ALTERNATIVE NATURAL TECHNOLOGIES SEQUENCING BATCH REACTOR PERFORMANCE VERIFICATION

REPORT FOR

Dr. C. M. Williams,

Director of N. C. State University Animal & Poultry Waste Management Center, and

Designee for Environmental Superior Technology Determinations for the agreement between N.C. Attorney General and Smithfield Foods/Premium Standard Farms/Frontline Farmers

TECHNOLOGY PROVIDER

C. Douglas Goldsmith, Ph.D.

Thomas Smith

Alternative Natural Technologies, Inc.

1847 Whittaker Hollow Road
Blacksburg, VA 24060

PREPARED BY

John J. Classen, Associate Professor

Sarah K. Liehr, Ph.D., P.E.

North Carolina State University

Department of Biological & Agricultural Engineering

Raleigh, NC 27695-7625

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

Alternative Natural Technologies, Inc. (ANT) Sequencing Batch Reactor (ABR) was one of the projects selected for demonstration and evaluation as a candidate Environmentally Superior Technology for swine manure management under an agreement between the North Carolina Attorney General and Smithfield Foods, Premium Standard Farms and Frontline Farmers. The main objective of the technology performance verification was to determine the effectiveness of the system in terms of conversion or removal of solids, organic matter, nutrients, and metals.

The ANT Sequencing Batch Reactor (SBR) wastewater treatment system was installed on the R. C. Hunt farm in Bailey, North Carolina to treat half of the wastewater from 4200 pigs in six confinement buildings on the farm with a design capacity of 12,800 feeder to finish swine. The SBR wastewater treatment system is comprised of an equalization (EQ) tank of 390 m^3 (104,000 gal) total capacity (0.76 m, 2.5 ft freeboard) with two floating mixers (5.6 kW, 7.5 hp each), a reactor tank of 1,370 m^3 (363,000 gal) total capacity (0.76 m, 2.5 ft freeboard) with four floating aerators (5.6 kW, 7.5 hp each) and mixers (22 kW, 30 hp each), and two pumps to move wastewater into and out of the reactor. All wastewater leaving the SBR, as well as wastewater from the rest of the farm, flows to the primary lagoon. Flush tanks are refilled from the secondary lagoon. The treated wastewater in the lagoon is applied to land growing hay, corn, soybeans, and oats.

Whole wastewater with no solids separation is pumped into the reactor at the beginning of a cycle and is treated through several stages: Fill, React, Waste, Settle, and Decant. During the Fill stage, a portion of the reactor volume is replaced with fresh wastewater. The React stage consists of alternating aerated and non aerated conditions to promote nitrification and denitrification. Excess biomass is removed during the Waste stage while the reactor is mixed. After biomass wasting and a one hour settling period, clarified wastewater is removed from the reactor in the Decant stage and the cycle is repeated. The installation at the Hunt farm did not include a biosolids handling system so the excess biomass was sent to the lagoon as was the clarified wastewater for spray field application. This report details performance as installed as well as the potential performance if a biosolids handling system were installed as in a full scale installation.

The SBR system cycles were controlled byprograms designed and developedn by Alternative Natural Technologies, Inc. and wre installed using National Instruments Windows friendly software by Aegis Solutions (Raleigh, NC). The SBR and equalization equipment had remote control, monitoring, and observation capabilities.

The system was constructed during 2003 and the biological process was established between October 2003 and January 2004. Wastewater flowed from the six adjacent production houses to the EQ tank and the appropriate volume of wastewater was pumped to the reactor, depending on the COD concentration. Excess wastewater flowed through the EQ tank to the lagoon system.

Automatic samplers were installed in late 2003. Sampling began in January 2004 and continued through August 2004. Samples were taken twice each week and analyzed for total Kjeldahl nitrogen (TKN), ammonia, nitrite plus nitrate, total and soluble phosphorus, copper, zinc, and

chemical oxygen demand (COD) as an indication of carbon content of the wastewater. Flow into and out of the SBR system was measured by in-line flow meters with automatic data transmission to the computer control system.

Without disposing of biosolids, the SBR system was able to consistently achieve 83%, 64%, and 60% removal of TKN, COD, and suspended solids COD, respectively, under normal loading conditions. Including the planned biosolids handling system, the SBR system removed 90% of TKN, 84% of COD, and 90% of suspended solids COD under normal loading conditions. The system worked well when the COD loading rate was less than the design loading rate of 1,100 kg/d (2,400 lb/d); however the system experienced severe upset when it received a shock load up to 2,100 kg/d. The system operated well but less efficiently under consistent (intentional) overloading of 30%.

Although not installed as part of the SBR system, a biosolids handling system would be an important part of a full scale installation for off site disposal of biosolids. A screw auger press with polymer addition capabilities for biosolids dewatering was tested near the end of the evaluation period. This test was conducted by Somat Waste Reduction Technology (Coatesville, PA).

The tables below summarize the performance under normal operating conditions and increased loading conditions. Performance with and without biosolids disposal are shown. Comparing results in the two tables shows higher loading rates makes little difference in the removal of COD and SS-COD. Nitrogen removal decreases with the higher loading rate but is still near or above 50%. Phosphorus removal seems to increase substantially with the higher loading rate.

Summary Table 1. Average influent concentrations, mass loading, and percent removal under normal loading conditions

Parameter	Concentration (mg/L)	Mass Loading Rate (kg /d)	% Removal
SBR System as Tested			
Total Kjeldahl Nitrogen (TKN)	862	79.8	83.0
Total Ammoniacal Nitrogen (TAN)	637	58.6	96.8
Chemical Oxygen Demand (COD)	7310	687	63.7
Suspended COD (SS-COD)	5400	506	60.4
SBR with Planned Wasted Biosolids Handling and Disposal			
Total Phosphorus (TP)	118	11.0	36.5
Ortho-Phosphate-P (o-PO4)	96	8.82	34.6
Copper (Cu)	2.46	0.242	76.1
Zinc (Zn)	3.94	0.362	81.4
Total Kjeldahl Nitrogen (TKN)	862	79.8	90.0
Chemical Oxygen Demand (COD)	7310	687	84.0
Suspended COD (SS-COD)	5400	506	89.7

Summary Table 2. Average influent concentrations, mass loading, and percent removal under increased loading conditions

Parameter	Concentration (mg/L)	Mass Loading Rate (kg /d)	% Removal
SBR System as Tested			
Total Kjeldahl Nitrogen (TKN)	913	135	48.7
Total Ammoniacal Nitrogen (TAN)	619	91.5	56.2
Chemical Oxygen Demand (COD)	8860	1310	63.6
Suspended COD (SS-COD)	6200	916	59.9
SBR with Planned Wasted Biosolids Handling and Disposal			
Total Phosphorus (TP)	144	21.2	56.5
Ortho-Phosphate-P (o-PO4)	114	16.8	51.6
Copper (Cu)	5.59	0.826	88.1
Zinc (Zn)	4.18	0.618	89.8
Total Kjeldahl Nitrogen (TKN)	9.13	134.8	56.6
Chemical Oxygen Demand (COD)	8860	1310	78.8
Suspended COD (SS-COD)	6200	916	88.2

1.0 INTRODUCTION

In 2000, the Attorney General of North Carolina entered into agreements with Smithfield Foods and Premium Standard Farms to fund the development and evaluation of swine waste treatment technologies that were environmentally superior to the existing lagoon and spray field system in use on most North Carolina farms. Information about the overall program is available at the following web site: http://www.cals.ncsu.edu/waste_mgt/smithfield_projects/smithfieldsite.htm. A technology or combination of technologies is deemed an Environmentally Superior Technology (EST) if it is permittable by the appropriate government authority, is determined to be technically, operationally, and economically feasible, and meets the following performance standards:

1. Eliminate the discharge of animal waste to surface waters and groundwater through direct discharge, seepage, or runoff;
2. Substantially eliminate atmospheric emissions of ammonia;
3. Substantially eliminate the emission of odor that is detectable beyond the boundaries of the farm;
4. Substantially eliminate the release of disease-transmitting vectors and airborne pathogens; and
5. Substantially eliminate nutrient and heavy metal contamination of soil and groundwater.

The complete agreement is available at http://www.cals.ncsu.edu/waste_mgt/smithfield_projects/agreement.pdf.

Several technologies were selected for evaluation through a proposal review process. The Alternative Natural Technologies, Inc. (ANT) Sequencing Batch Reactor (SBR) was selected for evaluation on a swine finishing farm in Bailey, North Carolina.

A Sequencing Batch Reactor (SBR) is a wastewater treatment system that is operated in a cycle of several stages (Surampalli et al., 1997; Tchobanoglous & Burton, 1991). The most common stages are Fill, React, Waste, Settle, and Decant. During the Fill stage, part of the liquid volume of the reactor is replaced with fresh wastewater. (This is sometimes referred to as semi-batch operation.) Treatment takes place during the React stage, which can consist of aerobic, anaerobic or a combination of aerobic, anoxic, and anaerobic conditions, depending on the goals of the system design. Excess biomass is removed during the Waste stage, which can be either while the reactor is mixed or after the Settle stage when the biomass is concentrated in the lower reaches of the reactor. After biomass wasting and settling, clarified wastewater is removed from the reactor in the Decant stage and the cycle is repeated. The cycle can be of any duration but is often 24 hours for convenience.

Many applications of the SBR have been reported. In the swine waste industry, several research teams have reported success in using the SBR to remove nitrogen, phosphorus and COD from production wastewater (Bicudo et al., 1999; Bortone et al., 1992; Kim et al., 2000; Kim et al., 2004; Tilche et al., 2000).

2.0 SYSTEM DESCRIPTION

The ANT Sequencing Batch Reactor (SBR) wastewater treatment system was installed on the R. C. Hunt farm in Bailey, North Carolina to treat half of the wastewater from 4200 pigs in six confinement buildings (Figure 1) on the farm with a design capacity of 12,800 feeder to finish swine. The SBR wastewater treatment system is comprised of an equalization (EQ) tank of 390 m^3 (104,000 gal) total capacity (0.76 m, 2.5 ft freeboard) with two floating mixers (AIRE-O_2 Mixer, 5.6 kW, 7.5 hp each), a reactor tank of 1,370 m^3 (363,000 gal) total capacity (0.76 m, 2.5 ft freeboard) with four floating aerator (AIRE-O_2 Triton Aerator/Mixer, 5.6 kW, 7.5 hp each) / mixer (AIRE-O_2 Mixer, 22 kW, 30 hp each) combinations, a feed pump to transfer wastewater from the EQ basin to the SBR reactor (Hydromatic 40RP series, 3.7 kW (5 hp) 1.32 m^3 per minute (350 gallons per minute) at 1200 R.P.M.), and an effluent pump to transfer treated wastewater to the primary lagoon (Hydromatic 60RP series, 3.7 kW (5 hp), 2.08 m^3 per minute (550 gallons per minute) at 900 R.P.M.) (Figure 2). All wastewater leaving the SBR, as well as wastewater from the rest of the farm, flows to the primary lagoon. Flush tanks are refilled from the secondary lagoon. The treated wastewater in the lagoon is applied to land growing hay, corn, soybeans, and oats.

