY RAW DATA

17 D AEROBIC MCRT
TRAIN 2 IFAS-SPONGE
TRAIN 4 CONTROL

TRAIN	DATE	SPIKE?	PROFILE	INF TKN	EFF NH3	SLDG N	SLDG P	NITR-1	NITR-2	DENITR	SLUDGE PROD	SLUDGE YIELD	ANX DN	AER DN	FRACTION AER DN	Q Inf	Q Inf /day	PERCENT NITR
2.00	02 JUN	NO	SHORT	66.80	6.30			8.07	7.97	6.16	39.21		4.89	1.20	0.19	72.00	207.36	0.89
2.00	05 JUN	NO	SHORT															
2.00	07 JUNE	NO	MEDIUM	63.80	3.80	0.12	0.014	7.93	7.82	6.04	35.71		4.98	1.06	0.16	72.00	207.36	0.90
2.00	09 JUN	NO	MEDIUM	62.00	1.60	0.11	0.015	8.01	7.83	6.19	31.88		5.13	0.97	0.16	72.00	207.36	0.89
2.00	17 JUN	NO	LONG	56.10	0.79	0.16	0.018	8.93	8.87	5.35	26.56		4.04	1.31	0.25	72.00	207.36	0.83
2.00	25 JUN	YES	MEDIUM	66.40	16.20	0.12	0.016	8.57	8.49	5.93	37.11		6.62	-0.88	-0.15	72.00	207.36	0.87
2.00	28 JUN	YES	SHORT	60.20	21.30	0.12	0.016	8.77	8.65	5.53	31.88		6.46	2.06	0.29	72.00	207.36	0.86
2.00	06 JUL	YES	SHORT	62.90	20.70	0.13	0.017	8.71	8.59	5.66	31.51		6.62	2.14	0.31	72.00	207.36	0.86
2.00	08 JUL	YES	LONG	61.80	11.60	0.16	0.017	8.94	8.83	5.89	36.76		5.74	0.95	0.14	72.00	207.36	0.72
2.00			SUM			0.860										72.00	207.36	
			AVG			0.121											AVG PRIO	0.88
			n			7.000		-0.10			34.46	0.358					AVG AFTE	ERR
											33.68	0.350						
			< SPIKE	61.98	3.07	0.13	0.016	7.73	7.65	5.92	33.08		4.78	1.14	0.19	72.00	207.36	0.88
			S D	4.28	2.13	0.02	0.001	0.47	0.46	0.33	5.08		0.43	0.13	0.03	0.00	0.00	0.03
			N	4.00	4.00	3.00	3.000	4.00	4.00	4.00	4.00		4.00	4.00	4.00	4.00	4.00	4.00
			> SPIKE	66.08	17.18	0.12	0.02	0.00	0.89	0.78	34.31	ERR	5.71	1.07	0.14	72.00	207.36	0.87
			S D	3.23	4.05	0.01	0.00	0.47	0.45	0.57	2.63	ERR	0.73	1.23	0.18	0.00	0.00	0.02
			N	4.00	4.00	4.00	4.00	4.00	4.00	4.00	4.00	0.00	4.00	4.00	4.00	4.00	4.00	4.00
			All	73.48	10.12	0.12	0.016	8.37	8.27	6.35	33.88		5.24	1.10	0.17	72.00	207.36	0.76
			S D	12.20	7.78	0.01	0.001	0.78	0.77	0.84	4.08		0.78	0.87	0.13	0.00	0.00	0.10
			N	8.00	8.00	7.00	7.000	8.00	8.00	8.00	8.00		8.00	8.00	8.00	8.00	8.00	8.00
4.00	02 JUN	NO	SHORT	68.40	36.30	0.10		2.51	2.38	2.09	32.16		0.88	1.43	0.88	72.00	207.36	0.23
4.00	06 JUN	NO	SHORT	67.60	31.60	0.04	0.016	1.62	1.68	1.47	37.06		0.67	0.90	0.61	72.00	207.36	0.18
4.00	07 JUN	NO	MEDIUM	66.20	28.70	0.07	0.020	2.40	2.28	2.09	33.79		0.80	1.40	0.71	72.00	207.36	0.24
4.00	09 JUN	NO	MEDIUM	62.00	30.00	0.11	0.016	1.46	1.32	1.16	37.06		0.61	0.54	0.47	72.00	207.36	0.16
4.00	17 JUN	NO	LONG	56.40	20.00	0.11	0.011	2.69	2.56	2.26	41.62		0.74	1.54	0.67	72.00	207.36	0.37
4.00	22 JUN	YES	MEDIUM	64.00	51.30	0.11	0.016	1.66	1.74	1.39	46.40		1.00	0.31	0.24	68.00	196.72	0.16
4.00	25 JUN	YES	MEDIUM	65.00	44.60	0.12	0.016	2.09	1.95	1.57	45.16		0.91	0.98	0.42	72.00	207.36	0.16
4.00	28 JUN	YES	SHORT	67.40	50.00	0.12	0.016	3.83	3.69	3.40	39.88		0.79	2.81	0.77	72.00	207.36	
4.00	06 JUL	YES	SHORT	63.30	53.60	0.12	0.014	1.73	1.62	1.33	37.46		0.61	0.92	0.61	67.00	192.96	0.14
4.00	08 JUL	YES	LONG	64.00	50.80		0.021	2.84	2.82	2.56	39.48		0.73	1.82	0.71	72.00	207.36	0.22
								0.00			39.16	0.372						
4.00			SUM			0.90										72.00	207.36	
			AVG			0.10											AVG PRIO	0.23
			n			9.00											AVG AFTE	0.13
			< SPIKE	63.72	29.52	0.09	0.016	2.17	2.04	1.82	36.84		0.84	1.16	0.63	72.00	207.36	0.23
			S D	4.72	5.31	0.03	0.003	0.47	0.46	0.43	3.32		0.08	0.39	0.08	0.00	0.00	0.07
			N	5.00	5.00	5.00	4.000	5.00	5.00	5.00	5.00		5.00	5.00	5.00	5.00	5.00	5.00
			> SPIKE	64.74	50.12	0.12	0.017	2.58	2.36	2.03	41.66		0.79	1.24	0.66	70.40	202.75	0.13
			S D	1.44	3.03	0.01	0.002	0.79	0.78	0.82	3.48		0.18	0.85	0.20	2.08	5.93	0.07
			N	5.00	5.00	4.00	5.000	5.00	5.00	5.00	5.00		5.00	5.00	5.00	5.00	5.00	5.00
			All	74.23	38.82	0.10	0.017	2.33	2.20	1.92	38.16		0.71	1.21	0.58	71.20	205.06	0.18
			S D	11.07	11.17	0.03	0.003	0.67	0.66	0.66	4.23		0.15	0.66	0.16	1.66	4.78	0.09
			N	10.00	10.00	9.00	9.000	10.00	10.00	10.00	10.00		10.00	10.00	10.00	10.00	10.00	10.00

1 7 D AEROBIC MCRT
TRAIN 2 IFAS SPONGE
TRAIN 4 CONTROL

TRAIN	DATE	SPIKE?	PROFILE	INF TKN	INF NH3-N	INF TP	ANA1 SCOD	ANA1 NH3-N	ANA1 NO2	ANA1 NO3	ANA1 OP	ANA2 MLSS	ANA2 MLVSS	ANA2 SCOD	ANA2 SKN	ANA2 NH3-N	ANA2 NO2	ANA2 NO3	ANA2 OP
2 00	02 JUN	NO	SHORT	66 80	60 50														
2 00	05 JUN	NO	SHORT																
2 00	07 JUNE	NO	MEDIUM	63 60	54 80	9 17						660 00	600 00	221 00	63 60	35 00	0 01	0 05	7 20
2 00	09 JUN	NO	MEDIUM	62 00	52 80	8 81								216 00		32 50	0 01	0 10	6 70
2 00	17 JUN	NO	LONG	55.10	50 20	9 69	255 00	39 80	0 00	0 02	5 60	450.00	410 00	249.00		38 30	0 00	0 02	5 60
2 00	25 JUN	YES	MEDIUM	83 50	78 20	9 25								242 00	59 60	52 00	0 00	0 00	7 00
2 00	28 JUN	YES	SHORT	90 20	82 60	8 58													
2 00	05 JUL	YES	SHORT	82 80	79 20	8 39								233 00		58 10	0 02	0 03	2 10
2 00	08 JUL	YES	LONG	81 80	81 80	8 38	241.00	48 90	0 00	0 00	6 20	630 00	610 00	239.00		48 00	0 00	0 00	6 20
2.00			SUM																
			AVG																
			n																
			< SPIKE	61 88	54 58	9 22	255 00	39 80	0 00	0 02	5 60	555 00	505 00	228 67	63 60	35 27	0 01	0 08	6 50
			S D.	4.26	3.79	0.36	0.00	0 00	0 00	0 00	0 00	105 00	95 00	14 52	0 00	2 38	0 00	0 03	0 67
			N	4.00	4 00	3 00	1.00	1.00	1.00	1.00	1 00	2.00	2.00	3 00	1 00	3 00	3.00	3 00	3.00
			> SPIKE	84 60	79 95	8 15	241 00	48 90	0 00	0 00	6 20	630 00	610 00	238 00	59 60	52 70	0 01	0 01	5 10
			S D	3 29	2 50	1 06	0 00	0 00	0 00	0 00	0 00	0.00	0 00	3 74	0 00	4 15	0 01	0 01	2 15
			N	4 00	4.00	4.00	1.00	1.00	1.00	1.00	1.00	1.00	1 00	3.00	1.00	3.00	3 00	3 00	3.00
			All	73 24	67.26	8 81	248 00	44 35	0 00	0 01	5 90	580 00	540 00	233 33	61 80	43 86	0 01	0 03	5 80
			S D.	11 99	13 09	0 99	7 00	4 55	0 00	0 01	0 30	92.74	92 01	11 59	2 00	9 35	0 01	0 03	1 74
			N	8.00	8 00	7.00	2 00	2 00	2 00	2 00	2.00	3 00	3.00	8 00	2 00	8 00	8.00	8 00	8 00
4 00	02 JUN	NO	SHORT	68 40	62 60														
4 00	05 JUN	NO	SHORT	67 60	48 10	9 38													
4 00	07 JUN	NO	MEDIUM	65 20	52 60	9 21						560.00	510.00	236 00	44 70	44 70	0 00	0 10	7 40
4 00	09 JUN	NO	MEDIUM	62.00	55 00	8 94								224 00	46 80	46 80	0 00	0 02	6 70
4 00	17 JUN	NO	LONG	55 40	46 40	8 12	276.00	36 80	0 00	0.01	5 60	540.00	510 00	272 00		35 50	0 00	0 02	6 20
4 00	22 JUN	YES	MEDIUM	84 00	84 00	9 39								275 00		76 30	0 00	0 00	7 40
4 00	25 JUN	YES	MEDIUM	85 00	73 40	9 36								265 00	71 00	60 60	0 00	0 00	7 10
4 00	28 JUN	YES	SHORT	87 40	82 60	8 87													
4 00	05 JUL	YES	SHORT	83.30	82 40	6 53								257 00		73 30	0 08	0 01	4 60
4 00	08 JUL	YES	LONG	84 00	83.00	8 52	250 00	67.90	0 00	0.00	6 30	550.00	530 00	248 00		62 80	0 00	0 00	6 30

1.7 D AEROBIC MCRT
TRAIN 2 IFAS-SPONGE
TRAIN 4 CONTROL

TRAIN	DATE	SPIKE?	PROFILE	ANX1 SCOD	ANX1 NH3-N	ANX1 NO2	ANX1 NO3	ANX1 OP	ANX2 MLSS	ANX2 MLVSS	ANX2 SCOD	ANX2 SKN	ANX2 NH3-N	ANX2 NO2	ANX2 NO3	ANX2 OP	AER1 MLSS	AER1 MLVSS
2 00	02 JUN	NO	SHORT						1150 00	1080 00	70 20	19 40	19 40	0 10	0 10	7 00		
2 00	05 JUN	NO	SHORT															
2 00	07 JUNE	NO	MEDIUM						1100 00	1000 00	74 10	20 80	14 90	0 00	0 00	6 00	1100 00	980 00
2 00	09 JUN	NO	MEDIUM								70 60	13 40	13 40	0 02	0 04	6 10	900 00	840 00
2 00	17 JUN	NO	LONG	90 60	14 10	0 10	0 20	5 00	830 00	770 00	72 30	14 00	11 60	0 00	0 01	5 20	730 00	670 00
2 00	25 JUN	YES	MEDIUM								42 70	42 70	30 30	0 04	0 05	6 30		
2 00	28 JUN	YES	SHORT						890 00	780 00	33 00	38 70	36 70	0 08	1 60	5 50		
2 00	05 JUL	YES	SHORT						890 00	890 00	78 00	39 50	36 60	0 01	0 04	4 20		
2 00	08 JUL	YES	LONG	87 40	25 90	0 30	0 91	5 60	1250 00	1130 00	65 80	38 00	25 80	0 00	0 00	5 60	1010 00	900 00
2 00			SUM															
			AVG															
			n															
			< SPIKE	90 60	14 10	0 10	0 20	5 00	1026 67	950 00	71 80	16 93	14 63	0 03	0 04	6 08	910 00	830 00
			S D	0 00	0 00	0 00	0 00	0 00	140 55	131 40	1 54	3 26	2 89	0 04	0 04	0 64	151 22	126 75
			N	1 00	1 00	1 00	1 00	1 00	3 00	3 00	4 00	4 00	4 00	4 00	4 00	4 00	3 00	3 00
			> SPIKE	87 40	25 90	0 30	0 91	5 60	1010 00	933 33	54 88	39 23	32 35	0 03	0 42	5 40	1010 00	900 00
			S D	0 00	0 00	0 00	0 00	0 00	169 71	148 14	17 89	2 39	4 59	0 03	0 68	0 76	0 00	0 00
			N	1 00	1 00	1 00	1 00	1 00	3 00	3 00	4 00	4 00	4 00	4 00	4 00	4 00	1 00	1 00
			All	79 10	20 00	0 20	0 56	ERR	1018 33	941 67	63 34	28 08	23 59	0 03	0 23	5 74	935 00	847 50
			S D	11 70	5 90	0 10	0 36	ERR	156 04	139 21	15 26	11 51	9 56	0 04	0 52	0 78	137 93	113 88
			N	2 00	2 00	2 00	2 00	ERR	6 00	6 00	6 00	6 00	6 00	6 00	6 00	6 00	4 00	4 00
4 00	02 JUN	NO	SHORT						1190 00	1090 00	119 00	49 00	49 00	0 00	0 00	7 60		
4 00	05 JUN	NO	SHORT						870 00	770 00	101 00	34 10	34 10	0 03	0 00	6 30		
4 00	07 JUN	NO	MEDIUM						1220 00	1135 00	108 00	41 90	38 40	0 04	0 02	6 00	950 00	900 00
4 00	09 JUN	NO	MEDIUM								72 00	44 30	37 50	0 00	0 02	5 90	910 00	830 00
4 00	17 JUN	NO	LONG	142 00	27 10	0 00	0 02	4 70	970 00	880 00	95 30	29 80	26 10	0 00	0 01	5 00	1090 00	1000 00
4 00	22 JUN	YES	MEDIUM								175 00	62 70	62 70	0 00	0 00	6 90	1090 00	1070 00
4 00	25 JUN	YES	MEDIUM								128 00	62 00	52 00	0 00	0 01	6 50		
4 00	28 JUN	YES	SHORT						870 00	780 00	91 30	65 30	58 30	0 00	0 00	5 40		
4 00	05 JUL	YES	SHORT						770 00	730 00	116 00	62 00	62 00	0 24	0 00	4 60		
4 00	08 JUL	YES	LONG	139 00	61 70				1020 00	900 00	137 00	66 20	61 70	0 00	0 00	5 40	1070 00	990 00