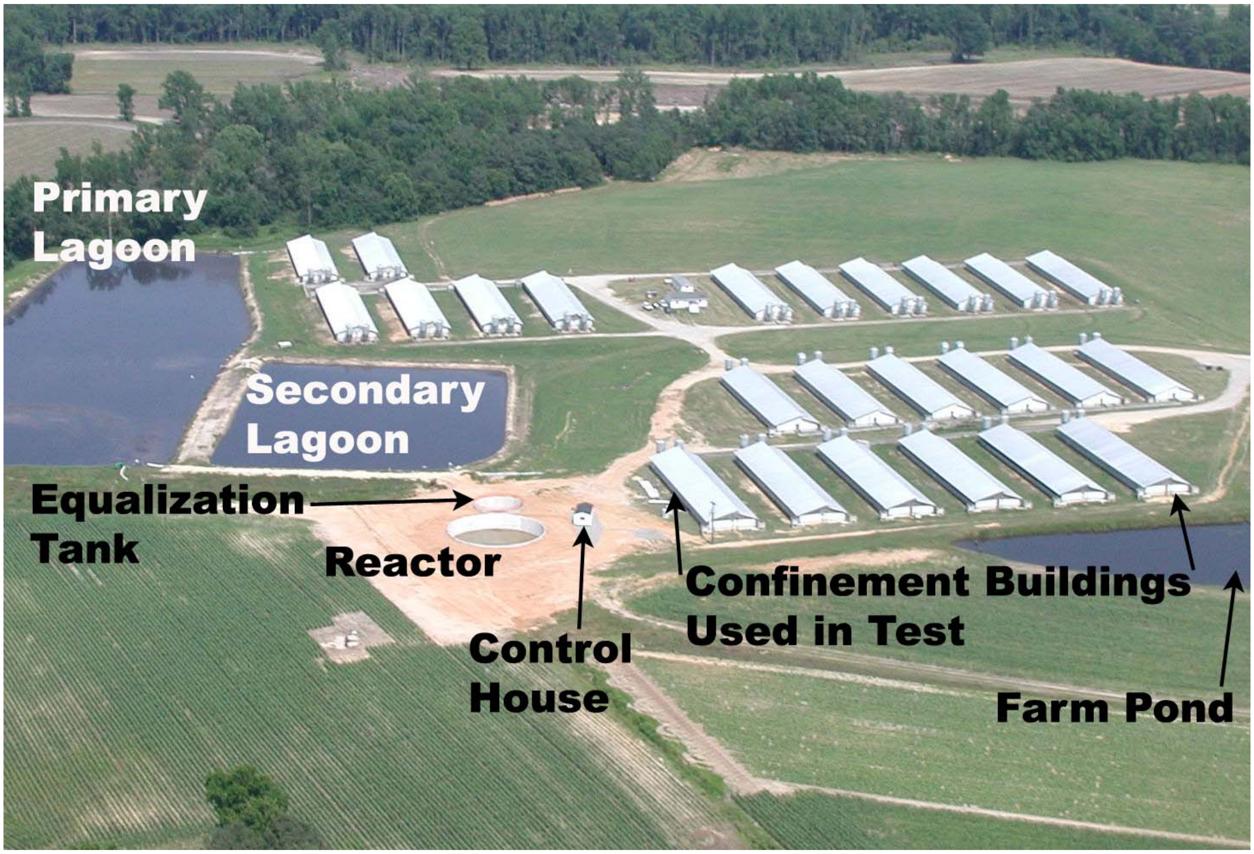

Figure 1. Aerial view of SBR on test site during construction of system

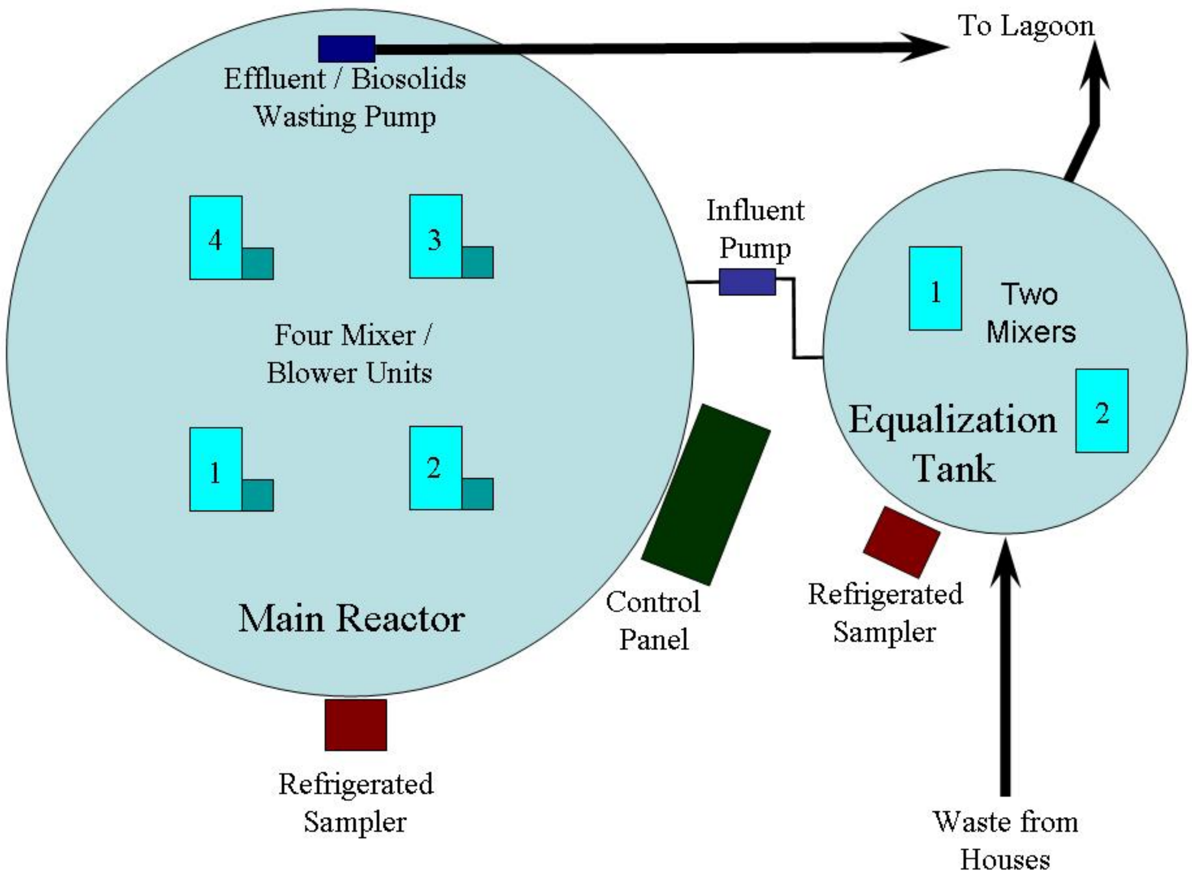

Figure 2. Schematic of SBR system

Wastewater flushed from the houses flows into the EQ basin. Excess wastewater in the EQ is carried to the primary lagoon by overflow piping. Floating mixers keep the wastewater well mixed and prevent settling of the solids. The SBR operates on a daily cycle. The end of the react stage generally occurred near 9:00 AM every morning so the first step of a new cycle was the biomass wasting stage. Biomass wasting took place while the reactor mixers were operating to better measure the actual biomass exiting the system. When biomass wasting is complete, all aerators and mixers are turned off to allow the reactor contents to settle. After settling, the clarified wastewater from just below the surface is pumped out of the reactor to the primary lagoon during the decant stage. After wasting and decanting are complete, fresh influent wastewater is added from the EQ basin, the reactor aerators are turned on and the react stage begins. Intermittent aeration cycles the reactor between aerobic and anoxic conditions during the react stage. The floating mixers operate continuously during the entire react stage of the cycle, regardless of the status of the aerators.

The SBR system cycles were controlled by an on-site computer and custom software designed and developed for this project by ANT, Inc. The operation of each pump, mixer, and aerator was scheduled independently and recorded by the computer. Also recorded were measurements of pH, temperature and dissolved oxygen in the SBR reactor tank. Figure 3 shows a typical operating scheme used to control the treatment system. Note the EQ tank mixer was always on as was at least one mixer in the SBR. Two of the SBR mixers and blowers were not used routinely but were available as backup if needed. The influent pump was operated twice during the cycle for short periods in order to prevent freezing of the pumps and transfer pipes during winter months.

	Step Delay (HH:MM:SS)	Effluent Pump Control	Mixer1 SBR Control	Mixer2 SBR Control	Mixer3 SBR Control	Mixer4 SBR Control	Blower1 SBR Control	Blower2 SBR Control	Blower3 SBR Control	Blower4 SBR Control	Influent Pump Control	Mixer1 EQ Control
Start of Process	0:00:01	0	0	0	0	0	0	0	0	0	0	0
Step 1 Waste	0:16:00	1	0	1	0	1	0	0	0	0	0	1
Step 2 Settle	1:00:00	0	0	0	0	0	0	0	0	0	0	1
Step 3 Decant	0:30:00	1	0	0	0	0	0	0	0	0	0	1
Step 4 Fill	1:11:00	0	0	1	0	1	0	1	0	1	1	1
Step 5	0:23:00	0	0	1	0	0	0	0	0	0	0	1
Step 6	1:00:00	0	0	1	0	1	0	1	0	1	0	1
Step 7	1:00:00	0	0	1	0	0	0	0	0	0	0	1
Step 8	1:00:00	0	0	1	0	1	0	1	0	1	0	1
Step 9	1:00:00	0	0	1	0	0	0	0	0	0	0	1
Step 10	1:00:00	0	0	1	0	1	0	1	0	1	0	1
Step 11	1:00:00	0	0	1	0	0	0	0	0	0	0	1
Step 12	0:57:00	0	0	1	0	1	0	1	0	1	0	1
Step 13	0:03:00	0	0	1	0	1	0	1	0	1	1	1
Step 14	1:00:00	0	0	1	0	0	0	0	0	0	0	1
Step 15	1:00:00	0	0	1	0	1	0	1	0	1	0	1
Step 16	1:00:00	0	0	1	0	0	0	0	0	0	0	1
Step 17	1:00:00	0	0	1	0	1	0	1	0	1	0	1
Step 18	1:00:00	0	0	1	0	0	0	0	0	0	0	1
Step 19	1:00:00	0	0	1	0	1	0	1	0	1	0	1
Step 20	1:00:00	0	0	1	0	0	0	0	0	0	0	1
Step 21	1:00:00	0	0	1	0	1	0	1	0	1	0	1
Step 22	1:00:00	0	0	1	0	0	0	0	0	0	0	1
Step 23	1:00:00	0	0	1	0	1	0	1	0	1	0	1
Step 24	0:01:00	0	0	1	0	0	0	0	0	0	1	1
Step 25	0:59:00	0	0	1	0	0	0	0	0	0	0	1
Step 26	1:00:00	0	0	1	0	1	0	1	0	1	0	1
Step 27	1:00:00	0	0	1	0	0	0	0	0	0	0	1
Step 28	0:40:00	0	0	1	0	1	0	1	0	1	0	1
End of Process	0:00:01	0	0	0	0	0	0	0	0	0	0	0

Figure 3. Typical control scheme for SBR system

The primary goals of the ANT system were to remove suspended solids, carbonaceous material measured as chemical oxygen demand (COD), and nitrogen both reduced nitrogen (ammonia) and oxidized nitrogen (nitrate). The process design of the SBR was based on a total COD load of 1,100 kg/d (2,400 lb/d) and total nitrogen load of 135 kg/d (300 lb/d). The system was initially set to operate with one cycle per day, a seven day hydraulic retention time (HRT) and a 35 day biosolids retention time (BSRT). A secondary goal was to determine if solids, COD, and nitrogen reductions could be maintained with lower BSRT and HRT. Results from various BSRTs provide data that allows for the sizing of tanks for any flow or loading rate.

The installation at the Hunt farm did not include a biosolids handling system. Because all biosolids and effluent from the SBR system were discharged to the lagoon, the evaluation considered both waste streams leaving the plant. Because a full scale installation would include some form of biosolids handling, the evaluation also considered the potential performance by quantifying the effluent stream separately.

In a new commercial installation, an alternative biosolids handling method would be attractive. A small test model of a polymer addition and screw press dewatering system was tested near the end of the evaluation period. This test was conducted by Somat Waste Reduction Technology (Coatesville, PA). The results of this evaluation are included in this report (Appendix A) but the samples were collected and analyzed by Somat and not by NCSU. Wasted biomass was diverted to a decanting sump rather than discharged to the lagoon. Additional thickening was obtained by repeating the settling process in an additional tank. The flocculant selected for this application was a cationic emulsion polymer manufactured by Ciba Specialty Chemicals, product ID – Zetag 7879FS40.

3.0 PERFORMANCE EVALUATION METHODS

The performance of the candidate Environmentally Superior Technologies is based on its environmental performance of the system as well as economic data and analysis. The environmental performance is based on efficiency of treatment for carbon, nutrients, and metals, measurements of pathogens in liquid and air, odor emissions, and release of ammonia to the atmosphere. The treatment efficiency of the SBR is the subject of this report and was determined by an analysis of flow data and periodic samples to quantify the fate of components of interest. The parameters quantified in samples were total Kjeldahl nitrogen (TKN), ammonia, nitrite plus nitrate, total and soluble phosphorus, copper, zinc, suspended solids and total and soluble chemical oxygen demand (COD) as an indication of carbon content of the wastewater. Suspended COD was calculated as the difference between total COD and soluble COD. All parameters were analyzed according to Standard Methods (Clesceri et al., 1995) as modified by the Environmental Analysis Laboratory at North Carolina State University (Classen et al., 2003). The pH of each sample was measured on-site at the time of collection.

Flow into and out of the SBR reactor was measured by in-line flow meters with automatic data transmission to the computer control system. Samples were collected twice per week except when the system was in transition between different operating conditions. Automatic refrigerated samplers (Model 6712FR, Isco, Inc., Lincoln, NE) equipped with 24 one liter bottles were installed at the EQ basin and at the SBR reactor. Time-weighted composite samples were collected from the EQ basin during the fill cycle, from the reactor during the wasting cycle, and again from the reactor during the decant cycle. A grab sample was also taken from the secondary lagoon on each sampling trip.

System performance was calculated for each parameter as the difference between the influent mass and effluent mass expressed as a percent of the influent mass. Influent mass was calculated as the concentration determined from laboratory analyses of the fill cycle samples multiplied by the influent volume measured by the flow meters. For the system as installed, effluent mass was calculated as the sum of the mass in the wasting cycle and in the decant cycle; the mass of each parameter in the wasting and decant cycles were determined in the same manner as for the influent, as the concentration determined from laboratory analyses of the decant and effluent cycle samples multiplied by the volume of each cycle measured by the flow meters. For the potential performance with a biosolids handling system, the entire flow out of the system was assumed to have the concentration of the effluent.

4.0 SYSTEM STARTUP AND OPERATION

The SBR system was constructed during the summer of 2003 and filled with groundwater during September 2003. Inoculum was added as return activated biosolids from a nitrifying waste treatment plant and was delivered to the site by tanker trucks in the amount of 13.6 m^3. This was a one percent inoculum by volume. The biosolids were between 2-3 percent solids in the inoculum. The SBR was monitored closely for floc formation by the 30 minute settling test in a one liter cylinder. Additional swine waste was added over time as given in Table 1 when good settling and reasonable total COD reduction was evident. Biomass was not wasted during this procedure to allow the biomass to maintain stationary phase growth and good settling characteristics. Additionally, this method allowed an increase in the total biomass concentration within the SBR towards the goal of 5000 mg/L.

Table 1. SBR startup chronology

Date	Activity	Daily Flow (m^3)	COD inf (mg/L)	COD eff (mg/L)	COD inf kg	COD % Red	30 min SV (mL)	SBR Biosolids (mg/L)
10/27/2003	SBR inoculated with 13.6 m^3 thickened biosolids						5	50
10/28/2003	Biomass building	22.7	17,700		401			
10/29/2003	Biomass building	22.7	14,100		320			
10/30-11/5	Biomass building							
11/6/2003	Biomass building	32.2	14,000	285	450	97.96	120	950
11/8/2003	Biomass building	32.2						
11/17-23/2003	Biomass building	48.3	14,600		706		260	1700
11/24/2003	Biomass building	64.4	12,800		820			
12/1/2003	Biomass building	80.4	11,200	814	910	92.76	400	3500
12/11/2003	Biomass building						500	4600
12/12/2003	Biomass building	80.4	11,100	1800	900	83.84		
1/5/2004*	Biomass building	80.4	5,600	976	452	82.57	670	5100
1/14/2004	Re-stabilization	114	4,570		518		300	4900
1/20/2004	NCSU begins test sampling							

*Barns being emptied and refilled resulted in a drop in COD

Verification testing began in late January 2004. In early February a large amount of feed was spilled in one of the production houses and washed into the under floor waste pit. This added organic matter caused a large spike in suspended components of the influent waste stream, upsetting the biological treatment process. After several sampling events, it became clear that the system would take some time to recover so sampling was suspended for approximately one month, until mid March. Sampling of the stable system proceeded twice each week until the end of August. Operational changes were initiated on June 24 in attempts to improve the system and to test the limits of the system.

Dissolved oxygen levels became consistently higher than expected late in the react stage, indicating the bacteria were not actively consuming organic matter or easily degraded COD was in low supply. Suspecting the reason was that the COD was being depleted, on June 25, 2004, ANT split the influent volume to create two 12 hour treatment cycles, delivering half the volume immediately after the decant stage and the other half midway through the react stage (approximately 10:30 pm). The duration of each fill stage was just over one hour. In August the loading rate was increased by increasing the flow rate in an effort to see how the system reacted. Sampling continued until the end of August.

5.0 PERFORMANCE RESULTS

5.1 TECHNOLOGY VERIFICATION CONDITIONS

5.1.1 Flow Rates

Design and optimization strategy of the SBR system is typically based on COD loading rate. This system was designed for a sustained COD loading rate of 1020 kg/day. COD mass loading rate is generally used for design and operation of microbial treatment processes because (1) COD is the best indicator of potential demand for oxygen, (2) COD is quick and easy to measure, and (3) COD-utilizing microorganisms (heterotrophs) tend to dominate microbial systems and can prevent ammonia oxidizing organisms from thriving. Therefore, COD is an important control parameter, even when nitrogen removal is the major concern.

Control of the inflow rate was based on attempting to keep the COD loading rate constant, until August 1, at which time the loading rate was approximately doubled to deliberately overload the system. Early in the study (February), an unexpected spike in COD loading occurred (as shown in Figure 4) due to cleaning operations in the swine houses. This extreme loading event caused subsequent disruption of the treatment function, as will be discussed later. The study design was based on preliminary concentration data, which predicted that this COD loading rate would correspond to a hydraulic retention time (HRT = tank volume / inflow rate) of seven days. However, because influent COD concentrations were highly variable, HRT was not held constant at seven days (Figure 5). For most of the study, the HRT was greater than seven days, until after August 1, when loading rates were increased by increasing the inflow rate. The average flow rate to the system during normal loading was 100 m^3/d (26,000 gpd); the average after August 1 was 150 m^3/d (39,000 gpd).

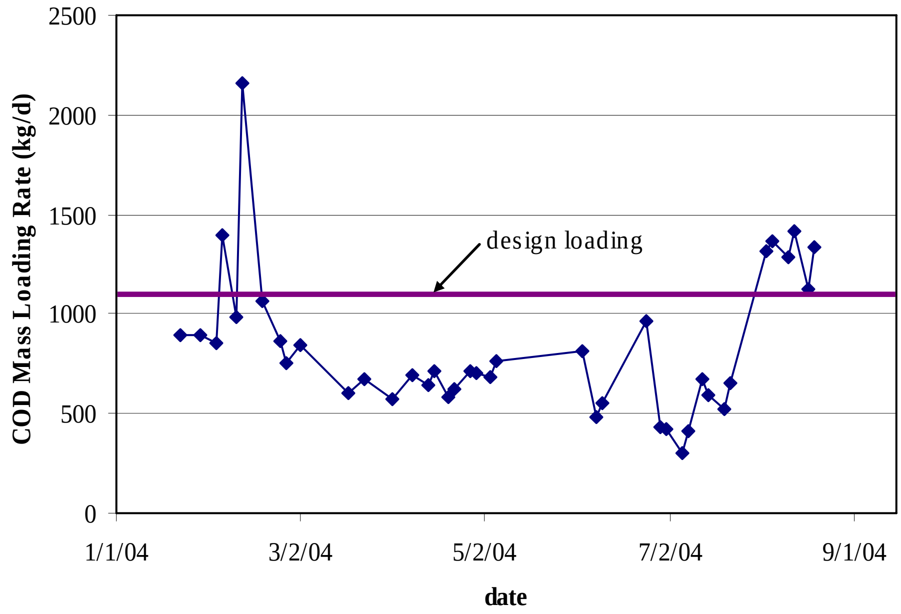

Figure 4. COD loading to the SBR system

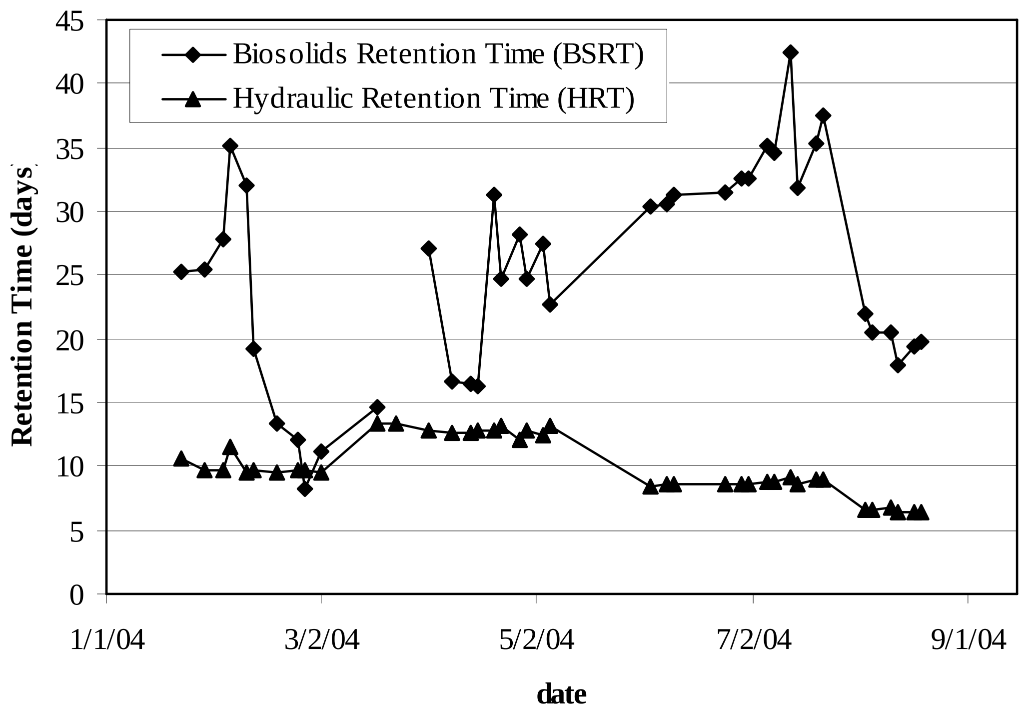

Figure 5. Biosolids retention time (BSRT) and hydraulic retention time (HRT)