1 7 D AEROBIC MCRT
TRAIN 2 IFAS SPONGE
TRAIN 4 CONTROL

TRAIN	DATE	SPIKE?	PROFILE	AER1 SCOD	AER1 SKN	AER1 NH3-N	AER1 NO2	AER1 NO3	AER1 OP	OUR WITH	OUR /SP	OUR W/O	AER2 MLSS	AER2 MLVSS	AER2 SCOD	AER2 SKN	AER2 NH3-N	AER2 NO2	AER2 NO3
2 00	02 JUN	NO	SHORT	40 80		17 30	0 30	1 80	7 10						38 00		11 70	0 40	4 90
2 00	05 JUN	NO	SHORT																
2 00	07 JUNE	NO	MEDIUM	46 30	14 10	11 80	0 30	1 70	6 70	1 15	0 02	0 46	1020 00	830 00	44 80	9 70	6 70	0 30	5 90
2 00	09 JUN	NO	MEDIUM	39 20	12 70	9 70	0 30	1 80	5 80	0 53	0 007	0 30	880 00	800 00	34 50	5 10	4 50	0 40	6 70
2 00	17 JUN	NO	LONG	44 80	15 30	10 00	0 20	1 30	5 80	1 32	0 027	0 35	720 00	660 00	41 50	6 10	4 83	0 30	4 70
2 00	25 JUN	YES	MEDIUM	47 40	40 00	27 10	0 30	2 00	8 00				1120 00	1105 00	42 60	28 40	21 50	0 40	7 20
2 00	28 JUN	YES	SHORT	63 00	38 20	36 70	0 08	0 10	5 70						29 80	28 30	27 90	0 40	5 70
2 00	05 JUL	YES	SHORT	37 50	34 60	34 60	0 34	1 60	1 60	0 77	0 0075	0 55			31 50	30 40	29 00	0 38	3 80
2 00	08 JUL	YES	LONG	47 20	28 70	21 40	0 37	2 30	5 10	0 82	0 014	0 33	1050 00	880 00	33 20	26 20	17 00	0 40	8 60
2 00			SUM								0 00804								
			AVG								0 0014								
			n								0 0075								
			< SPIKE	42 68	14 03	12 15	0 26	1 68	6 10	1 00	0 0151	0 3700	876 67	796 67	39 95	6 97	6 93	0 35	5 5.
			S D	2 88	1 08	3 08	0 04	0 23	0 58	0 34	0 0083	0 07	122 84	110 25	3 76	1 88	2 88	0 05	0 80
			N	4 00	3 00	4 00	4 00	4 00	4 00	3 00	3 0000	3 00	3 00	3 00	4 00	3 00	4 00	4 00	4 00
			> SPIKE	46 78	35 63	29 95	0 27	1 50	4 60	0 78	0 0108	0 44	1085 00	987 50	34 30	26 58	23 85	0 40	5 63
			S D	9 14	3 93	6 09	0 11	0 85	1 78	0 03	0 0033	0 11	35 00	107 50	4 83	1 58	4 88	0 01	1 29
			N	4 00	4 00	4 00	4 00	4 00	4 00	2 00	2 0000	2 00	2 00	2 00	4 00	4 00	4 00	4 00	4 00
			All	45 73	26 37	21 05	0 27	1 58	5 35	0 82		0 40	980 00	877 00	37 13	19 31	15 38	0 37	5 69
			S D	7 43	11 11	10 12	0 08	0 63	1 51	0 28		0 08	141 28	148 98	5 22	10 84	9 38	0 04	1 08
			N	8 00	7 00	8 00	8 00	8 00	8 00	5 00		5 00	5 00	5 00	8 00	7 00	8 00	8 00	8 00
4 00	02 JUN	NO	SHORT	46 20		40 80	0 30	0 02	7 20						45 00		38 20	0 50	0 50
4 00	05 JUN	NO	SHORT	51 80		32 80	0 20	0 10	6 50						44 30		31 80	0 50	0 40
4 00	07 JUN	NO	MEDIUM	50 80		44 30	0 20	0 10	5 70			0 44	880 00	800 00	47 80	38 20	32 30	0 50	0 40
4 00	09 JUN	NO	MEDIUM	38 20	38 20	35 20	0 20	0 10	5 80			0 27	940 00	880 00	36 10	37 30	33 80	0 50	0 30
4 00	17 JUN	NO	LONG	47 80	26 20	25 10	0 20	0 10	4 80			0 35	1080 00	980 00	43 80	23 70	22 40	0 50	0 40
4 00	22 JUN	YES	MEDIUM	81 00	67 10	67 10	0 30	0 10	6 20						71 50	64 90	64 90	0 60	0 70
4 00	25 JUN	YES	MEDIUM	69 50	56 00	50 00	0 30	0 20	6 10				1000 00	988 00	66 30	56 00	48 10	0 50	1 00
4 00	28 JUN	YES	SHORT	38 30	62 80	56 10	0 30	0 10	5 00						40 80	61 20	54 00	0 50	0 50
4 00	05 JUL	YES	SHORT	45 00	60 40	60 40	0 21	0 08	4 00			0 55			42 00	57 70	55 80	0 45	0 42
4 00	08 JUL	YES	LONG	70 40	58 10	58 20	0 25	0 18	5 20				1030 00	930 00	59 60	57 70	57 10	0 42	0 60
4 00			SUM																
			AVG																
			n																
			< SPIKE	46 98	32 70	35 84	0 22	0 08	5 92	ERR		0 35	980 00	880 00	43 42	32 40	31 88	0 50	0 40
			S D	4 55	6 50	6 65	0 04	0 03	0 88	ERR		0 07	74 83	74 83	3 91	6 17	6 44	0 00	0 08
			N	5 00	2 00	5 00	5 00	5 00	5 00	0 00		3 00	3 00	3 00	5 00	3 00	5 00	5 00	5 00
			> SPIKE	61 04	59 68	56 36	0 27	0 13	5 30	ERR		0 55	1015 00	958 50	58 06	57 50	54 00	0 48	0 62
			S D	16 05	1 88	3 48	0 04	0 04	0 80	ERR		0 00	15 00	29 50	12 52	2 13	3 13	0 06	0 21
			N	5 00	5 00	5 00	5 00	5 00	5 00	0 00		1 00	2 00	2 00	5 00	5 00	5 00	5 00	5 00
			All	54 00	51 97	46 00	0 25	0 11	5 61	ERR		0 40	982 00	911 80	49 74	46 09	42 94	0 50	0 51
			S D	13 74	12 77	11 64	0 05	0 04	0 90	ERR		0 10	64 62	72 28	11 22	12 84	11 92	0 04	0 19
			N	10 00	7 00	10 00	10 00	10 00	10 00	0 00		4 00	5 00	5 00	10 00	8 00	10 00	10 00	10 00

1 7 D AEROBIC MCRT
TRAIN 2 IFAS-SPONGE
TRAIN 4 CONTROL

TRAIN	DATE	SPIKE?	PROFILE	OUR WITH	OUR /SP	OUR W/O	EFF MLSS	EFF MLVSS	EFF SCOD	EFF SKN	EFF NH3-N	EFF NO2	EFF NO3	EFF OP
2 00	02 JUN	NO	SHORT				42 00	40 00	34 30	7 70	6 30	0 50	8 60	6 70
2 00	05 JUN	NO	SHORT											
2 00	07 JUNE	NO	MEDIUM	0 82	0 014	0 33	36 00	33 00	34 00	5 20	3 80	0 50	8 60	5 60
2 00	09 JUN	NO	MEDIUM	0 53	0 007	0 30	37 00	34 00	26 70	3 20	1 80	0 40	8 80	5 80
2 00	17 JUN	NO	LONG	0 54	0 011	0 14	40 00	35 00	32 30	1 50	0 70	0 30	7 30	4 80
2 00	25 JUN	YES	MEDIUM						30 00	22 00	15 20	0 40	12 30	5 90
2 00	28 JUN	YES	SHORT				40 00	27 50	23 80	22 80	21 30	0 80	10 20	5 50
2 00	05 JUL	YES	SHORT	0 58	0 00561	0 40	50 00	50 00	27 00	20 70	20 70	0 57	7 80	3 90
2 00	08 JUL	YES	LONG	0 83	0 0166	0 24	42 00	39 00	27 10	18 60	11 50	0 56	10 30	6 10
2 00			SUM							AVG PRI	3 07			
			AVG							AVG AFT	ERR			
			n											
			< SPIKE	0 63	0 0107	0 28	39 25	36 50	31 83	4 40	3 07	0 43	8 33	5 75
			S D	0 13	0 0029	0 08	1 82	2 89	3 06	2 31	2 13	0 08	0 80	0 64
			N	3 00	3 0000	3 00	4 00	4 00	4 00	4 00	4 00	4 00	4 00	4 00
			> SPIKE	0 89	0 0110	0 32	44 00	38 83	26 83	21 03	17 18	0 53	10 18	5 10
			S D	0 14	0 0056	0 08	4 32	0 18	2 27	1 65	4 05	0 08	1 58	ERR
			N	2 00	2 0000	2 00	3 00	3 00	4 00	4 00	4 00	4 00	4 00	ERR
			All	0 66		0 28	41 29	38 93	29 38	12 71	10 12	0 48	9 26	5 43
			S D	0 14		0 08	3 86	6 58	3 84	8 56	7 76	0 10	1 50	0 77
			N	5 00		5 00	7 00	7 00	8 00	8 00	8 00	8 00	8 00	8 00
4 00	02 JUN	NO	SHORT				30 00	30 00	37 00	37 40	36 30	0 70	1 30	6 80
4 00	05 JUN	NO	SHORT				24 00	20 00	44 30	39 90	31 80	0 70	1 00	5 90
4 00	07 JUN	NO	MEDIUM			0 19	23 00	23 00	38 90	34 70	29 70	0 80	0 80	5 50
4 00	09 JUN	NO	MEDIUM			0 25	27 00	23 00	36 10	36 10	30 00	0 80	0 80	5 60
4 00	17 JUN	NO	LONG			0 19	21 00	17 00	40 00	23 50	20 00	0 70	1 30	4 50
4 00	22 JUN	YES	MEDIUM				38 00	24 00	58 80	54 80	51 30	0 70	2 20	6 80
4 00	25 JUN	YES	MEDIUM						53 70	58 00	44 80	0 70	1 80	6 10
4 00	28 JUN	YES	SHORT				32 50	22 50	36 20	50 00	50 00	0 70	1 40	5 30
4 00	05 JUL	YES	SHORT			0 46	36 00	36 00	34 50	54 00	53 80	0 57	1 50	4 00
4 00	08 JUL	YES	LONG				34 00	31 00	44 10	50 00	50 00	0 58	1 30	6 00
4 00			SUM							AVG PRI	29 52			
			AVG							AVG AFT	46 00			
			n											
			< SPIKE	ERR		0 21	26 00	22 60	39 20	34 32	29 52	0 66	1 06	5 66
			S D	ERR		0 03	3 16	4 32	2 86	5 67	5 31	0 05	0 21	0 74
			N	0 00		3 00	5 00	5 00	5 00	5 00	5 00	5 00	5 00	5 00
			> SPIKE			0 45	35 66	26 66	45 46	53 14	50 12	0 65	1 64	5 24
			S D			0 00	2 70	0 17	9 52	2 30	3 03	0 06	0 33	0 73
			N			1 00	4 00	4 00	5 00	5 00	5 00	5 00	5 00	5 00
			All			0 27	29 83	25 38	42 33	43 73	39 82	0 66	1 36	5 46
			S D			0 11	6 16	6 08	7 70	10 38	11 17	0 06	0 40	0 76
			N			4 00	9 00	9 00	10 00	10 00	10 00	10 00	10 00	10 00

Nitrification Rate for Sponges — 25 sponges per L MLSS in Flasks 1, 2, 3

07/09/94 1.7 d Aer SS MCRT

4AER3 Flask 5	4AER3	4AER3	4AER3	4AER3	4AER3
Time [h]	NH3-N [mg/l]	NO2-N [mg/l]	NO3-N [mg/l]	NO2/3-N [mg/l]	N-TOTAL [mg/l]
initial					
0	47.5	0.63	1.8	2.43	49.93
0.2	47.2	0.67	1.2	1.87	49.07
0.9833333	43.6	0.85	1.2	2.05	45.65
1.9166667	41.9	1	1.3	2.3	44.2
3	39.5	1.3	1.5	2.8	42.3
4.5833333	37.2	1.5	1.6	3.1	40.3
6	35.7	1.8	1.7	3.5	39.2

NH3 REGRESSION

Regression Output:		
Constant		46.542819
Std Err of Y Est		1.1038532
R Squared		0.95261
No. of Observations		7
Degrees of Freedom		5
X Coefficient(s)	-1.989994	
Std Err of Coef.	0.1984964	

NO2/3 REGRESSION

Regression Output:		
Constant		2.0092534
Std Err of Y Est		0.2393485
R Squared		0.8603478
No. of Observations		7
Degrees of Freedom		5
X Coefficient(s)	0.2388747	
Std Err of Coef.	0.04304	

2AER3 Flask 4	2AER3	2AER3	2AER3	2AER3	2AER3
Time [h]	NH3-N [mg/l]	NO2-N [mg/l]	NO3-N [mg/l]	NO2/3-N [mg/l]	N-TOTAL [mg/l]
initial					
0	28.75	0.2	9.8	10	38.75
0.2	28.2	0.31	9.3	9.61	37.81
0.9833333	26	0.66	9.9	10.56	36.56
1.9166667	24.1	1	11.1	12.1	36.2
3	22.2	1.3	12.3	13.6	35.8
4.5833333	18.9	1.7	14.3	16	34.9
6	16.8	1.9	16.1	18	34.8

NH3 REGRESSION

Regression Output:		
Constant		28.319885
Std Err of Y Est		0.4111269
R Squared		0.993183
No. of Observations		7
Degrees of Freedom		5
X Coefficient(s)	-1.995356	
Std Err of Coef.	0.0739294	

NO2/3 REGRESSION

Regression Output:		
Constant		9.4907258
Std Err of Y Est		0.2871797
R Squared		0.9932877
No. of Observations		7
Degrees of Freedom		5
X Coefficient(s)	1.4046905	
Std Err of Coef.	0.051641	

SP.CEL1 Flask 1	SP.CEL1	SP.CEL1	SP.CEL1	SP.CELL1	SP.CELL1
Time [h]	NH3-N [mg/l]	NO2-N [mg/l]	NO3-N [mg/l]	NO2/3-N [mg/l]	N-TOTAL [mg/l]
initial					
0	46.7	0.16	9.4	9.56	56.26
0.2	45.4	0.3	9.4	9.7	55.1
0.9833333	40.3	0.8	11.2	12	52.3
1.9166667	35.8	0.91	11.6	12.51	48.31
3	31.8	1	13.9	14.9	46.7
4.5833333	27.1	1.1	17.2	18.3	45.4
6	24.1	1.1	21.1	22.2	46.3

NH3 REGRESSION

Regression Output:		
Constant		44.91486
Std Err of Y Est		1.7828892
R Squared		0.9654301
No. of Observations		7
Degrees of Freedom		5
X Coefficient(s)	-3.788453	
Std Err of Coef.	0.3206015	

NO2/3 REGRESSION

Regression Output:		
Constant		9.3013512
Std Err of Y Est		0.6111524
R Squared		0.9857187
No. of Observations		7
Degrees of Freedom		5
X Coefficient(s)	2.0415909	
Std Err of Coef.	0.1098983	

Nitrification Rate for Sponges 25 sponges per L MLSS in Flasks 1, 2, 3

07/09/94 1.7 d Aer SS MCRT

SP.CEL2 Flask 2

Time (h)	NH3 N (mg/l)	NO2 N (mg/l)	NO3 N (mg/l)	NO2/3 N (mg/l)	N TOTAL (mg/l)
initial					
0	46	0.16	9.4	9.56	55.56
0.2	43.6	0.25	9.3	9.55	53.15
0.9833333	37.2	0.68	12.3	12.98	50.18
1.9166667	31.8	0.65	12.6	13.25	45.05
3	29.3	0.74	15.9	16.64	45.94
4.5833333	24.1	0.75	19.5	20.25	44.35
6	20.5	0.68	23.1	23.78	44.28

NH3 REGRESSION

Regression Output:

Constant		42.964519
Std Err of Y Est		2.5174587
R Squared		0.9423087
No. of Observations		7
Degrees of Freedom		5
X Coefficient(s)	-4.091007	
Std Err of Coef.	0.4526928	

NO2/3 REGRESSION

Regression Output:

Constant		9.5319095
Std Err of Y Est		0.6566312
R Squared		0.9876596
No. of Observations		7
Degrees of Freedom		5
X Coefficient(s)	2.3548432	
Std Err of Coef.	0.1177167	

SP.CEL3 Flask 3

Time (h)	NH3 N (mg/l)	NO2 N (mg/l)	NO3 N (mg/l)	NO2/3 N (mg/l)	N TOTAL (mg/l)
initial					
0	45.5	0.16	9.4	9.56	55.06
0.2	45	0.2	9.2	9.4	54.4
0.9833333	37.2	0.49	13	13.49	50.69
1.9166667	32.4	0.48	13.6	14.08	46.48
3	27.1	0.47	16.6	17.07	44.17
4.5833333	21.3	0.5	21.9	22.4	43.7
6	16.8	0.49	26	26.49	43.29

NH3 REGRESSION

Regression Output:

Constant		43.711824
Std Err of Y Est		2.2116511
R Squared		0.9672925
No. of Observations		7
Degrees of Freedom		5
X Coefficient(s)	-4.83613	
Std Err of Coef.	0.3977021	

NO2/3 REGRESSION

Regression Output:

Constant		9.3769547
Std Err of Y Est		0.8049812
R Squared		0.9868896
No. of Observations		7
Degrees of Freedom		5
X Coefficient(s)	2.8082708	
Std Err of Coef.	0.1447528	

CALCULATIONS BASED ON NH3

	Cell 1	Cell 2	Cell 3	ML,2Aer3	ML,4Aer3
nit.rate (mg/l/h)	3.7884526	4.0910071	4.8361298	1.9953562	1.9899939
rate per sp. (mg/l/d)	1.7213725	2.0118248	2.7271426		
composite rate (mg/L/min)	0.0727624	0.0803263	0.0989543		
enhancement rate	2.187952	2.415396	2.9755386	1	
Total Nitr (mg/d)	2420.3683	2671.9727	3291.6167	8383.9577	

CALCULATIONS BASED ON NO2/3

	Cell 1	Cell 2	Cell 3	ML,2Aer3	ML,4Aer3
nit.rate (mg/l.h)	2.0415909	2.3548432	2.8082708	1.4046905	0.2388747
rate per sp. (mg/d/sp)	0.6114244	0.9121466	1.3474371		
composite rate (mg/L/min)	0.0355882	0.0434195	0.0547552		
enhancement rate	1.5201147	1.8546214	2.3388145	1	
Total Nitr (mg/d)	1183.8051	1444.3057	1821.3761	4449.487	
Denit rate (mg/d/sp)	1.109948	1.0996782	1.3797055		

TIME (h)	4aer3	2aer3	SP CELL1	SP CELL2	SP CELL3
MLSS (mg/L)					
0.2	860	1070	1080	1100	1050
4.58333	880	1060	1020	1070	1080
MLVSS (mg/L)					
0.2	800	970	960	980	960
4.58333	770	940	960	950	1000

Nitrification Rate for Sponges
07/21/94 1.7 d Aer SS MCRT

Flask 1, 2, 3: 25 sponges per L MLSS
Flask 4: IFAS-Sponge MLSS
Flask 5: Control MLSS

4AER3 Flask 5 Time [h]	4AER3 NH3-N [mg/l]	4AER3 NO2-N [mg/l]	4AER3 NO3-N [mg/l]	4AER3 NO2/3-N [mg/l]	4AER3 N-TOTAL [mg/l]
initial					
0	51.5	0.89	1.63	2.52	54.02
0.0833333	51.4	0.95	1.43	2.38	53.78
1	47.5	1.4	1.65	3.05	50.55
2	43.9	1.88	1.86	3.74	47.64
3	42.2	2.2	2.12	4.32	46.52
4.5	40.5	2.83	2.76	5.59	46.09
6	36	3.38	2.75	6.13	42.13

NH3 REGRESSION

Regression Output:		
Constant		51.495359
Std Err of Y Est		0.3347837
R Squared		0.9971866
No. of Observations		7
Degrees of Freedom		5
X Coefficient(s)	-2.531601	
Std Err of Coef.	0.0601366	

NO2/3 REGRESSION

Regression Output:		
Constant		1.4316341
Std Err of Y Est		0.2066219
R Squared		0.8782081
No. of Observations		7
Degrees of Freedom		5
X Coefficient(s)	0.2228566	
Std Err of Coef.	0.0371151	

2AER3 Flask 4 Time [h]	2AER3 NH3-N [mg/l]	2AER3 NO2-N [mg/l]	2AER3 NO3-N [mg/l]	2AER3 NO2/3-N [mg/l]	2AER3 N-TOTAL [mg/l]
initial					
0	45.7	0.45	6.83	7.28	52.98
0.0833333	45.6	0.49	6.25	6.74	52.34
1.5	42.2	0.85	6.85	7.7	49.9
2.9166667	39	1.24	7.49	8.73	47.73
3.6666667	37.5	1.46	8.12	9.58	47.08
4.5833333	34.6	1.83	9.37	11.2	45.8
6	32	2.07	10.24	12.31	44.31

NH3 REGRESSION

Regression Output:		
Constant		45.733579
Std Err of Y Est		0.2712767
R Squared		0.9978026
No. of Observations		7
Degrees of Freedom		5
X Coefficient(s)	-2.321869	
Std Err of Coef.	0.048729	

NO2/3 REGRESSION

Regression Output:		
Constant		6.2297375
Std Err of Y Est		0.4639348
R Squared		0.9160527
No. of Observations		7
Degrees of Freedom		5
X Coefficient(s)	0.6155647	
Std Err of Coef.	0.0833358	

SP.CELL Flask 1 Time [h]	SP.CELL NH3-N [mg/l]	SP.CELL NO2-N [mg/l]	SP.CELL NO3-N [mg/l]	SP.CELL NO2/3-N [mg/l]	SP.CELL N-TOTAL [mg/l]
initial					
0	68.1	0.41	7.33	7.74	75.84
0.0833333	67.6	0.44	6.82	7.26	74.86
1.5	60.1	0.7	7.87	8.57	68.67
2.9166667	53.4	0.27	7.71	7.98	61.38
3.6666667	52.4	0.31	9.12	9.43	61.83

NH3 REGRESSION

Regression Output:		
Constant		67.155906
Std Err of Y Est		1.2539673
R Squared		0.9844704
No. of Observations		7
Degrees of Freedom		5
X Coefficient(s)	-4.010205	
Std Err of Coef.	0.225248	

NO2/3 REGRESSION

Regression Output:		
Constant		6.5593854
Std Err of Y Est		0.8997989
R Squared		0.8548343
No. of Observations		7
Degrees of Freedom		5
X Coefficient(s)	0.8770294	
Std Err of Coef.	0.1616293	

Nitrification Rate for Sponges
07/21/94 1.7 d Aer SS MCRT

Flask 1, 2, 3: 25 sponges per L MLSS
Flask 4: IFAS Sponge MLSS
Flask 5: Control MLSS

SP.CEL2 SP.CELL2 SP.CELL2 SP.CELL2 SP.CELL2 SP.CELL2
Flask 2

Time [h]	NH3 N [mg/l]	NO2 N [mg/l]	NO3 N [mg/l]	NO2/3 N [mg/l]	N TOTAL [mg/l]
initial					
0	67.5	0.38	8.13	8.51	76.01
0.0833333	65	0.42	8.38	8.8	73.8
1.5	55.6	0.63	10.99	11.62	67.22
2.9166667	47.5	0.71	13.75	14.46	61.96
3.6666667	45.6	0	17.31	17.31	62.91
4.5833333	39	0	21.76	21.76	60.76
6	32	0	26.41	26.41	58.41

NH3 REGRESSION

Regression Output:

Constant		65.705714
Std Err of Y Est		1.3587629
R Squared		0.9910596
No. of Observations		7
Degrees of Freedom		5
X Coefficient(s)	-5.746133	
Std Err of Coef.	0.2440723	

NO2/3 REGRESSION

Regression Output:

Constant		7.2035883
Std Err of Y Est		1.4131539
R Squared		0.9655044
No. of Observations		7
Degrees of Freedom		5
X Coefficient(s)	3.002927	
Std Err of Coef.	0.2538424	

SP.CEL3 SP.CELL3 SP.CELL3 SP.CELL3 SP.CELL3 SP.CELL3
Flask 3

Time [h]	NH3 N [mg/l]	NO2 N [mg/l]	NO3 N [mg/l]	NO2/3 N [mg/l]	N TOTAL [mg/l]
initial					
0	47	0	8.53	8.53	55.53
0.0833333	45	0	7.88	7.88	52.88
1.5	37.2	0.74	9.63	10.37	47.57
2.9166667	32.4	0.75	10.3	11.05	43.45
3.6666667	27.1	0.75	11.3	12.05	39.15
4.5833333	21.3	0.74	12.28	13.02	34.32
6	16.8	0.79	12.92	13.71	30.51