The operational parameter that is most important to treatment efficiency is not the HRT, but the biosolids retention time (BSRT). BSRT is equal to the mass of suspended biosolids in the tank divided by the rate of suspended biosolids leaving the tank each day. This gives the number of days biosolids are retained in the reactor, which gives an indication of the time that microorganisms have to biodegrade the waste components. The BSRT also represents the age of the microbial mass, which influences their metabolic rate and the settling characteristics. BSRT is controlled by the rate of biosolids wasting from the treatment reactor. In this system, biosolids are wasted while the reactor is mixing. The amount of mixed liquor wasted, along with the concentration of suspended biosolids in the mixed liquor and in the effluent, determine the BSRT. After the biosolids are wasted, the mixers are turned off and the tank contents are allowed to settle; the effluent is then drawn off the top. If the biosolids have not settled well, the effluent will contain a lot of suspended solids, which increases the rate of biosolids leaving the reactor, which shortens the BSRT. Therefore, it is essential to get good settling of the biosolids to be able to get an adequately long BSRT for good treatment. Good settling generally depends on having a system that is operating well with development of aerobic microbial populations.

The goal for this system was to have a BSRT of 35 days. This goal was not always met, although the BSRT was generally above 25 days when it received no more than the design loading rate (Figure 5), which was adequate for good treatment. After the unexpected spike in February, the system was under extreme stress, causing a shift in the microbial population that led to complete deterioration of the settling. Because of this event, it was not possible to maintain an adequate BSRT for good treatment, and in fact the BSRT was approximately equal to the HRT (Figure 5), indicating almost complete lack of settling. The system recovered by April 1. The treatment efficiency during this time (between mid-February and April 1) is included in the general discussion of treatment efficiency, but is not included in the discussion of “normal loading”. The BSRT also fell below 25 days after August 1 when the system was deliberately overloaded for testing purposes. Treatment efficiency during this period of operation will also be discussed separately.

5.1.2 Airflow and Dissolved Oxygen

Air is supplied by four 5.6 kW (7.5 hp) Aire-O_2 Triton aerator. Each is associated with a 22 kW (30 hp) mixer by the same company. The mixer can operate independently of the aerator to provide mixing without air transfer. The system design specified two units; the additional two units were added for reliability and the capacity to test higher loading rates.

Dissolved oxygen (DO) levels were monitored continuously as the aerators cycled on and off on a 24-hour cycle. Average DO concentrations varied during the evaluation (Figure 6), reflecting differences in oxygen demand loading rates, different operating strategies for the aerators, and different treatment efficiencies leading to differing amounts of oxygen demanding material in the reactor.

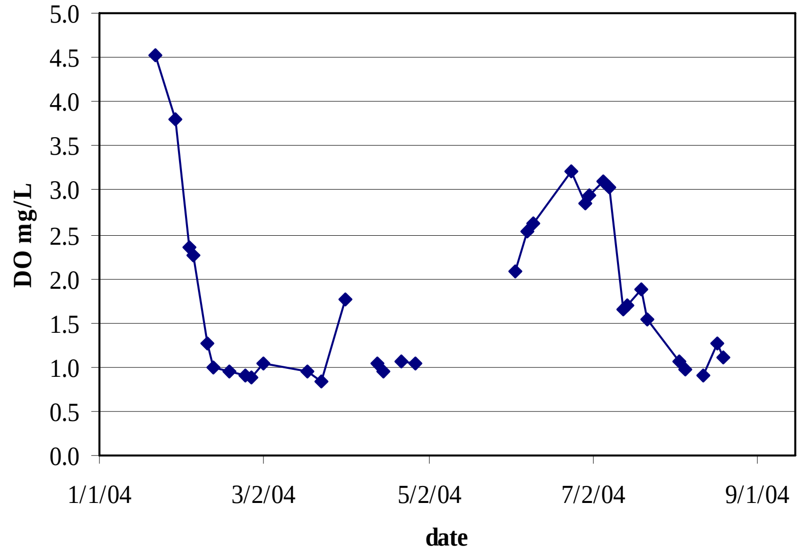

Figure 6. Average dissolved oxygen (DO) concentrations in the SBR tank

5.1.3 Temperature and pH

Average temperatures in the influent and effluent increased fairly steadily during the evaluation, as the time of the evaluation moved from February to late August (Figure 7). Differences in temperature of the influent and effluent averaged 7^{o}C. The pH of the reactor tank was between 7.0 and 8.0 during this study (Figure 8) which is a normal range for this type of treatment system.

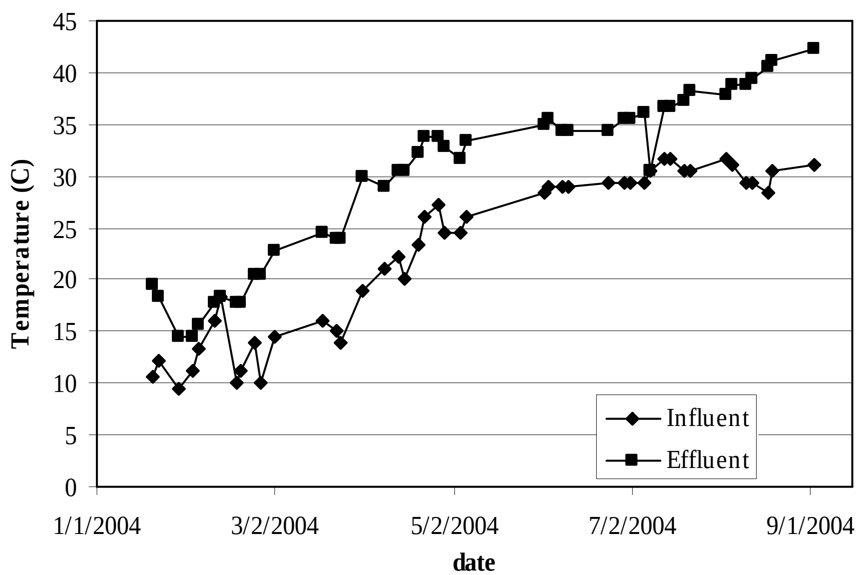

Figure 7. Average temperature (^{o}C)

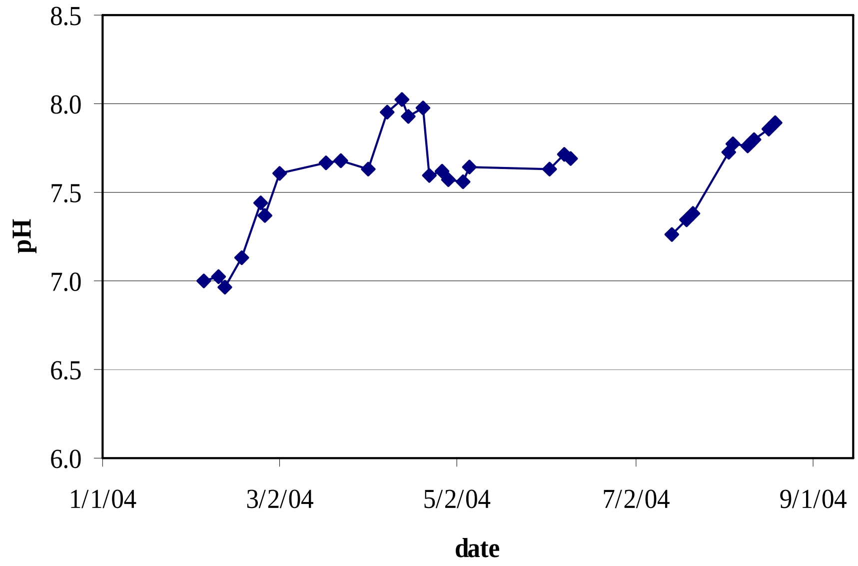

Figure 8. Average pH in the SBR tank

5.2 Treatment Efficiency of System as Installed

The installation at the Hunt farm did not include a biosolids handling system so the excess biomass was sent to the lagoon as was the clarified wastewater. Consequently there are two ways to describe the efficiency of the SBR system. First, because the biosolids remained on site and were lagoon disposed, the effluent stream and wasted biosolids were both used to calculate the efficiency of the system as installed. Second, in anticipation of including a biosolids handling and disposal component in a full scale SBR installation, the treatment efficiency was calculated from the effluent stream alone. This section of the report describes the efficiency as installed; section 5.3 describes the efficiency including the planned biosolids handling system.

5.2.1 Nitrogen Removal Efficiency

Concentrations: inflow, lagoon, effluent, waste (ML)

Nitrogen in the influent was all in the form of total Kjeldahl nitrogen (TKN). Concentrations of TKN varied over the study period (Figure 9), with an average of approximately 890 mg N/L. Total ammoniacal nitrogen (TAN) made up approximately 73% of the TKN. Suspended solids TKN made up approximately 26% of the total.

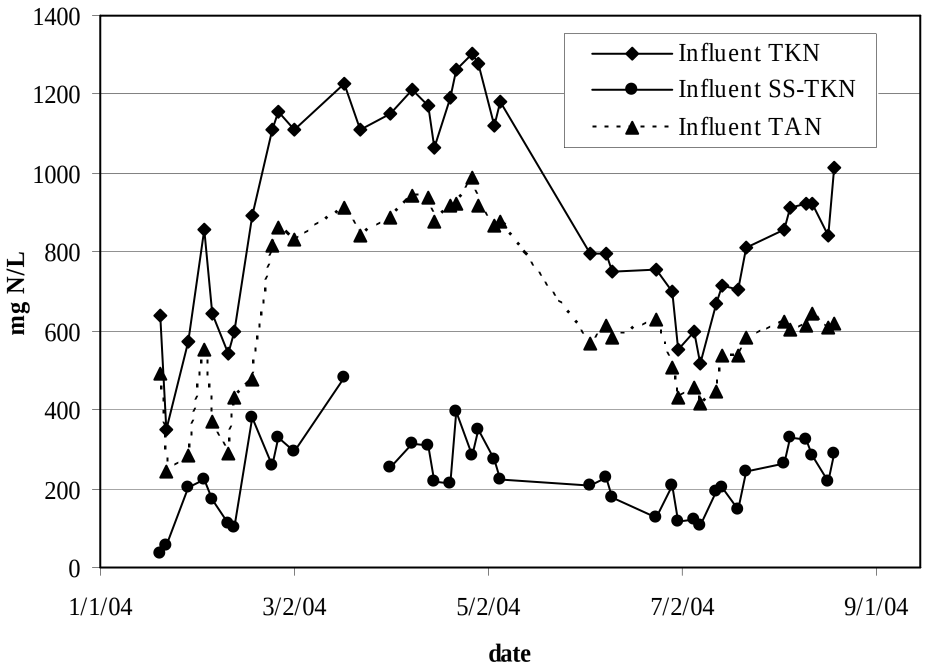

Figure 9. Influent concentrations of TKN, suspended TKN, and total ammoniacal-N (TAN)

Total Loading: Animals Plus Flush Water

The total nitrogen mass loading to the system was calculated using the composite sample concentration of the influent to the system and the total volume of wastewater added per day. The spike in loading that occurred in February (Figure 10) was not as dramatic as the spike in COD loading (Figure 4). The TKN loading rate also clearly shows the increased loading that occurred in August.

The mass loading, as calculated above, includes nitrogen from the manure as well as nitrogen contained in the flush water from the secondary lagoon. Lagoon concentrations were much lower than the manure concentrations, but the volume of flush water was relatively large. (Lagoon concentrations can be seen compared to input concentrations in Figure 11.) The relative contributions from the manure and the flush water vary as the pigs grow. Estimates were made of the relative contributions using the pig weights determined by the OPEN evaluation team during five weeks of the study period and using average factors of 0.5 kg N/day per 1000 kg live weight and 142 L/day of manure per 1000 kg live weight (ASAE, 2003; Barker et al., 1994). Mass balance was used to calculate the volume of flush water (Table 2). The first date represents the least weight of pigs with all the houses full, with weight of pigs ranging from 23 to 45 kg/head. The last date represents a case close to the maximum weight of pigs, with weight of pigs ranging from 77 to 100 kg/head. The estimated percent of the total nitrogen input that came from manure ranged from 66% for the smaller pigs to 86% for the larger pigs.

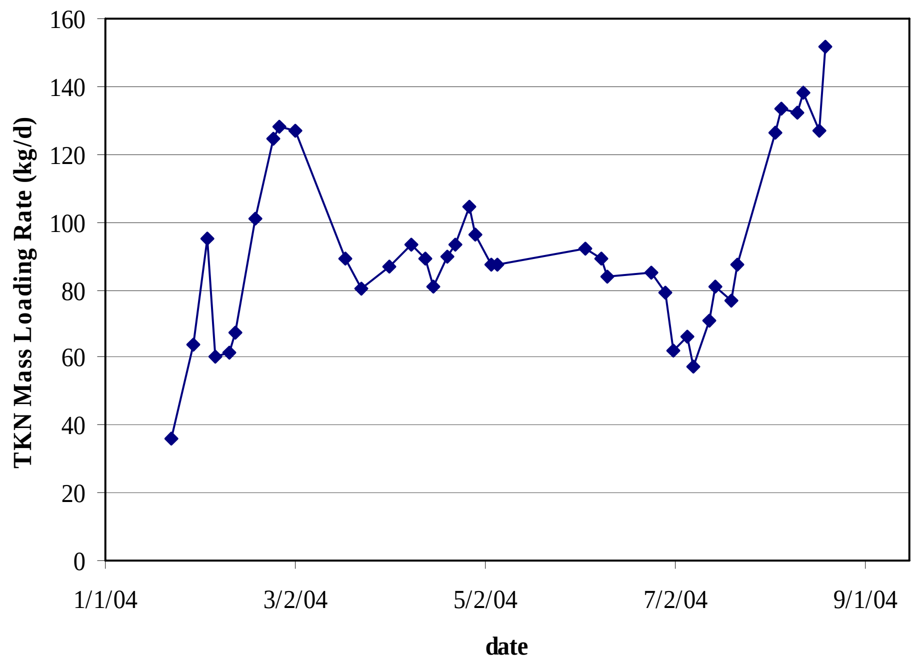

Figure 10. Mass loading rate of TKN to the SBR system

Concentrations of TKN in the influent and effluent indicate significant nitrogen removal took place at all times that the system was operating (Figure 11). Effluent quality was especially good during times when waste loading was within design specifications. Total ammoniacal nitrogen (TAN) concentrations also indicate very good removal in the treatment reactor (Figure 12). During times of normal loading rates, the effluent concentrations of TKN and ammonia were substantially lower than that of the lagoon (Figures 11 and 12), indicating that this system would eventually reduce ammonia levels in the lagoon if the entire waste stream was treated.

Table 2. Estimated nitrogen contributions from manure and flush water

Date	Mass of Pigs (kg)	Manure N (kg N/d)	Manure Volume (m^3/d)	Inflow TKN (mg N/L)	Lagoon TKN (mg N/L)	Flush Volume (m^3/d)	N (flush) / N (total)	N (manure) / N (total)
2/16/2004	119,635	59.8	17.0	895	361	83.6	0.34	0.66
2/23/2004	135,025	67.5	19.2	1,110	377	63.2	0.26	0.74
3/1/2004	149,667	74.8	21.2	1,110	344	66.9	0.24	0.76
4/19/2004	274,527	137.3	38.9	1,190	276	99.5	0.17	0.83
4/26/2004	287,500	143.8	40.8	1,300	270	87.7	0.14	0.86

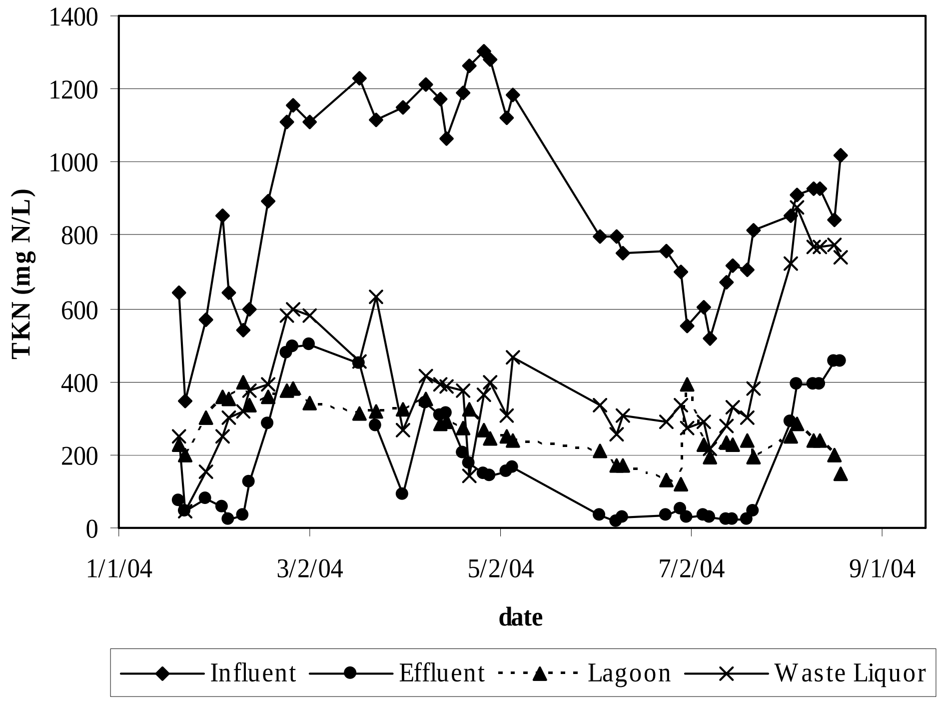

Figure 11. TKN concentrations in the SBR system

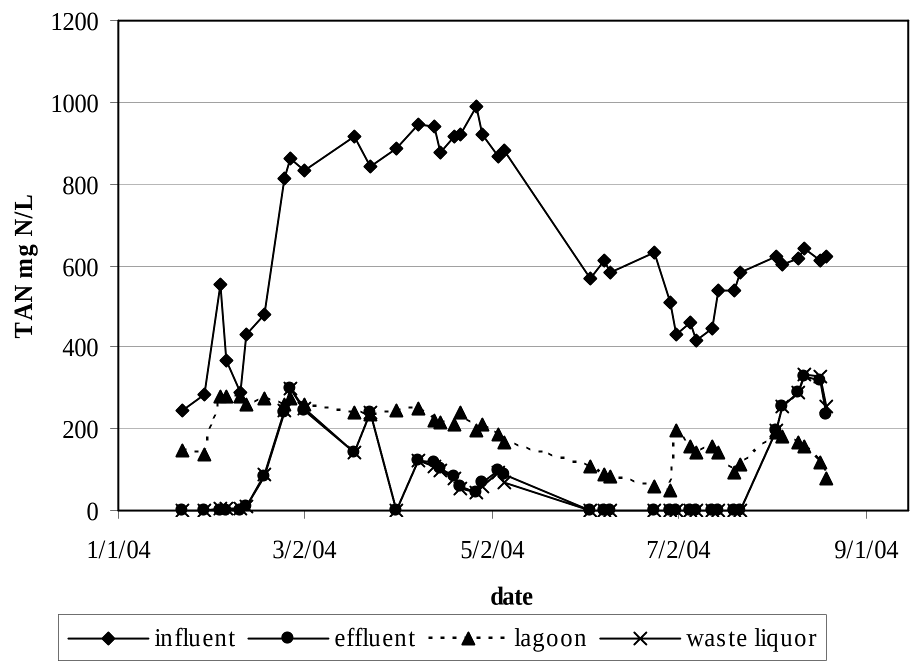

Figure 12. Concentration of TAN in the influent, effluent, lagoon, and waste liquor

Removal Rates and Removal Efficiencies

The effluent quality does not give the total picture, however, of actual nitrogen removal because it does not include nitrogen in the waste liquor that was removed prior to settling as a means of wasting biosolids from the reactor. Without a biosolids handling system installed, the wasted biosolids were sent to the lagoon just as the effluent was. Consequently, the mass in both waste streams was included in calculations of treatment efficiency of the SBR system as tested. In terms of nitrogen, this only affected the TKN removal (not TAN) because TAN concentrations were the same in the effluent and in the waste liquor.

TKN removal by the treatment system generally varied between 45 and 85 kg N/day throughout the study period, regardless of loading rate (Figure 13). The period of overloading at the end of the evaluation did not significantly increase or decrease the rate of nitrogen removal. However, the removal efficiency (percent removed) did significantly decrease during that period (Figure 14). During the time that the system was operating within design loading criteria, the average removal efficiency was 83%. Total ammoniacal-N removal efficiency was even higher, with average 97% removal when the system was not COD-overloaded (Figure 15). The following discussion will include only data collected while the system was operating within design loading criteria.