NH3 REGRESSION

Regression Output:

Constant		45.853185
Std Err of Y Est		1.2508024
R Squared		0.9901933
No. of Observations		7
Degrees of Freedom		5
X Coefficient(s)	-5.022522	
Std Err of Coef.	0.2246795	

NO2/3 REGRESSION

Regression Output:

Constant		8.2214405
Std Err of Y Est		0.3273258
R Squared		0.9746646
No. of Observations		7
Degrees of Freedom		5
X Coefficient(s)	0.8154622	
Std Err of Coef.	0.058797	

CALCULATIONS BASED ON NH3

	Cell 1	Cell 2	Cell 3	ML_2Aer3	ML_4Aer3
nit.rate [mg/l/h]	4.0107049	5.7461332	5.0225224	2.3218694	2.5316005
rate per sp. [mg/l/d]	1.620802	3.2872932	2.5976269		
composite rate [mg/L/min]	0.0747146	0.1181128	0.1000225		
enhancement rate	1.930717	3.0521811	2.584706	1	
Total Nitr [mg/d]	2485.3051	3928.903	3327.1483	9741.3564	

CALCULATIONS BASED ON NO2/3

	Cell 1	Cell 2	Cell 3	ML_2Aer3	ML_4Aer3
nit.rate [mg/l.h]	0.8770294	3.002927	0.8154622	0.6155647	0.2228566
rate per sp. [mg/d/sp]	0.2510062	2.2918679	0.1919017		
composite rate [mg/L/min]	0.0151545	0.068302	0.0136153		
enhancement rate	1.477134	6.6574937	1.3271078	1	
Total Nitr [mg/d]	504.10012	2271.9965	452.90082	3228.9975	
Denit rate per sp. [mg/d/sp]	1.3697959	0.9954254	2.4007252		

TIME [h]	4aer3	2aer3	SP CELL1	SP CELL2	SP CELL3
MLSS (mg/L)					
2.9166667	1760	920	920	1180	910
4.5833333	1790	890	920	1060	860
MLVSS (mg/L)					
0.2	1140	820	780	1070	890
4.58333	1150	790	900	890	830

1.0 DAY RAW DATA

1.0 DAY AEROBIC MCRT
TRAIN 2 IFAS-SPONGE
TRAIN 4 CONTROL

TRAIN	DATE	SPIKE?	PROFILE	INF TKN	EFF NH3N	SLDG N	NITR-1	NITR-2	DENITR	SLUDGE PROD	SLUDGE YIELD	ANX DN	AER DN	FRACTION AER DN	Q inf	Q inf l/day	PERCENT NITR
2.00	07 OCT	NO	MEDIUM	69.23	15.40	0.09	6.44	6.31	5.48	46.89		3.21	2.28	0.41	72.00	207.36	0.71
2.00	09 OCT	NO	LONG	70.06	17.50	0.14	6.47	6.30	4.56	31.06		4.39	0.17	0.04	72.00	207.36	0.59
2.00	11 OCT	NO	LONG	69.76	17.00	0.11	6.57	6.42	4.64	31.06		4.74	-0.10	-0.02	72.00	207.36	0.60
2.00	15 OCT	NO	MEDIUM	67.73	14.60	0.10	6.36	6.27	5.01	32.86		3.56	1.45	0.29	72.00	207.36	0.62
2.00	18 OCT	NO	SHORT	69.12	18.90	0.13	5.27	5.13	3.72	39.58		4.26	-0.54	-0.15	72.00	207.36	0.54
2.00			SUM			0.565									72.00	207.36	
			AVG			0.113										AVG PRIOR	0.61
			n			5.000	-0.25			38.49	0.354					AVG AFTER	
			AVG	69.18	16.68	0.11	6.22	6.09	4.68	36.29		4.03	0.65	0.11	72.00	207.36	0.61
			S.D.	0.80	1.53	0.02	0.48	0.48	0.58	6.16		0.58	1.05	0.21	0.00	0.00	0.08
			N	5.00	5.00	5.00	5.00	5.00	5.00	5.00		5.00	5.00	5.00	5.00	5.00	5.00
4.00	07 OCT	NO	MEDIUM	67.95	44.70	0.12	-0.22	-0.32	-0.45	35.98		0.37	-0.82	1.83	72.00	207.36	-0.02
4.00	09 OCT	NO	LONG	68.30	45.80	0.10	0.26	0.26	0.26	40.83		0.29	-0.03	-0.14	72.00	207.36	0.03
4.00	11 OCT	NO	LONG	67.41	43.10	0.12	-0.18	-0.29	-0.39	35.98		1.24	-1.64	4.17	72.00	207.36	-0.02
4.00	15 OCT	NO	MEDIUM	68.46	37.70	0.18	0.22	0.11	-0.03	34.60		0.25	-0.28	8.96	72.00	207.36	0.02
4.00	18 OCT	NO	SHORT	69.12	42.00	0.10	-0.27	-0.41	-0.60	60.80		0.54	-1.14	1.90	72.00	207.36	-0.04
4.00			SUM			0.602									72.00	207.36	
			AVG			0.120										AVG PRIOR	-0.01
			n			5.000	0.00			41.66	0.369					AVG AFTER	ERR
			AVG	67.85	42.66	0.12	-0.04	-0.13	-0.24	41.66		0.54	-0.78	3.35	72.00	207.36	0.01
			S.D.	0.89	2.60	0.02	0.22	0.26	0.31	9.85		0.37	0.58	3.12	0.00	0.00	0.03
			N	5.00	5.00	5.00	5.00	5.00	5.00	5.00		5.00	5.00	5.00	5.00	5.00	5.00

1.0 DAY AEROBIC MCRT
TRAIN 2 IFAS-SPONGE
TRAIN 4 CONTROL

TRAIN	DATE	SPIKE?	PROFILE	INF TKN	INF NH3-N	INF TP	ANA1 SCOD	ANA1 NH3-N	ANA1 NO2	ANA1 NO3	ANA1 OP	ANA2 MLSS	ANA2 MLVSS	ANA2 SCOD	ANA2 SKN	ANA2 NH3-N	ANA2 NO2	ANA2 NO3	ANA2 OP
2 00	07 OCT	NO	MEDIUM	69 23	57 10									200 00		37 90	0 00	0 00	12 20
2 00	09 OCT	NO	LONG	70 08	54 20	9 23	277 00	38 80	0 50	0 10	7 90	380 00	300 00	267 00		37 20	0 00	0 00	7 80
2 00	11 OCT	NO	LONG	69 76	57 30	9 17	200 00	39 80	0 00	0 00	5 70			198 00		39 80	0 00	0 00	5 30
2 00	15 OCT	NO	MEDIUM	67 73	61 80	8 81								307 00		39 30	0 00	0 00	4 90
2 00	18 OCT	NO	SHORT	69 12	53 20	9 69													
2.00			SUM																
			AVG																
			n																
			AVG	69 18	56 72	9 23	238 50	39 30	0 25	0 05	6 80	380 00	300 00	243 00	ERR	38 55	0 00	0 00	7 55
			S D	0 80	3 00	0 31	38 50	0 50	0 25	0 05	1 10	0 00	0 00	48 22	ERR	1 05	0 00	0 00	2 91
			N	5 00	5 00	4 00	2 00	2 00	2 00	2 00	2 00	1 00	1 00	4 00	0 00	4 00	4 00	4 00	4 00
4 00	07 OCT	NO	MEDIUM	67 95	57 10									235 00		50 50	0 00	0 00	11 70
4 00	09 OCT	NO	LONG	72 74	54 20	9 38	312 00	52 00	0 00	0 00	6 50			309 00		52 00	0 00	0 00	7 90
4 00	11 OCT	NO	LONG	67 41	55 00	9 21	234 00	50 70	0 00	0 00	5 50	810 00	810 00	234 00		48 70	0 00	0 00	5 70
4 00	15 OCT	NO	MEDIUM	66 46	64 30	8 84								314 00		52 40	0 00	0 00	5 00
4 00	18 OCT	NO	SHORT	69 12	55 30	8 12													
4.00			SUM																
			AVG																
			n																
			AVG	68 74	57 18	8 91	273 00	51 35	0 00	0 00	7 00	810 00	810 00	273 00	ERR	50 90		0 00	7 58
			S D	2 18	3 68	0 48	39 00	0 85	0 00	0 00	1 50	0 00	0 00	36 54	ERR	1 45		0 00	2 61
			N	5 00	5 00	4 00	2 00	2 00	2 00	2 00	2 00	1 00	1 00	4 00	0 00	4 00		4 00	4 00

1.0 DAY AEROBIC MCRT
TRAIN 2 IFAS-SPONGE
TRAIN 4 CONTROL

TRAIN	DATE	SPIKE?	PROFILE	ANX1 SCOD	ANX1 NH3-N	ANX1 NO2	ANX1 NO3	ANX1 OP	ANX2 MLSS	ANX2 MLVSS	ANX2 SCOD	ANX2 SKN	ANX2 NH3-N	ANX2 NO2	ANX2 NO3	ANX2 OP	AER1 MLSS	AER1 MLVSS	AER1 SCOD
2 00	07 OCT	NO	MEDIUM								87 40	29 10	25 20	0 50	0 30	11 30			48 00
2 00	09 OCT	NO	LONG	159 00	27 70	0 00	0 00	7 60	630 00	530 00	141 00	32 40	27 70	1 40	1 30	7 50	670 00	460 00	59 20
2 00	11 OCT	NO	LONG	104 00	27 70	0 70	1 50	5 00			97 60	30 50	28 60	0 20	0 00	5 00	490 00	450 00	57 60
2 00	15 OCT	NO	MEDIUM						470 00	460 00	163 00	30 50	26 00	0 20	0 70	6 50	500 00	470 00	83 00
2 00	18 OCT	NO	SHORT								75 80	34 70	29 30	0 00	0 00	4 10	700 00	560 00	44 20
																			70 5
2 00			SUM																
			AVG																
			n																
			AVG	131 50	27 70	0 35	0 75	6 30	550 00	495 00	112 98	31 44	27 40	0 48	0 48	6 68	580 00	485 00	60 42
			S D.	27 50	0 00	0 35	0 75	1 30	80 00	35 00	33 35	1 94	1 58	0 50	0 49	2 50	85 66	43 87	13 15
			N	2.00	2.00	2.00	2.00	2.00	2 00	2.00	5.00	5.00	5.00	5.00	5.00	5.00	4.00	4 00	6 00
4 00	07 OCT	NO	MEDIUM								149 00	49 80	48 50	0 00	0 00	11 00			98 50
4 00	09 OCT	NO	LONG	202 00	47 80	0 00	0 00	9 70			193 00	51 80	47 80	0 00	0 00	7 30	580 00	520 00	118 00
4 00	11 OCT	NO	LONG	165 00	45 80	0 00	0 00	5 20	990 00	870 00	158 00	52 80	44 90	0 00	0 00	5 20	560 00	490 00	
4 00	15 OCT	NO	MEDIUM						800 00	550 00	186 00	48 20	46 30	0 00	0 00	5 00	590 00	560 00	108 00
4 00	18 OCT	NO	SHORT						700 00	600 00	126 30	49 00	53 20	0 00	0 00	4 10	790 00	690 00	89 50
4.00			SUM																
			AVG																
			n																
			AVG	183 50	46 80	0 00	0 00	7 45	763 33	673 33	164 48	50 34	48 14	0 00	0 00	6 52	630 00	565 00	98 50
			S D.	18 50	1 00	0 00	0 00	2 25	185 40	140 55	26 63	1 75	2 82	0 00	0 00	2 47	93 01	78 32	18 11
			N	2.00	2.00	2.00	2.00	2.00	3 00	3.00	5.00	5.00	5.00	5.00	5.00	5.00	4 00	4 00	4 00

10 DAY AEROBIC MCRT
TRAIN 2 IFAS-SPONGE
TRAIN 4 CONTROL

TRAIN	DATE	SPIKE?	PROFILE	AER1 SKN	AER1 NH3-N	AER1 NO2	AER1 NO3	AER1 OP	OUR WITH	OUR /SP	OUR W/O	AER2 M'SS	AER2 MLVSS	AER2 SCOD	AER2 SKN	AER2 NH3-N	AER2 NO2	AER2 NO3	AER2 OP	OUR WITH	OUR /SP	OUR W/O
2 00	07 OCT	NO	MEDIUM	25 20	23 30	0 70	1 00	11 00	0 59	0 01	0 24	800 00	610 00	37 80	22 40	19 00	0 30	4 20	11 00	0 62	0 01125	0 22
2 00	09 OCT	NO	LONG	29 70	25 50	1 40	1 20	7 60	0 77	0 014	0 28	480 00	430 00	52 80	26 90	23 50	0 60	4 90	7 50	0 33	0 005175	0 15
2 00	11 OCT	NO	LONG	26 80	25 50	0 50	0 90	4 60	0 66	0 0136	0 18	480 00	450 00	66 20	22 40	20 80	0 70	5 30	4 80	0 74	0 018725	0 13
2 00	15 OCT	NO	MEDIUM	27 40	23 00	0 40	0 80	6 00				450 00	420 00	52 00	24 10	18 70	0 50	3 40	6 00			
2 00	18 OCT	NO	SHORT	31 80	28 20	0 50	0 60	4 00				700 00	660 00	37 80	28 70	24 40	0 60	3 80	4 00			
														63 7								
2 00			SUM																			
			AVG																			
			n																			
																				ADDITIONAL SLUDGE PROD		
			AVG	26 22	25 10	0 70	0 86	6 66	0 67	0 0125	0 23	586 00	500 00	46 25	24 80	21 30	0 54	4 34	6 66	0 56	0 0111	0 17
			S D	2 34	1 88	0 36	0 23	2 53	0 08	0 00	0 04	136 38	82 46	7 38	2 51	2 31	0 14	0 88	2 47	0 17	0 0047	0 04
			N	5 00	5 00	5 00	5 00	5 00	3 00	3 00	3 00	5 00	5 00	6 00	5 00	5 00	5 00	5 00	5 00	3 00	3 00	3 00
4 00	07 OCT	NO	MEDIUM	47 80	46 50	0 00	0 00	10 80			0 42	580 00	420 00	97 00	46 80	44 70	0 40	0 90	10 80			0 28
4 00	09 OCT	NO	LONG	47 30	45 80	0 00	0 00	8 70			0 45	680 00	580 00	110 00	47 30	43 90	0 00	0 00	8 20			0 33
4 00	11 OCT	NO	LONG	49 8	43 10	0 00	0 00	4 80			0 46	480 00	400 00		47 80	43 10	0 30	0 20	4 90			0 33
4 00	15 OCT	NO	MEDIUM	44 80	44 40	0 00	0 00	5 20				700 00	650 00	99 00	44 50	40 80	0 20	0 20	5 00			
4 00	18 OCT	NO	SHORT	48 70	48 20	0 00	0 00	4 30				800 00	680 00	66 80	47 80	42 00	0 00	0 10	4 10			
4 00			SUM																			
			AVG																			
			n																			
			AVG	47 84	45 80	0 00	0 00	6 32	ERR		0 44	644 00	550 00	93 70	46 88	42 92	0 18	0 28	6 22			0 31
			S D	1 67	2 08	0 00	0 00	2 29	ERR		0 01	108 37	118 83	15 20	1 26	1 35	0 18	0 32	2 43			0 02
			N	5 00	5 00	5 00	5 00	5 00	0 00		3 00	5 00	5 00	4 00	5 00	5 00	5 00	5 00	5 00			3 00

1.0 DAY AEROBIC MCRT
TRAIN 2 IFAS-SPONGE
TRAIN 4 CONTROL

TRAIN	DATE	SPIKE?	PROFILE	AVG MLSS	AER3 MLSS	AER3 MLVSS	AER3 COD	AER3 SCOD	AER3 TKN	AER3 SKN	AER3 NH3-N	AER3 TP	AER3 NO2	AER3 NO3	AER3 OP	OUR WITH	OUR /SP	OUR W/O
2 00	07 OCT	NO	MEDIUM	770 00	770 00	590 00	1041 00	38 60	84 60	17 20	15 40		0 60	7 50	11 10	0 82	0 0165	0 23
2 00	09 OCT	NO	LONG	510 00	510 00	420 00	838 00	43 20	89 60	21 30	19 00		0 60	9 00	8 80	0 28	0 00405	0 15
2 00	11 OCT	NO	LONG	510 00	510 00	490 00	744 00	40 00	71 10	17 70	17 70		0 30	6 20	4 60	0 74	0 017025	0 11
2 00	15 OCT	NO	MEDIUM	540 00	540 00	510 00	736 00	42 00	68 30	20 70	15 90		0 40	7 10	5 90			
2 00	18 OCT	NO	SHORT	650 00	650 00	490 00	931 00	37 90	110 00	25 50	20 50		0 60	7 70	3 90			
								41 4										
2 00			SUM															
			AVG															
			n	625 00	598 00													
				1 03														
			AVG	598 00	598 00	500 00		40 18	84 72	20 48	17 70	ERR	0 54	7 80	8 86	0 61	0 0125	0 18
			S D	101 11	101 11	54 41		2 31	14 95	2 98	1 90	ERR	0 17	0 65	2 70	0 24	0 01	0 05
			N	5 00	5 00	5 00		8 00	5 00	5 00	5 00	0 00	5 00	5 00	5 00	3 00	3 00	3 00
4 00	07 OCT	NO	MEDIUM	520 00	520 00	330 00	691 00	69 90	107 50	45 40	44 70		0 40	0 50	10 70			0 20
4 00	09 OCT	NO	LONG	590 00	590 00	520 00	874 00	78 90	108 00	47 30	43 90	22 20	0 50	0 20	8 60			0 24
4 00	11 OCT	NO	LONG	520 00	520 00	480 00	808 00	65 60	105 30	47 60	43 10	22 48	0 60	2 40	5 20			0 24
4 00	15 OCT	NO	MEDIUM	500 00	500 00	450 00	944 00	63 00	123 00	41 40	39 30	20 52	0 40	0 20	4 80			
4 00	18 OCT	NO	SHORT	880 00	880 00	780 00	1168 00	56 60	135 00	47 90	42 00	16 18	0 70	0 60	3 90			
				602 00	ERR													
4 00			SUM	ERR														
			AVG	ERR														
			n															
			AVG	602 00	602 00	512 00		66 84	115 36	45 92	42 60	20 35	0 52	0 78	6 24			0 23
			S D	142 32	142 32	148 24		7 37	11 79	2 42	1 66	2 52	0 12	0 63	2 39			0 02
			N	5 00	5 00	5 00		5 00	5 00	5 00	5 00	4 00	5 00	5 00	5 00			3 00

1.0 DAY AEROBIC MCRT
TRAIN 2 IFAS-SPONGE
TRAIN 4 CONTROL

TRAIN	DATE	SPIKE?	PROFILE	EFF MLVSS	EFF SCOD	EFF SKN	EFF NH3-N	EFF NO2	EFF NO3	EFF OP
2.00	07 OCT	NO	MEDIUM	27.20	46.10	17.20	15.40	0.60	4.00	11.30
2.00	09 OCT	NO	LONG	34.60	36.30	17.90	17.50	0.80	8.40	7.50
2.00	11 OCT	NO	LONG	43.40	38.40	17.10	17.00	0.70	8.60	4.90
2.00	15 OCT	NO	MEDIUM	50.00	40.00	16.00	14.60	0.50	6.10	6.00
2.00	18 OCT	NO	SHORT	65.10	28.40	22.70	18.90	0.70	6.80	3.80
2.00			SUM			AVG PRI	16.68			
			AVG			AVG AFT	ERR			
			n							
			AVG	44.06	37.84	18.18	16.68	0.66	6.78	6.70
			S.D.	13.05	5.74	2.34	1.53	0.10	1.68	2.61
			N	5.00	5.00	5.00	5.00	5.00	5.00	5.00
4.00	07 OCT	NO	MEDIUM	15.90	60.40	44.80	44.70	0.50	0.60	11.00
4.00	09 OCT	NO	LONG	30.00	72.60	47.30	45.80			
4.00	11 OCT	NO	LONG	20.00	69.00	44.00	43.10	0.60	0.50	5.10
4.00	15 OCT	NO	MEDIUM	25.50	58.00	41.20	37.70	0.50	0.70	4.40
4.00	18 OCT	NO	SHORT	24.10	56.80	46.20	42.00	0.70	0.90	4.00
4.00			SUM			AVG PRI	42.66			
			AVG			AVG AFT	ERR			
			n							
			AVG	23.10	63.36	44.70	42.66	0.58	0.68	6.13
			S.D.	4.81	6.29	2.09	2.80	0.08	0.15	2.84
			N	5.00	5.00	5.00	5.00	4.00	4.00	4.00

Nitrification Rate for Sponges — Flasks 1, 2, 3: 25 sponges per L of MLSS from IFAS-Sponge System

10/25/94 1.0 d Aer SS MCRT — Flask 4: IFAS-Sponge MLSS

2AER3 Flask 4	2AER3	2AER3	2AER3	2AER3	2AER3
Time [h]	NH3-N [mg/l]	NO2-N [mg/l]	NO3-N [mg/l]	NO2/3-N [mg/l]	N-TOTAL [mg/l]
initial	12.3	0.86	7.2		
0.083	38.2	0	6.5	6.5	44.7
1	36.7	0	6.5	6.5	43.2
2	35.2	1.7	6.8	8.5	43.7
3	33.8	2.1	7	9.1	42.9
4.5	33.2	2.4	7.6	10	43.2
6.03	33	3.32	7.8	11.12	44.12

NH3 REGRESSION

Regression Output:		
Constant		37.453962
Std Err of Y Est		0.8324589
R Squared		0.8731276
No. of Observations		6
Degrees of Freedom		4
X Coefficient(s)	-0.880261	
Std Err of Coef.	0.1677746	

NO2/3 REGRESSION

Regression Output:		
Constant		6.3494073
Std Err of Y Est		0.4560422
R Squared		0.9521568
No. of Observations		6
Degrees of Freedom		4
X Coefficient(s)	0.8200539	
Std Err of Coef.	0.0919112	

SP.CEL1 Flask 1	SP.CELL1	SP.CELL1	SP.CELL1	SP.CELL1	SP.CELL1
Time [h]	NH3-N [mg/l]	NO2-N [mg/l]	NO3-N [mg/l]	NO2/3-N [mg/l]	N-TOTAL [mg/l]
initial	17	0.9	6.9		
0.083	60.5	0	6.1	6.1	66.6
1	57.2	2.13	6.4	8.53	65.73
2	53.9	2.57	6.4	8.97	62.87
3	50.7	2.86	6.7	9.56	60.26
4.5	48.7	3.26	7.2	10.46	59.16
6.03	45	2.92	8.21	11.13	56.13

NH3 REGRESSION

Regression Output:		
Constant		59.676691
Std Err of Y Est		1.0011352
R Squared		0.975224
No. of Observations		6
Degrees of Freedom		4
X Coefficient(s)	-2.531761	
Std Err of Coef.	0.2017698	

NO2/3 REGRESSION

Regression Output:		
Constant		7.0728697
Std Err of Y Est		0.7065123
R Squared		0.8713518
No. of Observations		6
Degrees of Freedom		4
X Coefficient(s)	0.7411534	
Std Err of Coef.	0.1423912	

SP.CEL2 Flask 2	SP.CELL2	SP.CELL2	SP.CELL2	SP.CELL2	SP.CELL2
Time [h]	NH3-N [mg/l]	NO2-N [mg/l]	NO3-N [mg/l]	NO2/3-N [mg/l]	N-TOTAL [mg/l]
initial	15.7	0.72	7.8		
0.083	54.9	0	7.22	7.22	62.12
1	50.7	1.51	9.4	10.91	61.61
2	44.9	1.89	11.6	13.49	58.39
3	42.3	1.86	13.7	15.56	57.86
4.5	38.2	0	17.5	17.5	55.7
6.03	34.5	1.96	21.8	23.76	58.26

NH3 REGRESSION

Regression Output:		
Constant		53.610994
Std Err of Y Est		1.5423461
R Squared		0.9672917
No. of Observations		6
Degrees of Freedom		4
X Coefficient(s)	-3.380844	
Std Err of Coef.	0.3108459	

NO2/3 REGRESSION

Regression Output:		
Constant		7.7314818
Std Err of Y Est		1.0834855
R Squared		0.9710909
No. of Observations		6
Degrees of Freedom		4
X Coefficient(s)	2.5312171	
Std Err of Coef.	0.2183667	

Nitrification Rate for Sponges — Flasks 1, 2, 3: 25 sponges per L of MLSS from IFAS-Sponge System

10/25/94 1.0 d Aer SS MCRT — Flask 4: IFAS-Sponge MLSS

SP.CEL3 Flask 3 Time [h]	SP.CELL NH3-N [mg/l]	SP.CELL NO2-N [mg/l]	SP.CELL NO3-N [mg/l]	SP.CELL NO2/3-N [mg/l]	SP.CELL3 N-TOTAL [mg/l]
initial	15.7	0.66	10.9		
0.083	53.9	0	10.4	10.4	64.3
1	48.7	1.18	13.3	14.48	63.18
2	44	1.68	16.2	17.88	61.88
3	39.8	1.74	18.6	20.34	60.14
4.5	36.7	1.63	24.4	26.03	62.73
6.03	33.2	1.87	30.6	32.47	65.67

NH3 REGRESSION

Regression Output:		
Constant		52.13375
Std Err of Y Est		1.803211
R Squared		0.956324
No. of Observations		6
Degrees of Freedom		4
X Coefficient(s)	-3.4011	
Std Err of Coef.	0.363421	

NO2/3 REGRESSION

Regression Output:		
Constant		10.32887
Std Err of Y Est		0.618338
R Squared		0.995201
No. of Observations		6
Degrees of Freedom		4
X Coefficient(s)	3.589162	
Std Err of Coef.	0.12462	

CALCULATIONS BASED ON NH3

	Cell 1	Cell 2	Cell 3	ML_2Aer3	ML_4Aer3
nit rate [mg/l/h]	2.531761	3.380844	3.401102	0.880261	ERR
rate per sp. [mg/l/d]	1.58544	2.40056	2.420008		
composite rate [mg/L/min]	0.053611	0.074838	0.075345		
enhancement rate	3.654223	5.101095	5.135615	1	
Total Nitr [mg/d]	1783.322	2489.419	2506.266	6779.006	

CALCULATIONS BASED ON NO2/3

	Cell 1	Cell 2	Cell 3	ML_2Aer3	ML_4Aer3
nit.rate [mg/l.h]	0.741153	2.531217	3.589162	0.820054	ERR
rate per sp. [mg/d/sp]	-0.07574	1.642717	2.658344		
composite rate [mg/L/min]	0.009508	0.05426	0.080708		
enhancement rate	0.695679	3.969971	5.905109	1	
Total Nitr [mg/d]	316.2822	1804.899	2684.686	4805.868	
Denit Rate [mg/d/sp]	1.661185	0.757844	-0.23834		