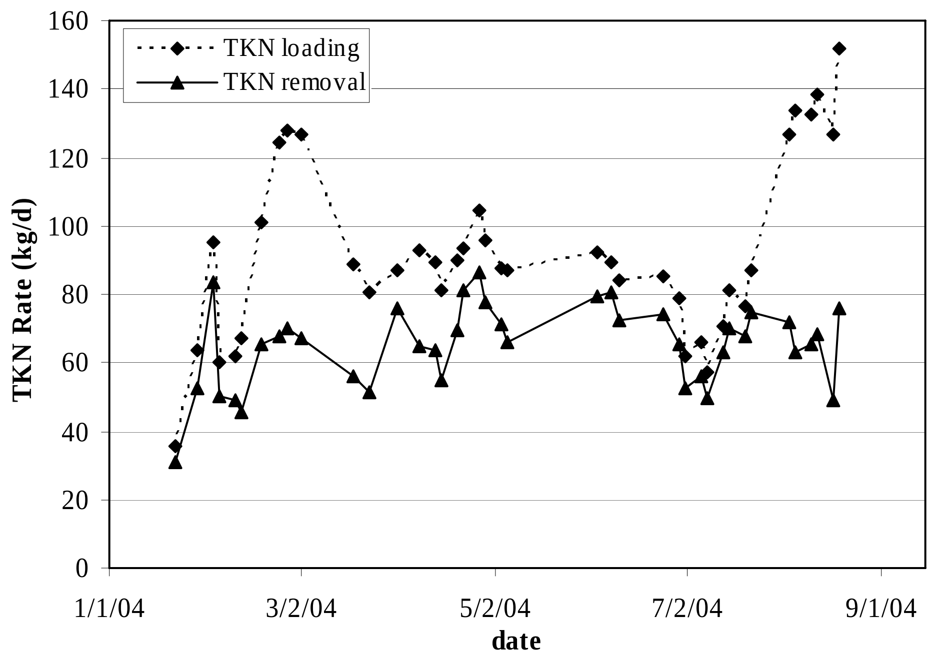

Figure 13. Mass flow of TKN in the SBR system

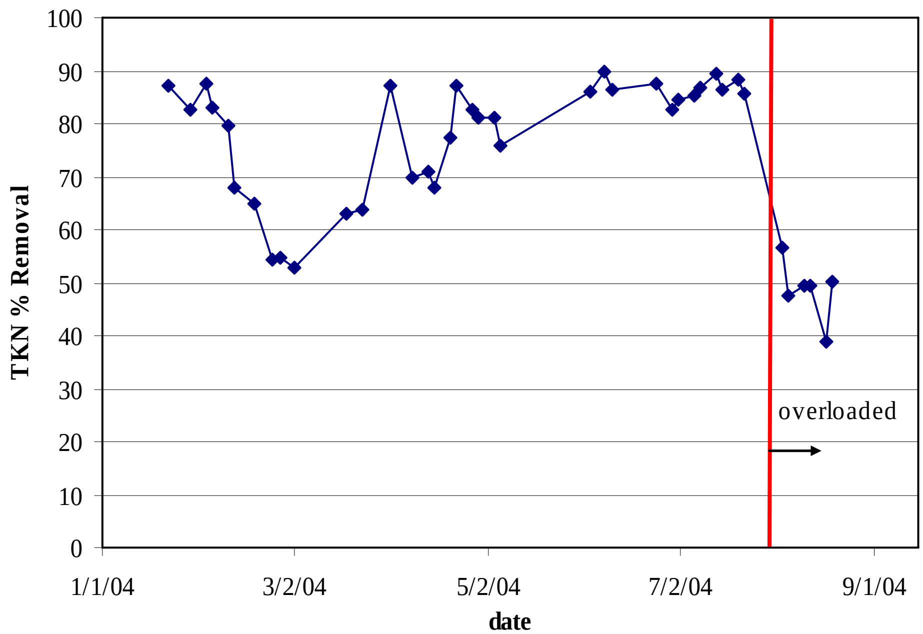

Figure 14. Removal efficiency (%) of TKN from the SBR system

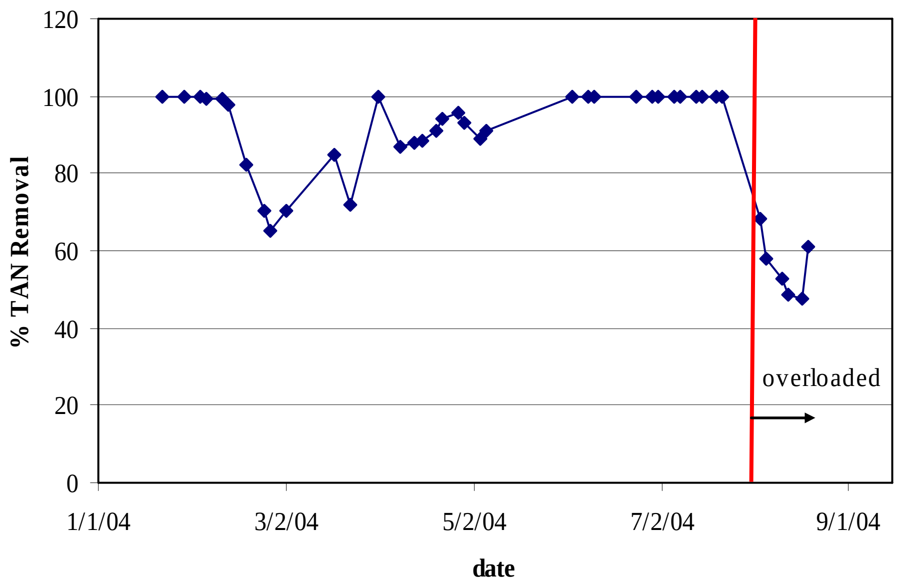

Figure 15. Removal efficiency (%) of TAN from the SBR system

Removal Rate vs. Loading Rate

The TKN removal percentage was not a function of mass loading for the range of loading rates considered. However, the mass removal rate did increase with increased mass loading (Figure 16). This increase did not continue outside the range of design COD loading rates.

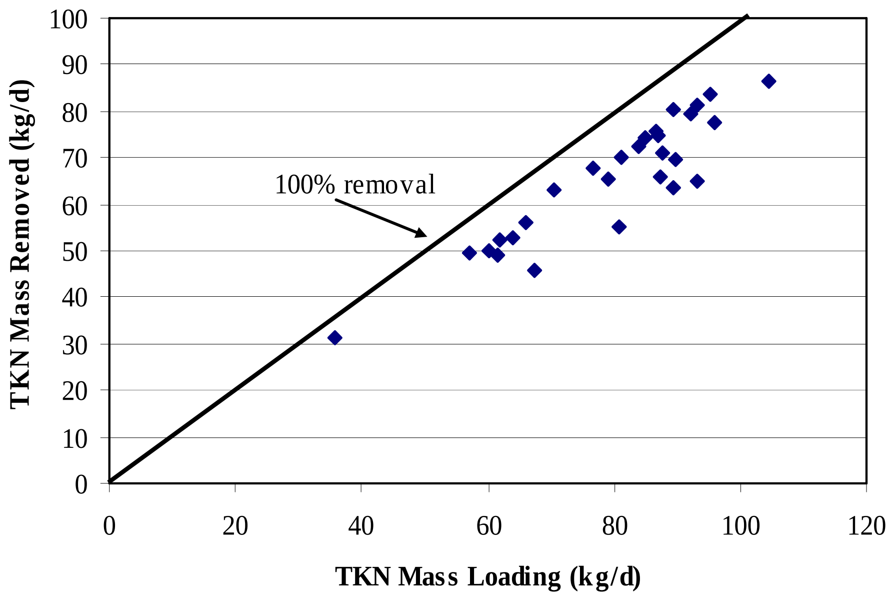

Figure 16. TKN mass removal rate as a function of TKN mass loading rate under normal loading conditions

Biosolids retention time (BSRT) is an important parameter in the control of microbial treatment processes. Treatment efficiency for TKN increased with increasing BSRT when BSRT was less than 25 days, but there was no improvement in efficiency for BSRT greater than 25 days (Figure 17). Again, this relationship was not consistent outside the range of design COD loading rates. TAN removal efficiency was also very high, frequently close to 100%, when the BSRT was greater than 25 days (Figure 17).

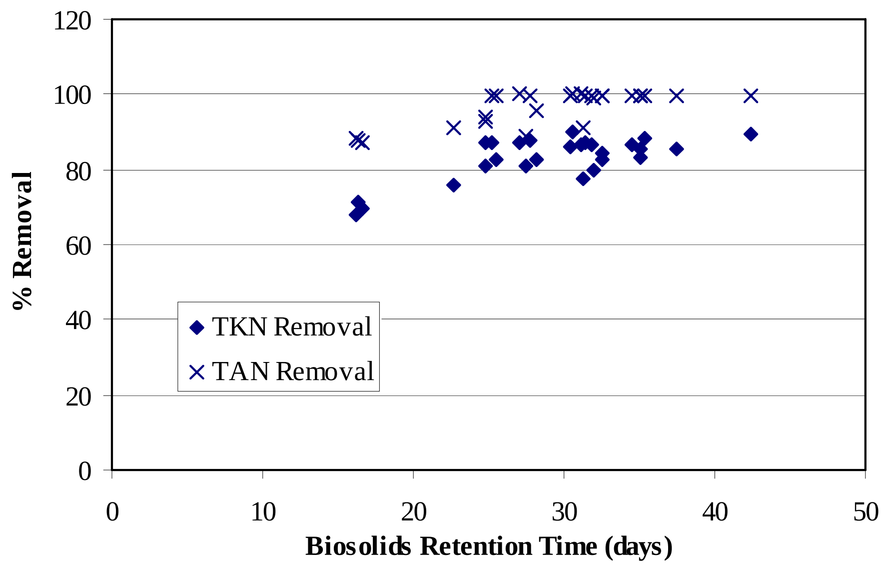

Figure 17. Nitrogen removal efficiency (%) as a function of biosolids retention time

Nitrogen Removal Mechanism

The nitrogen removal mechanism was not measured directly, but there is good evidence that the major removal mechanism was the microbial process of nitrification (conversion of ammonia to nitrate or nitrite) followed by denitrification (conversion of nitrate or nitrite to N_2 gas). The first step of this process, conversion of ammonia to nitrate or nitrite, is generally thought to be the rate-limiting step in oxygen limited systems. Therefore, even in systems where this process is the major removal mechanism for nitrogen, accumulation of nitrate or nitrite is not always observed. However, there were periods of time during the operation of this system when significant concentrations of nitrate or nitrite were observed (Figure 18). Therefore, direct evidence exists that nitrification was taking place in this system during those times.

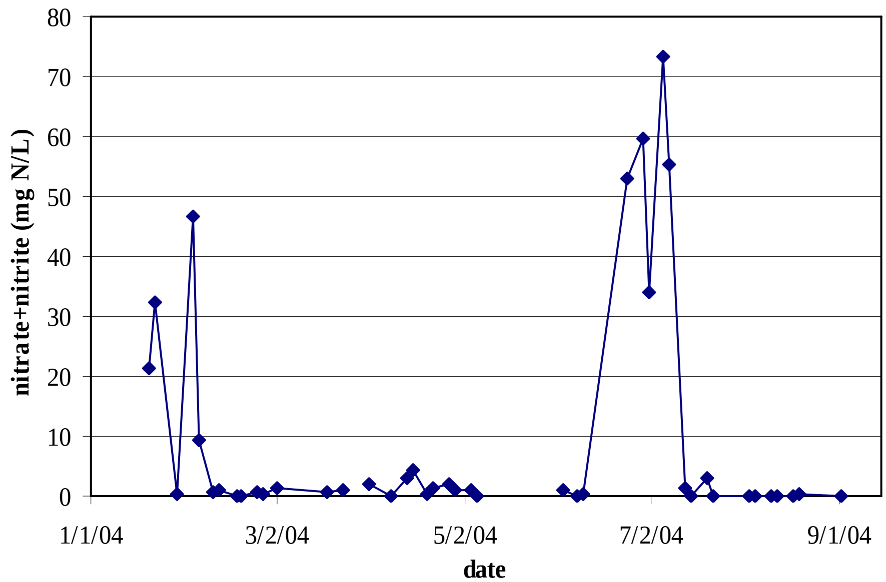

Figure 18. Concentrations of nitrate plus nitrite nitrogen in the SBR

There is another effect of nitrification / denitrification that can be directly observed. The nitrification step results in the production of acid, which is released to the water and consumes an equivalent amount of alkalinity (7.14 mg of alkalinity per mg of N). The denitrification reaction replaces half of the alkalinity that was consumed by the nitrification reaction. Therefore, nitrogen that is removed by the nitrification / denitrification process will consume approximately 3.57 mg of alkalinity per mg of N removed. Alkalinity was significantly reduced in the treatment reactor of this system (Figure 19). The ratio of the actual amount of alkalinity consumed in the treatment system to the theoretical amount that would have been consumed by the amount of nitrogen removed was calculated (Figure 20). During initial operation, this ratio was less than one, indicating that the nitrogen removal microbial population may have not been well established at this time. During the time period of normal operation (April through July), the ratio averaged 0.82). Since this ratio was calculated using theoretical numbers, it is not an exact representation of the system, but it does indicate that a high percent of the nitrogen removed was likely due to nitrification / denitrification rather than volatilization.