TIME [h]	4aer3	2aer3	SP CELL	SP CELL	SP CELL
MLSS (mg/L)					
0.2	860	1070	1080	1100	1050
4.58333	880	1060	1020	1070	1080
MLVSS (mg/L)					
0.2	800	970	960	980	960
4.58333	770	940	960	950	1000

Nitrification Rate for Sponges — Flask 1, 2, 3: 25 sponges per L of IFAS-Sponge MLSS
10/27/94 10 d Aer SS MCRT — Flask 4: IFAS-Sponge MLSS

2AER3	2AER3	2AER3	2AER3	2AER3	2AER3
Time [h]	NH3-N [mg/l]	NO2-N [mg/l]	NO3-N [mg/l]	NO2/3-N [mg/l]	N-TOTAL [mg/l]
initial	11.4	0.83	7.9		
0.117	25.5	0.79	7.44	8.23	33.73
1	25.5	1.11	7.77	8.88	34.38
2.05	24.5	1.39	8.22	9.61	34.11
3.1	24.5	1.95	9.83	11.78	36.28
4.5	22.6	2.14	10.9	13.04	35.64
5.9	20.9	2.36	9.41	11.77	32.67

NH3 REGRESSION

Regression Output:		
Constant		26.14837
Std Err of Y Est		0.570849
R Squared		0.921137
No. of Observations		6
Degrees of Freedom		4
X Coefficient(s)	-0.8034	
Std Err of Coef.	0.117537	

NO2/3 REGRESSION

Regression Output:		
Constant		8.394247
Std Err of Y Est		1.003509
R Squared		0.779357
No. of Observations		6
Degrees of Freedom		4
X Coefficient(s)	0.776656	
Std Err of Coef.	0.206621	

SP.CELL	SP.CELL	SP.CELL	SP.CELL	SP.CELL	SP.CELL
Time [h]	NH3-N [mg/l]	NO2-N [mg/l]	NO3-N [mg/l]	NO2/3-N [mg/l]	N-TOTAL [mg/l]
initial	12.3	0.75	7.6		
0.117	38.2	0.83	7.31	8.14	46.34
1	33.9	1.26	7.99	9.25	43.15
2.05	31.2	1.6	8.85	10.45	41.65
3.1	27.7	1.76	8.62	10.38	38.08
4.5	24.5	0.98	21.7	22.68	47.18
5.9	24.5	2.33	12.6	14.93	39.43

NH3 REGRESSION

Regression Output:		
Constant		36.71382
Std Err of Y Est		1.724056
R Squared		0.920567
No. of Observations		6
Degrees of Freedom		4
X Coefficient(s)	-2.41693	
Std Err of Coef.	0.354981	

NO2/3 REGRESSION

Regression Output:		
Constant		7.538333
Std Err of Y Est		4.128614
R Squared		0.53835
No. of Observations		6
Degrees of Freedom		4
X Coefficient(s)	1.835963	
Std Err of Coef.	0.850077	

SP.CEL2	SP.CELL	SP.CELL	SP.CELL	SP.CELL	SP.CELL2
Time [h]	NH3-N [mg/l]	NO2-N [mg/l]	NO3-N [mg/l]	NO2/3-N [mg/l]	N-TOTAL [mg/l]
initial	11.8	0.64	8.54		
0.117	39.8	0.67	8.63	9.3	49.1
1	33.9	0.84	11.52	12.36	46.26
2.05	30	0.91	14.62	15.53	45.53
3.1	27.7	0.95	17.7	18.65	46.35
4.5	24.5	0.6	22.4	23	47.5
5.9	21.7	0.99	26.2	27.19	48.89

NH3 REGRESSION

Regression Output:		
Constant		37.74184
Std Err of Y Est		1.737849
R Squared		0.943738
No. of Observations		6
Degrees of Freedom		4
X Coefficient(s)	-2.931	
Std Err of Coef.	0.357821	

NO2/3 REGRESSION

Regression Output:		
Constant		9.135281
Std Err of Y Est		0.138953
R Squared		0.999653
No. of Observations		6
Degrees of Freedom		4
X Coefficient(s)	3.073037	
Std Err of Coef.	0.02861	

Nitrification Rate for Sponges — Flask 1, 2, 3: 25 sponges per L of IFAS-Sponge MLSS

10/27/94 10 d Aer SS MCRT — Flask 4: IFAS-Sponge MLSS

SP.CEL3 SP.CEL3 SP.CEL3 SP.CEL3 SP.CEL3 SP.CEL3

Time [h]	NH3-N [mg/l]	NO2-N [mg/l]	NO3-N [mg/l]	NO2/3-N [mg/l]	N-TOTAL [mg/l]
initial	11.4	0.62	9.38		
0.117	39.8	0.7	9.67	10.37	50.17
1	33.9	0.77	12.56	13.33	47.23
2.05	30	0.83	16.04	16.87	46.87
3.1	26.6	0.86	19.9	20.76	47.36
4.5	23.5	0.83	24.4	25.23	48.73
5.9	20.9	0.83	29.6	30.43	51.33

NH3 REGRESSION

Regression Output:		
Constant		37.79719
Std Err of Y Est		1.7921547
R Squared		0.9471715
No. of Observations		6
Degrees of Freedom		4
X Coefficient(s)	-3.124926	
Std Err of Coef.	0.3690027	

NO2/3 REGRESSION

Regression Output:		
Constant		9.3769547
Std Err of Y Est		0.8049812
R Squared		0.9868896
No. of Observations		7
Degrees of Freedom		5
X Coefficient(s)	2.8082708	
Std Err of Coef.	0.1447528	

CALCULATIONS BASED ON NH3

	Cell 1	Cell 2	Cell 3	ML,2Aer3	ML,4Aer3
nit rate [mg/l/h]	2.4169282	2.9310022	3.1249261	0.8033979	ERR
rate per sp. [mg/l/d]	1.548989	2.0425001	2.228667		
composite rate [mg/L/min]	0.0515858	0.0644377	0.0692858		
enhancement rate	3.8525735	4.8123856	5.174455	1	
Total Nitr [mg/d]	1715.9509	2143.4549	2304.722	6164.1278	

CALCULATIONS BASED ON NO2/3

	Cell 1	Cell 2	Cell 3	ML,2Aer3	ML,4Aer3
nit rate [mg/l.h]	1.8359633	3.0730374	2.8082708	0.7766555	ERR
rate per sp. [mg/d/sp]	1.0169355	2.2045266	1.9503506		
composite rate [mg/L/min]	0.0373559	0.0682827	0.0616636		
enhancement rate	2.8859029	5.2751361	4.7637769	1	
Total Nitr [mg/d]	1242.6058	2271.3565	2051.1766	5565.1389	
Denit rate [mg/d/sp]	0.5320535	-0.162027	0.2783163		

TIME [h]	4aer3	2aer3	SP CEL1	SP CEL2	SP CEL3
MLSS (mg/L)					
0.2	860	1070	1080	1100	1050
4.58333	880	1060	1020	1070	1080
MLVSS (mg/L)					
0.2	800	970	960	980	960
4.58333	770	940	960	950	1000

0.3 DAY RAW DATA

0.33 DAY AER SS MCRT
TRAIN 2 IFAS-SPONGE
TRAIN 4 CONTROL

TRAIN	DATE	SPIKE?	PROFILE	INF TKN	EFF NH3N	SLDG N	SLDG P	NITR-1	NITR-2	DENITR	SLUDGE PROD	SLUDGE YIELD	ANX DN	AER DN	FRACTION AER DN	Q Inf	Q Inf L/DAY	PERCENT NITR
2.00	25 DEC	NO	MEDIUM	57.65	32.00	0.12	0.087	1.67	1.59	1.08	27.65		0.75	0.32	0.30	72.00	207.36	0.19
2.00	27 DEC	NO	LONG	56.49	27.40	0.09	0.116	2.53	2.42	1.68	27.43		1.08	0.62	0.37	72.00	207.36	0.30
2.00	29 DEC	NO	MEDIUM	55.88	28.50	0.11	0.099	2.36	2.16	1.43	25.77		1.18	0.25	0.16	72.00	207.36	0.27
2.00	31 DEC	NO	MEDIUM	52.92	23.40	0.11	0.102	2.37	2.27	1.53	26.60		1.00	0.53	0.35	72.00	207.36	0.30
2.00	02 Jan	NO	Medium	56.70	23.80	0.15	0.075	3.26	3.16	2.39	34.09		1.13	1.26	0.53	72.00	207.36	0.42
2.00			SUM			0.573												
			AVG			0.115											AVG PRIO	0.30
			n			5.000		-0.00			28.39	0.334					AVG AFTE	
											29.78	0.350	Yield					
			AVG	55.92	27.02	0.11	0.092	2.44	2.33	1.62	28.35		1.02	0.60	0.34	72.00	207.36	0.30
			S.D.	1.81	3.18	0.02	0.018	0.51	0.51	0.44	2.98		0.15	0.38	0.11	0.00	0.00	0.07
			N	5.00	5.00	5.00	5.000	5.00	5.00	5.00	5.00		5.00	5.00	5.00	5.00	5.00	5.00
4.00	25 DEC	NO	MEDIUM	57.65	37.50					-0.04			0.08	-0.12	3.00	72.00	207.36	0.00
4.00	27 DEC	NO	LONG	57.96	35.30	0.12	0.099	0.66	0.61	0.59	34.61		0.13	0.45	0.77	72.00	207.36	0.08
4.00	29 DEC	NO	MEDIUM	56.18	37.50	0.15	0.126	-0.34	-0.36	-0.38	22.36		0.08	-0.45	1.21	72.00	207.36	-0.04
4.00	31 DEC	NO	MEDIUM	50.61	34.00	0.07	0.096	-0.39	-0.41	-0.42	31.49		0.07	-0.49	1.18	72.00	207.36	-0.06
4.00	02 JAN	NO	MEDIUM	56.18	36.00	0.11	0.084	0.06	0.06	0.05	33.15		0.02	0.03	0.67	72.00	207.36	0.01
4.00			SUM			0.461										72.00	207.36	
			AVG			0.115											AVG PRIO	0.00
			n			4.000		-0.18			32.01	0.40					AVG AFTE	ERR
			AVG	55.71	36.06	0.12	0.101	-0.00	-0.03	-0.04	30.48		0.07	-0.12	1.36	72.00	207.36	0.00
			S.D.	2.66	1.34	0.03	0.016	0.42	0.41	0.36	4.61		0.04	0.35	0.85	0.00	0.00	0.05
			N	5.00	5.00	4.00	4.000	4.00	4.00	5.00	4.00		5.00	5.00	5.00	5.00	5.00	5.00

0.33 DAY AER SS MCRT
TRAIN 2 IFAS-SPONGE
TRAIN 4 CONTROL

TRAIN	DATE	SPIKE?	PROFILE	INF COD	INF TKN	INF NH3-N	INF TP	ANA1 SCOD	ANA1 NH3-N	ANA1 NO2	ANA1 NO3	ANA1 OP
2.00	25 DEC	NO	MEDIUM	469	57.65	52.40	8.08					
2.00	27 DEC	NO	LONG	386	56.48	48.40	9.12	262.00	42.20	0.29	0.52	3.42
2.00	29 DEC	NO	MEDIUM	455	55.86	49.40	8.68					
2.00	31 DEC	NO	MEDIUM	447	52.92	46.50	7.26					
2.00	02 Jan	NO	Medium	467	56.70	50.60	7.88					
				443	59.955							
2.00			SUM									
			AVG									
			n									
			AVG	448.43	55.92	49.70	8.20	262.00	42.20	0.29	0.52	3.42
			S.D.	30.48	1.61	1.95	0.64	0.00	0.00	0.00	0.00	0.00
			N	5.00	5.00	5.00	5.00	1.00	1.00	1.00	1.00	1.00
				513.00								
				436.00								
4.00	25 DEC	NO	MEDIUM	482.00	57.65	53.40	7.88					
4.00	27 DEC	NO	LONG	398.00	57.96	49.40	8.18					
4.00	29 DEC	NO	MEDIUM	433.00	58.18	49.40	8.22					
4.00	31 DEC	NO	MEDIUM	399.00	50.61	46.50	7.68					
4.00	02 JAN	NO	MEDIUM	474.00	58.18	51.40	7.18					
				433	61.11							
4.00			SUM									
			AVG									
			n									
			AVG	436.71	55.71	50.02	7.82	ERR	ERR	ERR	ERR	ERR
			S.D.	35.71	2.66	2.30	0.39	ERR	ERR	ERR	ERR	ERR
			N	5.00	5.00	5.00	5.00	0.00	0.00	0.00	0.00	0.00

0.33 DAY AER SS MCRT
TRAIN 2 IFAS SPONGE
TRAIN 4 CONTROL

TRAIN	DATE	SPIKE?	PROFILE	ANA2 MLSS	ANA2 MLVSS	ANA2 SCOD	ANA2 NH3-N	ANA2 NO2	ANA2 NO3	ANA2 OP	ANX1 SCOD	ANX1 NH3-N	ANX1 NO2	ANX1 NO3	ANX1 OP	ANX2 MLSS	ANX2 MLVSS	ANX2 SCOD	ANX2 SKN
2.00	25 DEC	NO	MEDIUM			319.00	47.50	0.00	0.00	8.29								203.00	41.70
2.00	27 DEC	NO	LONG	120.00	104.00	256.00	42.20	0.23	0.04	4.31	169.00	36.00	0.24	0.11	2.84	124.00	112.00	188.00	38.40
2.00	29 DEC	NO	MEDIUM			329.00	42.20	0.00	0.00	4.80								201.00	40.90
2.00	31 DEC	NO	MEDIUM			248.00	36.20	0.00	0.00	5.32								163.00	36.40
2.00	02 Jan	NO	Medium					0.00	0.00	5.89								193.00	37.80
																		193	34.8
2.00			SUM																
			AVG																
			n																
			AVG	120.00	104.00	288.25	42.53	0.05	0.01	5.72	169.00	36.00	0.24	0.11	2.84	124.00	112.00	185.60	39.04
			S D	0.00	0.00	36.01	3.30	0.09	0.02	1.39	0.00	0.00	0.00	0.00	0.00	0.00	0.00	16.82	1.97
			N	1.00	1.00	4.00	4.00	5.00	5.00	5.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	5.00	5.00
4.00	25 DEC	NO	MEDIUM															231.00	45.10
4.00	27 DEC	NO	LONG															198.00	44.00
4.00	29 DEC	NO	MEDIUM															227.00	44.00
4.00	31 DEC	NO	MEDIUM															179.00	43.30
4.00	02 JAN	NO	MEDIUM															224.00	45.10
																		217	39.9
4.00			SUM																
			AVG																
			n																
			AVG	ERR	ERR	ERR	ERR		ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	211.40	44.30
			S D	ERR	ERR	ERR	ERR		ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	ERR	20.36	0.70
			N	0.00	0.00	0.00	0.00		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	5.00	5.00

0 33 DAY AER SS MCRT
TRAIN 2 IFAS-SPONGE
TRAIN 4 CONTROL

TRAIN	DATE	SPIKE?	PROFILE	ANX2 NH3 N	ANX2 NO2	ANX2 NO3	ANX2 OP	AER1 SCOD	AER1 SKN	AER1 NH3-N	AER1 NO2	AER1 NO3	AER1 OP	OUR w sp	OUR per sp	OUR W/O	AER2 MLSS	AER2 MLVSS	AER2 SCOD
2 00	25 DEC	NO	MEDIUM	41 40	0 00	0 33	7 48	146 00	39 20	39 00	0 00	0 12	6 19	0 7875	0 0122	0 38	136 00	136 00	58 00
2 00	27 DEC	NO	LONG	38 00	0 13	0 17	4 34	71 00	33 30	33 30	0 00	0 09	3 64	0 659563	0 0094	0 35	132 00	116 00	68 00
2 00	29 DEC	NO	MEDIUM	37 50	0 11	0 15	4 52	59 60	37 20	32 00	0 37	0 61	4 03	0 797	0 0148	0 28	116 00	96 00	58 60
2 00	31 DEC	NO	MEDIUM	33 30	0 00	0 70	4 96	83 70	33 00	29 60	0 07	0 08	6 27	0 8969	0 0150	0 38	132 00	129 00	36 30
2 00	02 Jan	NO	Medium	35 70	0 11	0 12	5 20	103 00	33 60	32 00	0 00	0 07	4 79	0 892583	0 0094	0 39	156 00	124 00	50 20
								70 5											53 7
2 00			SUM																
			AVG																
			n																
			AVG	38 78	0 07	0 29	5 30	77 56	35 26	33 18	0 09	0 19	4 98	0 7687	0 0122	0 35	134 40	120 20	53 36
			S D	2 67	0 06	0 22	1 13	14 83	2 49	3 15	0 14	0 21	1 06	0 0840	0 0025	0 04	12 80	13 75	10 42
			N	5 00	5 00	5 00	5 00	5 00	5 00	5 00	5 00	5 00	5 00	5 0000	5 0000	5 00	5 00	5 00	5 00
4 00	25 DEC	NO	MEDIUM	44 70	0 00	0 00	6 87	167 00		42 20						0 41	220 00	196 00	104 00
4 00	27 DEC	NO	LONG	42 20	0 00	0 02	3 21	124 00		39 00						0 44	128 00	124 00	105 00
4 00	29 DEC	NO	MEDIUM	43 80	0 00	0 00	3 93	173 00		40 50						0 38	116 00	108 00	116 00
4 00	31 DEC	NO	MEDIUM	39 00	0 00	0 00	4 54	131 00		36 00						0 38	144 00	128 00	81 50
4 00	02 JAN	NO	MEDIUM	43 00	0 00	0 00	4 57	180 00		39 00						0 52	180 00	140 00	99 00
4 00			SUM																
			AVG																
			n																
			AVG	42 56	0 00	0 00	4 62	151 00	ERR	39 34	ERR	ERR	ERR		ERR	0 42	157 60	138 80	101 10
			S D	1 97	0 00	0 01	1 23	19 75	ERR	2 05	ERR	ERR	ERR		ERR	0 05	37 91	30 35	11 26
			N	5 00	5 00	5 00	5 00	5 00	0 00	5 00	0 00	0 00	0 00		0 0000	5 00	5 00	5 00	5 00

0.33 DAY AER SS MCRT
TRAIN 2 IFAS-SPONGE
TRAIN 4 CONTROL

TRAIN	DATE	SPIKE?	PROFILE	AER2 SKN	AER2 NH3-N	AER2 NO2	AER2 NO3	AER2 OP	OUR w sp	OUR per sp	OUR W/O	AVG MLSS	AER3 MLSS	AER3 MLVSS	AER3 COD	AER3 SCOD	AER3 TKN	AER3 SKN
												145	145					
2 00	25 DEC	NO	MEDIUM	36 70	36 00	0 11	0 23	6 16	0 683	0 0100	0.35	134 00	134 00	126 00		52 00		33 90
2 00	27 DEC	NO	LONG	31 40	30 80	0 33	0 84	3 66	0 4045	0 0084	0.10	132 00	132 00	112 00	227 00	46 00	39 90	28 60
2 00	29 DEC	NO	MEDIUM	34 20	32 00	0 37	0 61	4 03	0 756125	0 0164	0.16	120 00	124 00	96 00	173 00	54 90	42 80	28 80
2 00	31 DEC	NO	MEDIUM	29 40	27 40	0 34	0 58	4 51	0 405313	0.0079	0 13	130 00	128 00	116 00	172 00	35 00	39 60	25 80
2 00	02 Jan	NO	Medium	28 00	27 90	0 37	0 47	4 29	0.388938	0.0056	0 20	160 00	164 00	120 00	192 00	45 00	49 30	25 20
												128	128	110	242	53 8	43	25 8
2 00			SUM															
			AVG															
			n									132 11	135 00					
											ADDITIONAL SLUDGE PROD	-0 10						
											ADDITIONAL N IN SLUDGE	-0 01						
			AVG	31 94	30 82	0 30	0 55	4 53	0 53	0 0097	0 19	135 20	136 40	114 00		47 75	42 90	28 46
			S D.	3 18	3 11	0 10	0 20	0 86	0 18	0.0038	0.09	13 30	14 22	10 12		8 79	3 90	3 08
			N	5 00	5 00	5 00	5 00	5 00	5 00	5 00	5.00	5 00	5 00	5 00		8 00	4 00	5 00
												110 00	110 00					
												130 00	130 00					
												110 00	110 00					
4 00	25 DEC	NO	MEDIUM		38 20						0 48	212 00	212 00	208 00		72 40		38 50
4 00	27 DEC	NO	LONG		38 00						0 27	148 00	168 00	116 00	267 00	71 00	57 90	37 00
4 00	29 DEC	NO	MEDIUM		37 50						0 30	112 00	108 00	96 00	238 00	78 40	56 60	40 00
4 00	31 DEC	NO	MEDIUM		34 00						0 30	148 00	152 00	116 00	246 00	80 70	45 50	34 70
4 00	02 JAN	NO	MEDIUM		38 00						0 32	170 00	160 00	132 00		83 00	56 00	38 10
												116	116	104	213	67 2	53	34 3
											0 33	139 56	152 67					
4 00			SUM								0 01	-0 48						
			AVG								0 00	0 00						
			n															
			AVG	ERR	38 34	ERR	ERR	ERR			0 33	158 00	160 00	133 80		73 10	54 00	37 66
			S D.	ERR	1 45	ERR	ERR	ERR			0 07	32 79	33 27	38 91		7 55	4 98	1 76
			N	0 00	5 00	0 00	0 00	0 00			5.00	5 00	5 00	5 00		5 00	4 00	5 00

0 33 DAY AER SS MCRT
TRAIN 2 IFAS SPONGE
TRAIN 4 CONTROL

TRAIN	DATE	SPIKE?	PROFILE	AER3 NH3 N	AER3 TP	AER3 NO2	AER3 NO3	AER3 OP	OUR WITH	OUR per Sp	OUR W/O	EFF MLSS	EFF MLVSS	EFF COD	EFF SCOD	EFF TKN	EFF SKN	EFF NH3 N	EFF TP	EFF NO2	EFF NO3	EFF OP
2 00	25 DEC	NO	MEDIUM	32 00	15 13	0 39	2 54	6 18	0 38	0 0088	0 15	134 00	126 00		52 00		33 90	32 00	15 13	0 39	2 54	6 18
2 00	27 DEC	NO	LONG	27 40	18 51	0 51	3 58	3 26	0 30	0 0053	0 12	132 00	112 00	227 00	46 00	39 90	28 80	27 40	18 51	0 51	3 58	3 26
2 00	29 DEC	NO	MEDIUM	28 50	16 81	0 87	3 82	4 58	0 58	0 0150		124 00	98 00	173 00	54 90	42 80	28 80	28 50	16 81	0 87	3 82	4 58
2 00	31 DEC	NO	MEDIUM	23 40	17 44	0 47	3 58	4 35	0 85	0 0150	0 10	128 00	116 00	172 00	35 00	38 80	25 80	23 40	17 44	0 47	3 58	4 35
2 00	02 Jan	NO	Medium	23 80	18 08	0 48	3 81	5 79	0 81	0 0146	0 07	164 00	120 00	192 00	46 00	48 30	25 20	23 80	18 08	0 48	3 81	5 79
2 00			SUM														AVG PRI	27 02				
			AVG														AVG AFT	ERR				
			n																			
			AVG	27 02	17 19	0 54	3 43	4 83	0 50	0 0113	0 11	138 40	114 00		46 58		28 46	27 02		0 54	3 43	4 83
			S D	3 18	1 18	0 17	0 45	1 05	0 14	0 0044	0 03	14 22	10 12		8 86		3 08	3 18		0 17	0 45	1 05
			N	5 00	6 00	6 00	6 00	6 00	6 00	6 00	4 00	6 00	5 00		6 00		6 00	6 00		5 00	5 00	5 00
4 00	25 DEC	NO	MEDIUM	37 50	15 95	0 09	0 10	5 28			0 19	212 00	208 00		72 40		38 50	37 50	15 95	0 09	0 10	5 28
4 00	27 DEC	NO	LONG	35 30	19 50	0 23	0 11	2 83			0 10	188 00	116 00	267 00	71 00	57 80	37 00	35 30	19 50	0 23	0 11	2 83
4 00	29 DEC	NO	MEDIUM	37 50	16 82	0 12	0 07	3 19			0 18	108 00	98 00	238 00	78 40	58 60	40 00	37 50	16 82	0 12	0 07	3 19
4 00	31 DEC	NO	MEDIUM	34 00	17 88	0 10	0 08	3 27			0 10	152 00	116 00	248 00	80 70	45 50	34 70	34 00	17 88	0 10	0 08	3 27
4 00	02 JAN	NO	MEDIUM	36 00	16 77	0 00	0 04	3 38			0 20	180 00	132 00		83 00	56 00	38 10	36 00	16 77	0 00	0 04	3 38
4 00			SUM														AVG PRI	36 08				
			AVG														AVG AFT	ERR				
			n																			
			AVG	36 08	17 38	0 11	0 08	3 59			0 15	180 00	133 80		73 10		ERR	36 08		0 11	0 08	3 59
			S D	1 34	1 22	0 07	0 03	0 86			0 04	33 27	36 91		7 56		ERR	1 34		0 07	0 03	0 86
			N	5 00	5 00	6 00	6 00	5 00			5 00	6 00	6 00		5 00		ERR	6 00		5 00	5 00	5 00

Nitrification Rate for Sponges — Flasks 1, 2, 3: 25 sponges per L of IFAS-Sponge System MLSS
01/04/95 0.3 d Aer SS MCRT — Flask 4: IFAS Sponge MLSS

2AER3 Flask 4 IFAS-Sponge MLSS	2AER3	2AER3	2AER3	2AER3	2AER3
Time [h]	NH3-N [mg/l]	NO2-N [mg/l]	NO3-N [mg/l]	NO2/3-N [mg/l]	N-TOTAL [mg/l]
initial					
0	35.6	0.6	3.4	4	39.6
1	34.2	0.7	3.5	4.2	38.4
2.05	34.2	0.7	3.6	4.3	38.5
2.98	34.2	0	3.6	3.6	37.8
4	32.8	0	3.7	3.7	36.5
5	32.8	0.9	3.6	4.5	37.3

NH3 REGRESSION

Regression Output:	
Constant	35.27329
Std Err of Y Est	0.450107
R Squared	0.854072
No. of Observations	6
Degrees of Freedom	4
X Coefficient(s)	-0.5216
Std Err of Coef.	0.107803

NO2/3 REGRESSION

Regression Output:	
Constant	4.025356
Std Err of Y Est	0.391571
R Squared	0.002743
No. of Observations	6
Degrees of Freedom	4
X Coefficient(s)	0.009838
Std Err of Coef.	0.093784

SP.CEL1 Flask 1	SP.CELL	SP.CELL	SP.CELL	SP.CELL	SP.CELL1
Time [h]	NH3-N [mg/l]	NO2-N [mg/l]	NO3-N [mg/l]	NO2/3-N [mg/l]	N-TOTAL [mg/l]
initial					
0	35.6	0	3.1	3.1	38.7
1	34.2	0.7	2.6	3.3	37.5
2.05	34.2	0.7	2.3	3	37.2
2.98	32.8	0.8	2	2.8	35.6
4	32.8	0.9	1.8	2.7	35.5
5	31.4	0	1.6	1.6	33