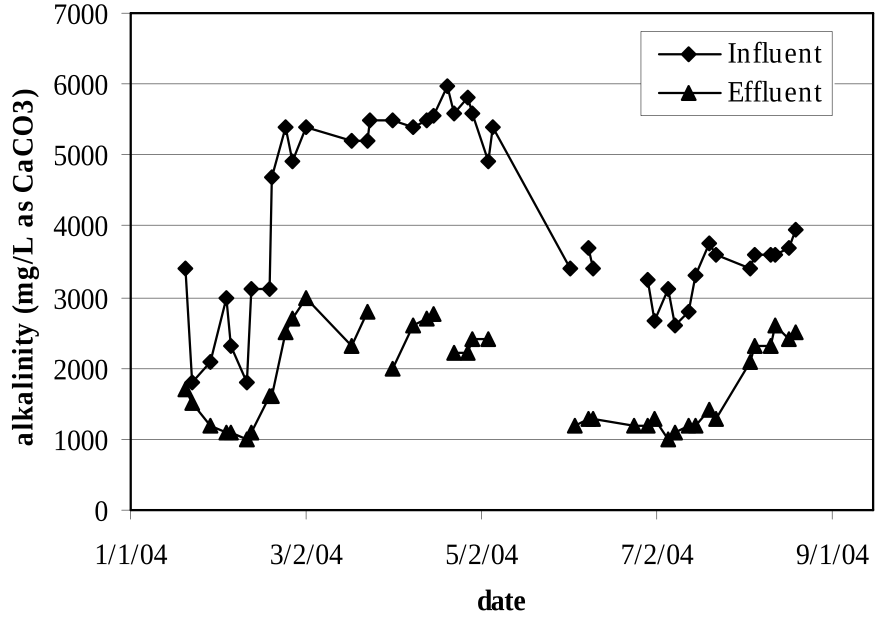

Figure 19. Concentrations of alkalinity in the influent and effluent of the SBR system

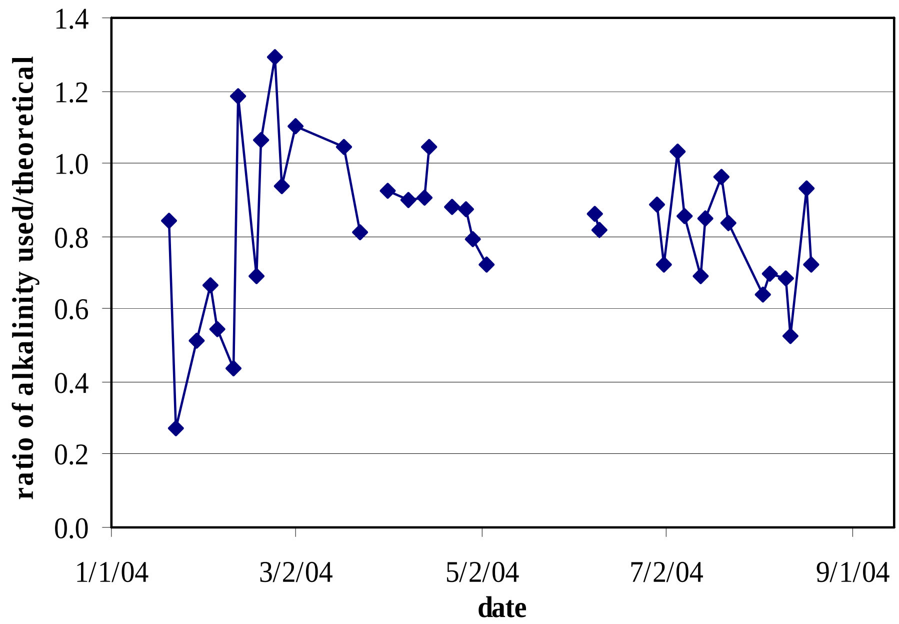

Figure 20. Ratio of alkalinity consumed to the theoretical consumption of alkalinity expected due to nitrification / denitrification in the SBR system

5.2.2 COD Removal Efficiency

Concentrations: inflow, lagoon, effluent, waste (ML)

Influent COD concentrations varied between 3800 and 10400 mg/L, except in mid- to late February (Figure 21), with an average of 7700 mg/L. We cannot be sure of the cause of the spike in COD concentration at that time, but workers at the farm indicated they were cleaning a feed spill at that time. This spill is the most likely cause of the spike, given that the increased COD is entirely suspended (particulate), with no evidence of increased soluble COD. At other times, during normal loading, suspended COD made up approximately 74% of the total COD, while soluble COD was approximately 26% of the total. This distribution of soluble and particulate matter is opposite the distribution for nitrogen, which was composed of mostly soluble ammonia nitrogen.

Effluent COD concentrations were considerably lower than the influent (Figure 22). However, the biosolids wasting stream (from the mixed liquor) was frequently as high in COD concentration as the influent because of the high fraction of suspended COD in the mixed liquor. The suspended COD in the mixed liquor is partly composed of original waste solids, but also includes microbial biomass that grew in the reactor environment.

During times of normal loading rates, the effluent concentration of COD was lower than that of the lagoon (Figure 22), indicating the possibility that this system may eventually reduce COD levels in the lagoon.

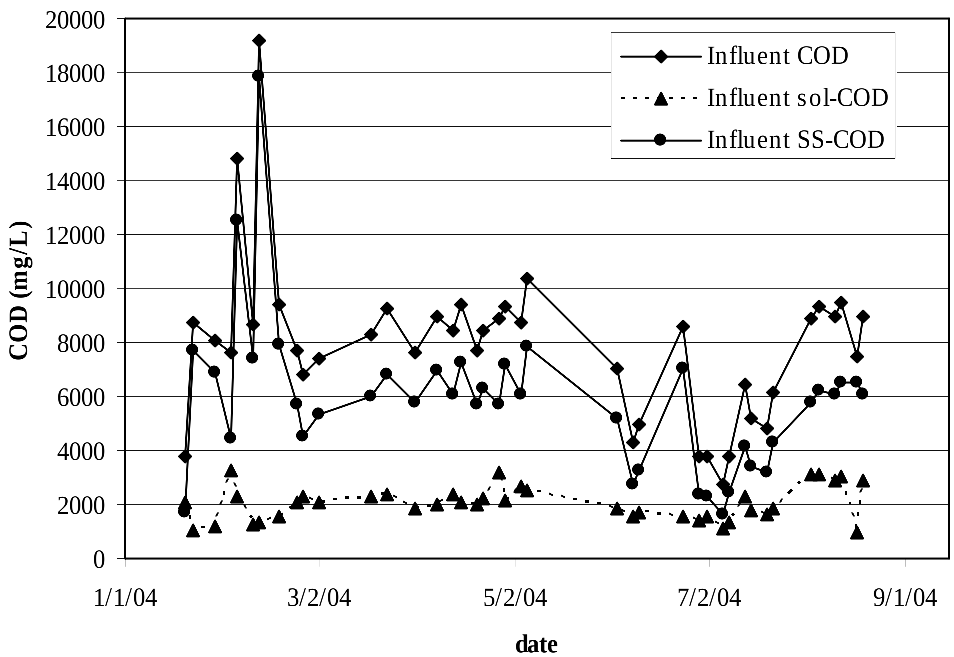

Figure 21. Influent COD partition

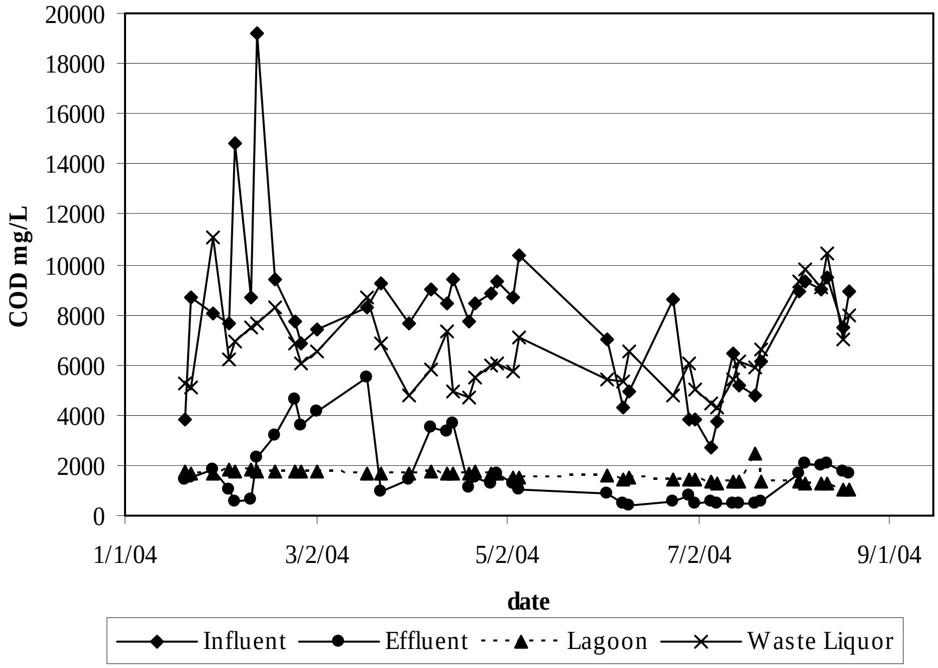

Figure 22. COD concentrations in the SBR system

Total COD loading (animals plus flush water) and removal rates

The COD mass removal rate was calculated by including both the effluent stream and the waste liquor in the outflow from the system. Removal rate followed very closely with the COD mass loading rate (Figure 23). Even when loading rate increased, as it did dramatically in February, the removal rate also increased. Greater than 80% removal occurred during the COD spike in February (Figure 24). This high treatment efficiency might have occurred because a large fraction of the COD in the influent was particulate, and since the spike was caused by feed particles, the additional particulate COD initially settled out fairly easily. Therefore, the COD remaining in the effluent stream was relatively low. Immediately following this spike event, however, removal efficiency dropped substantially as the effects on the microbial population became evident. At this time, very little settling occurred in the SBR reactor (as indicated by the low biosolids retention time). By early April the microbes had recovered and normal treatment efficiency resumed.