NH3 REGRESSION

Regression Output:	
Constant	35.4041
Std Err of Y Est	0.420606
R Squared	0.934357
No. of Observations	6
Degrees of Freedom	4
X Coefficient(s)	-0.76012
Std Err of Coef.	0.100738

NO2/3 REGRESSION

Regression Output:	
Constant	3.430899
Std Err of Y Est	0.362974
R Squared	0.709642
No. of Observations	6
Degrees of Freedom	4
X Coefficient(s)	-0.27182
Std Err of Coef.	0.086935

SP.CEL2 Flask 2	SP.CELL	SP.CELL	SP.CELL	SP.CELL	SP.CELL2
Time [h]	NH3-N [mg/l]	NO2-N [mg/l]	NO3-N [mg/l]	NO2/3-N [mg/l]	N-TOTAL [mg/l]
initial					
0	35.6	0.6	3	3.6	39.2
1	34.2	0	3.1	3.1	37.3
2.05	34.2	0	3.4	3.4	37.6
2.98	32.8	0	3.5	3.5	36.3
4	32.8	0	3.8	3.8	36.6
5	31.4	1.2	4.1	5.3	36.7

NH3 REGRESSION

Regression Output:	
Constant	35.4041
Std Err of Y Est	0.420606
R Squared	0.934357
No. of Observations	6
Degrees of Freedom	4
X Coefficient(s)	-0.76012
Std Err of Coef.	0.100738

NO2/3 REGRESSION

Regression Output:	
Constant	3.016505
Std Err of Y Est	0.590493
R Squared	0.53944
No. of Observations	6
Degrees of Freedom	4
X Coefficient(s)	0.306119
Std Err of Coef.	0.141427

Nitrification Rate for Sponges — Flasks 1, 2, 3: 25 sponges per L. of IFAS-Sponge System MLSS

01/04/95 0.3 d Aer SS MCRT — Flask 4: IFAS Sponge MLSS

SP.CELL3 SP.CELL3 SP.CELL3 SP.CELL3 SP.CELL3 SP.CELL3
Flask 3

Time [h]	NH3-N [mg/l]	NO2-N [mg/l]	NO3-N [mg/l]	NO2/3-N [mg/l]	N-TOTAL [mg/l]
initial					
0	32.8	0	3.8	3.8	36.6
1	31.4	0.7	5.9	6.6	38
2.05	30.2	0.8	8.7	9.5	39.7
2.98	27.7	0.8	11	11.8	39.5
4	26.6	0.8	13.9	14.7	41.3
5	24.5	0.8	16.5	17.3	41.8

NH3 REGRESSION

Regression Output:		
Constant		33.04963
Std Err of Y Est		0.3950093
R Squared		0.987323
No. of Observations		6
Degrees of Freedom		4
X Coefficient(s)	-1.669846	
Std Err of Coef.	0.0946072	

NO2/3 REGRESSION

Regression Output:		
Constant		3.867238
Std Err of Y Est		0.0892059
R Squared		0.9997485
No. of Observations		6
Degrees of Freedom		4
X Coefficient(s)	2.6943827	
Std Err of Coef	0.0213654	

CALCULATIONS BASED ON NH3

	Cell 1	Cell 2	Cell 3	ML-2Aer3	ML-4Aer3
nit rate [mg/l/h]	0.760121	0.760121	1.6698455	0.5216045	
rate per sp. [mg/SP/d]	0.2862199	0.2862199	1.3778893		
composite rate [mg/L/min]	0.0151038	0.0151038	0.0435327		
enhancement rate	1.7373903	1.7373903	5.0075569	1	
Total Nitr [mg/d]	502.4142	502.4142	1448.0728	2452.9012	

CALCULATIONS BASED ON NO2/3

	Cell 1	Cell 2	Cell 3	ML-2Aer3	ML-4Aer3
nit rate [mg/l.h]	-0.271816	0.3061192	2.6943827	0.0098378	ERR
rate per sp. [mg/d/sp]	-0.270388	0.2844302	2.5771631		
composite rate [mg/L/min]	-0.006904	0.0075448	0.0672514		
enhancement rate	-42.10461	46.014927	410.1607	1	
Total Nitr [mg/d]	-229.6419	250.96906	2237.049	2258.3762	
Denit rate [mg/d/sp]	0.5566075	0.0017897	-1.199274		

TIME [h]	4aer3	2aer3	SP CEL1	SP CEL2	SP CEL3
MLSS (mg/L)					
0		150	160	182.5	155
5		137.5	132.5	125	150
MLVSS (mg/L)					
0		122.5	140	165	127.5
5		117.5	122.5	112.5	117.5

Nitrification Rate for Sponges — Flasks 1, 2, 3: 25 sponges per L of MLSS of IFAS-Sponge System
01/03/95 0.3 d Aer SS MCRT — Flask 4: IFAS-Sponge MLSS

2AER3 IFAS-Sponge MLSS Flask 4 Time [h]	2AER3 NH3-N [mg/l]	2AER3 NO2-N [mg/l]	2AER3 NO3-N [mg/l]	2AER3 NO2/3-N [mg/l]	2AER3 N-TOTAL [mg/l]
initial					
0	30.9	0.5	3.04	3.54	34.44
1	30.5	0.56	3.29	3.85	34.35
2	30.3	0.63	3.46	4.09	34.39
3	29.4	0.65	3.43	4.08	33.48
4.57	28.5	0	3.76	3.76	32.26
6	27.9	0	3.65	3.65	31.55

NH3 REGRESSION

Regression Output:	
Constant	31.03988
Std Err of Y Est	0.18684
R Squared	0.980411
No. of Observations	6
Degrees of Freedom	4
X Coefficient(s)	-0.52742
Std Err of Coef.	0.037276

NO2/3 REGRESSION

Regression Output:	
Constant	3.837378
Std Err of Y Est	0.250806
R Squared	0.00107
No. of Observations	6
Degrees of Freedom	4
X Coefficient(s)	-0.00328
Std Err of Coef.	0.050037

SP.CELL1 Flask 1 Time [h]	SP.CELL NH3-N [mg/l]	SP.CELL NO2-N [mg/l]	SP.CELL NO3-N [mg/l]	SP.CELL NO2/3-N [mg/l]	SP.CELL1 N-TOTAL [mg/l]
initial					
0	31.8	0.48	2.98	3.46	35.26
1	31.4	0.56	2.61	3.17	34.57
2	30.3	0.63	2.37	3	33.3
3	27.9	0.64	2.13	2.77	30.67
4.57	26.8	0	1.81	1.81	28.61
6	25.8	0	1.79	1.79	27.59

NH3 REGRESSION

Regression Output:	
Constant	32.02877
Std Err of Y Est	0.583325
R Squared	0.956901
No. of Observations	6
Degrees of Freedom	4
X Coefficient(s)	-1.09672
Std Err of Coef.	0.116376

NO2/3 REGRESSION

Regression Output:	
Constant	3.512506
Std Err of Y Est	0.193733
R Squared	0.940114
No. of Observations	6
Degrees of Freedom	4
X Coefficient(s)	-0.30628
Std Err of Coef.	0.038651

SP.CELL2 Flask 2 Time [h]	SP.CELL NH3-N [mg/l]	SP.CELL NO2-N [mg/l]	SP.CELL NO3-N [mg/l]	SP.CELL NO2/3-N [mg/l]	SP.CELL2 N-TOTAL [mg/l]
initial					
0	28.8	0.49	3.33	3.82	32.62
1	26.8	0.62	3.35	3.97	30.77
2	25.8	0.73	3.37	4.1	29.9
3	24.8	0.76	3.39	4.15	28.95
4.57	23.3	0	3.5	3.5	26.8

NH3 REGRESSION

Regression Output:	
Constant	28.23013
Std Err of Y Est	0.393342
R Squared	0.979285
No. of Observations	6
Degrees of Freedom	4
X Coefficient(s)	-1.0791
Std Err of Coef.	0.078474

NO2/3 REGRESSION

Regression Output:	
Constant	4.029179
Std Err of Y Est	0.24262
R Squared	0.26576
No. of Observations	6
Degrees of Freedom	4
X Coefficient(s)	-0.05824
Std Err of Coef.	0.048404

Nitrification Rate for Sponges — Flasks 1, 2, 3: 25 sponges per L of MLSS of IFAS-Sponge System

01/03/95 0.3 d Aer SS MCRT — Flask 4: IFAS-Sponge MLSS

SP.CEL3 SP.CELL3 SP.CELL3 SP.CELL3 SP.CELL3 SP.CELL3 Flask 3

Time [h]	NH3-N [mg/l]	NO2-N [mg/l]	NO3-N [mg/l]	NO2/3-N [mg/l]	N-TOTAL [mg/l]
initial					
0	25.8	0.47	3.38	3.85	29.65
1	23.3	0.54	6.25	6.79	30.09
2	21.1	0.57	8.96	9.53	30.63
3	18.3	0	11.74	11.74	30.04
4.57	15.6	0	16.2	16.2	31.8
6	12.05	0	21.64	21.64	33.69

NH3 REGRESSION

Regression Output:

Constant		25.599167
Std Err of Y Est		0.3241195
R Squared		0.9967355
No. of Observations		6
Degrees of Freedom		4
X Coefficient(s)	-2.259807	
Std Err of Coef.	0.0646636	

NO2/3 REGRESSION

Regression Output:

Constant		3.675754
Std Err of Y Est		0.5700536
R Squared		0.9937943
No. of Observations		6
Degrees of Freedom		4
X Coefficient(s)	2.8784234	
Std Err of Coef.	0.1137288	

CALCULATIONS BASED ON NH3

	Cell 1	Cell 2	Cell 3	ML_2Aer3	ML_4Aer3
nit.rate [mg/l/h]	1.0967166	1.079104	2.2598072	0.5274156	ERR
rate per sp. [mg/l/d]	0.3643527	0.3530806	1.1087306		
composite rate [mg/L/min]	0.0172238	0.0169302	0.0366086		
enhancement rate	1.9594164	1.9260223	4.1646802	1	
Total Nitr [mg/d]	572.93179	563.16738	1217.7492	2353.8484	

CALCULATIONS BASED ON NO2/3

	Cell 1	Cell 2	Cell 3	ML_2Aer3	ML_4Aer3
nit.rate [mg/l.h]	-0.306279	-0.058242	2.8784234	-0.003275	ERR
rate per sp. [mg/d/sp]	-0.290883	-0.052768	2.7664306		
composite rate [mg/L/min]	-0.007621	-0.00142	0.0719966		
enhancement rate	139.61689	26.015208	-1318.99	1	
Total Nitr [mg/d]	-253.5028	-47.2359	2394.8953	2094.1565	
Denit rate [mg/d/sp]	0.655236	0.4058491	-1.6577		

TIME [h]	4aer3	2aer3	SP CEL1	SP CEL2	SP CEL3
MLSS (mg/L)					
0		137.5	172.5	182.5	225
6		138.5	132.5	127.5	165
MLVSS (mg/L)					
0		122	152.5	162.5	195
6		128.5	125	107.5	143

Table C1. Nitrification Rate Measurements from Batch Tests

Table C1A. Nitrification Rates on Sponges

MCRT	3.1	2.4	1.7	1	0.3
Location	MG/SP/	MG/SP/	MG/SP/	MG/SP/	MG/SP/D
0-33%	2.075	2.82	1.67	1.565	0.323
33-67%	3.02	4.58	2.65	2.22	0.318
67-100%	0.737	2.32	2.66	2.355	1.243
Total	5.832	9.72	6.98	6.14	1.884

Total removal (mg/d on sponges, 880 sponges in each cell)

5132.16	8553.6	6142.4	5403.2	1657.92

Table C1B. Rates of Nitrification on Sponges (mg/sponge/day)

Cell	Cell 1	Cell 2	Cell 3	SCODbio	SCODbio	SCODbio	SCOD	SCODbio	NH4N
				Cell 1	Cell 2	Cell 3			
mg/sp/d	mg/sp/d	mg/sp/d	mg/sp/d	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
				15.1			35.1	15.1	9.1
2.82	2.82			17.2			37.2	17.2	10.3
1.67	1.67			26.1			46.1	26.1	12.2
1.565	1.565			40.4			60.4	40.4	25.1
0.282	0.282			69			89	69	33.2
0.36	0.36			57.6			77.6	57.6	33.2
3.02		3.02			9.2		30	9.2	2.6
4.13		4.13			10		29.2	10	4.1
5.02		5.02			9.2		29.2	9.2	4.1
2.22		2.22			18.4		38.4	18.4	6.9
2.355		2.355			28.3		48.3	28.3	21.3
0.35		0.35			34.1		54.1	34.1	30.8
0.684			0.684			6.3	26.3	6.3	0.4
0.79			0.79			6.3	26.3	6.3	0.9
2.32			2.32			7.2	27.2	7.2	0.9
2.66			2.66			14.7	34.7	14.7	3.3
2.355			2.355			20.2	40.2	20.2	17.7
1.243			1.243			27.8	47.8	27.8	27

Table C1C. Nitrification Rates per Cell (mg/L/min)

MCRT	Cell 1	Cell2	Cell3	MLSS	MLSS Control
3.1	0.103	0.138	0.079	0.068	0.081
2.4	0.106	0.152	0.093	0.037	0.04329
1.7	0.072	0.0973	0.0975	0.032	0.02867
1	0.053	0.07	0.076	0.0139	0
0.33	0.0166	0.0164	0.0405	0.0097	0

VITA

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