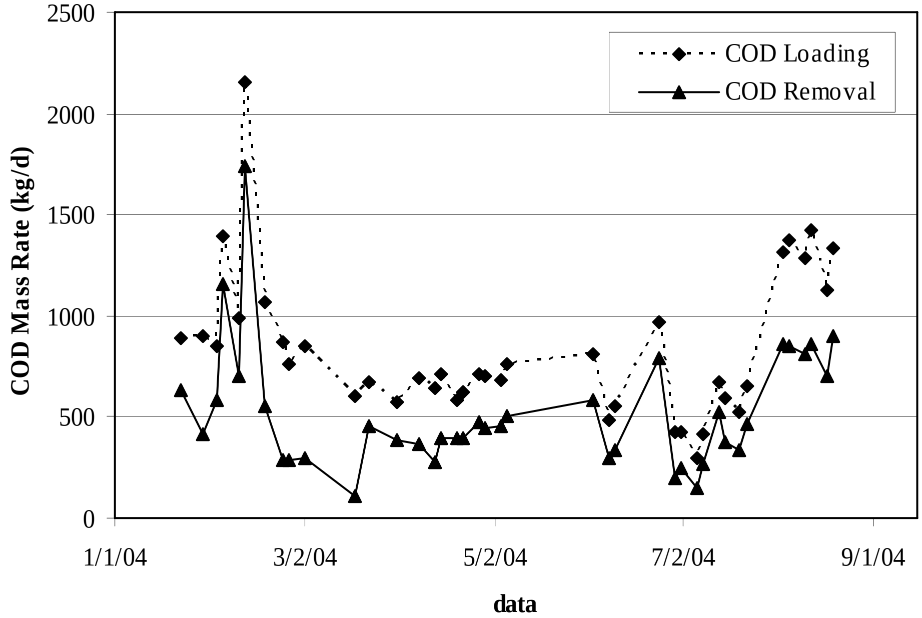

Figure 23. Mass flow of COD in SBR system

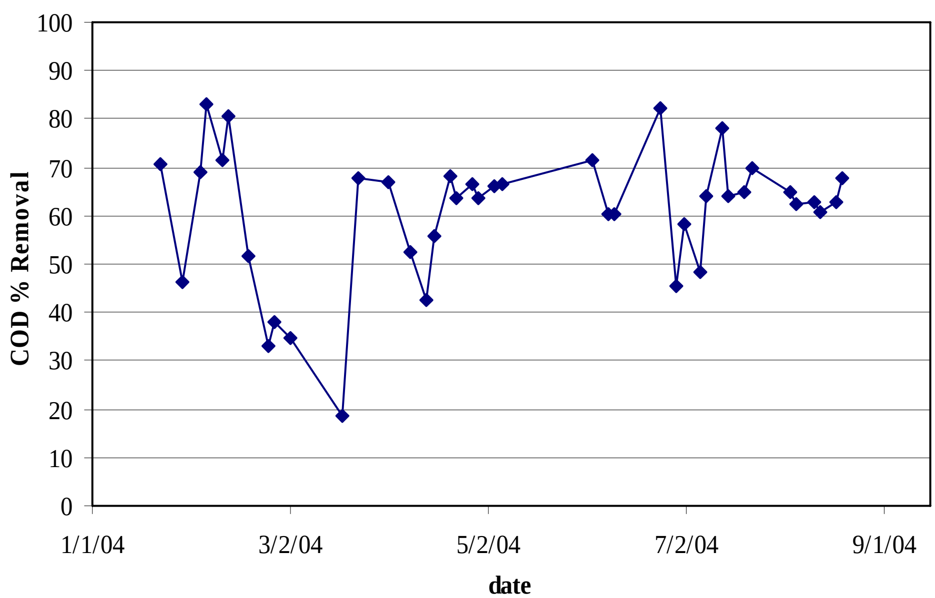

Figure 24. Removal efficiency (%) of COD from the SBR system

Removal vs. Loading Rate

COD removal rate was proportional to the mass loading rate during periods of normal COD loading (Figure 25). The average removal efficiency was 64% of the mass loading. Unlike the relationship for TKN removal, this relationship was consistent for the higher loading rates. This different relationship occurs because of the different mechanisms that dominate removal of these two constituents. A large proportion of the TKN was in the form of soluble ammonia, and removal occurred by microbial transformation. This mechanism tends to become inhibited at higher loading rates. One explanation might be that a large proportion of the COD was in the form of particulates, and removal involved settling which allowed particulates to stay in the reactor long enough to be broken down into soluble biodegradable components. There was even a slight increase in treatment efficiency with increased mass loading rate (Figure 26), although any relationship of percent removal with either loading rate or biosolids retention time was indistinct above a BSRT of 25 days. Another possible explanation might be that, since heterotrophs grow and consume oxygen faster than autotrophs, they are able to respond to higher COD loading with higher COD consumption. Autotrophs, however, are not able to respond to higher ammonia loading, leaving the mass removal rate constant, at least at BSRT values greater than 25 days.

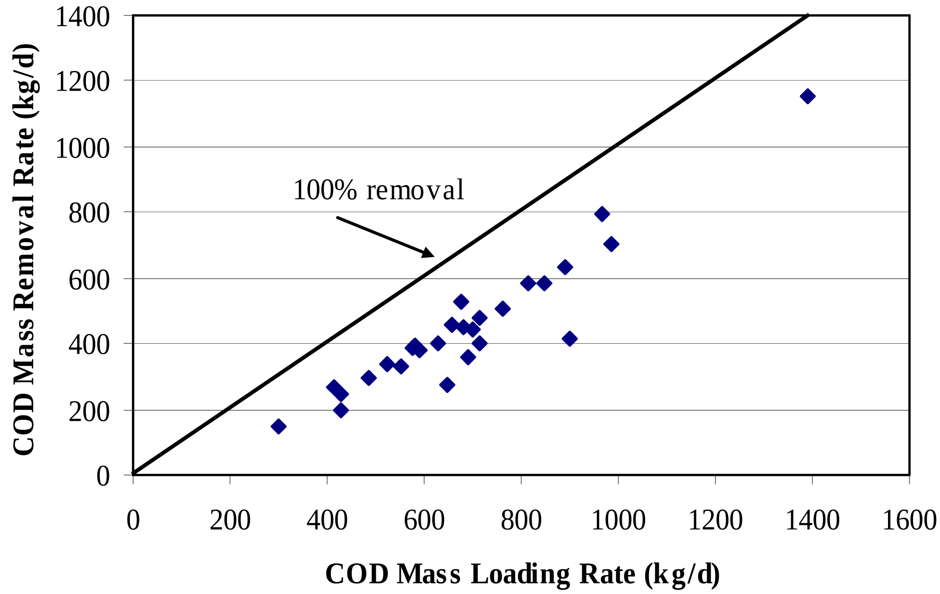

Figure 25. COD mass removal rate as a function of COD mass loading rate under normal loading conditions

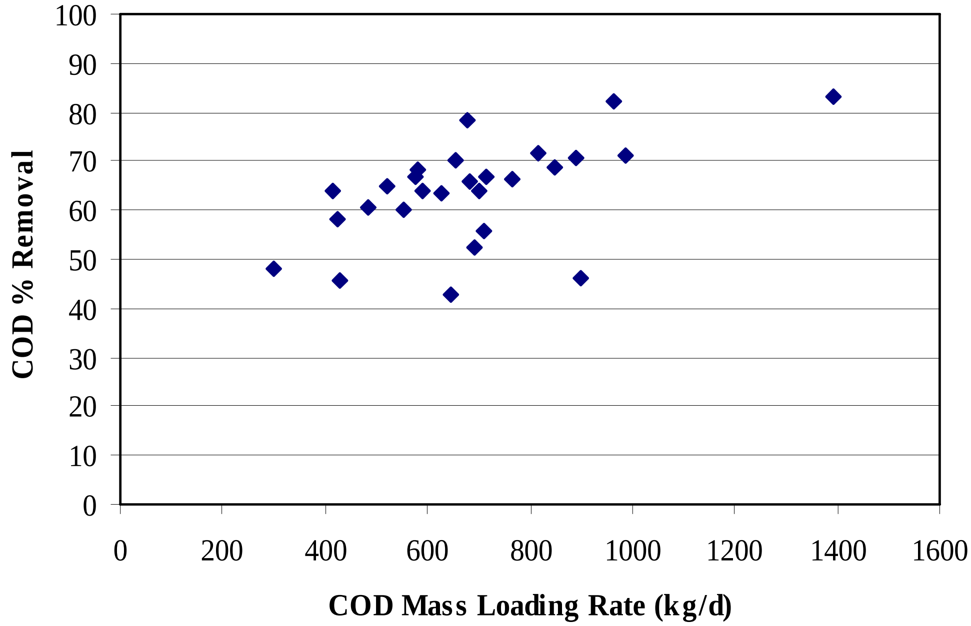

Figure 26. COD removal efficiency (%) as a function of COD mass loading in the SBR

5.2.3 Suspended Solids Removal Efficiency

Concentrations: inflow, lagoon, effluent, waste (ML)

Average percent of the total suspended solids that were volatile (organic) solids (VSS) was 92% (std. dev. of 5%). A good measurement of the VSS parameter is suspended COD (SS-COD). This measurement is more reliable than direct measurement of suspended solids at these high levels. The influent SS-COD concentration was, in general, higher during the early half of the evaluation period (Figure 27). The increased suspended solids concentration in the influent in mid-February is very apparent. The effluent concentrations were relatively high at times when settling was not good in the SBR reactor (also indicated by low BSRT at those times). At other times, when the system was operating normally, the effluent concentrations of suspended solids were very low.

The SS-COD loading rate to the system increased in February corresponding to the increase in influent concentration (Figure 28). Loading rate also increased at the end of the evaluation (August) due to deliberate increase of flow rate to the system.

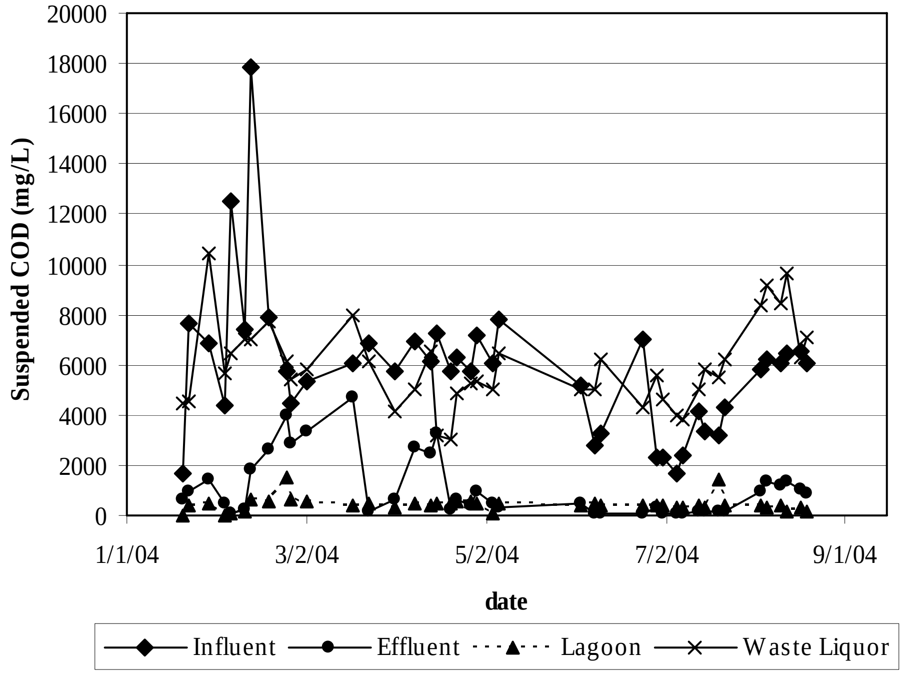

Figure 27. Suspended COD concentrations in the SBR system

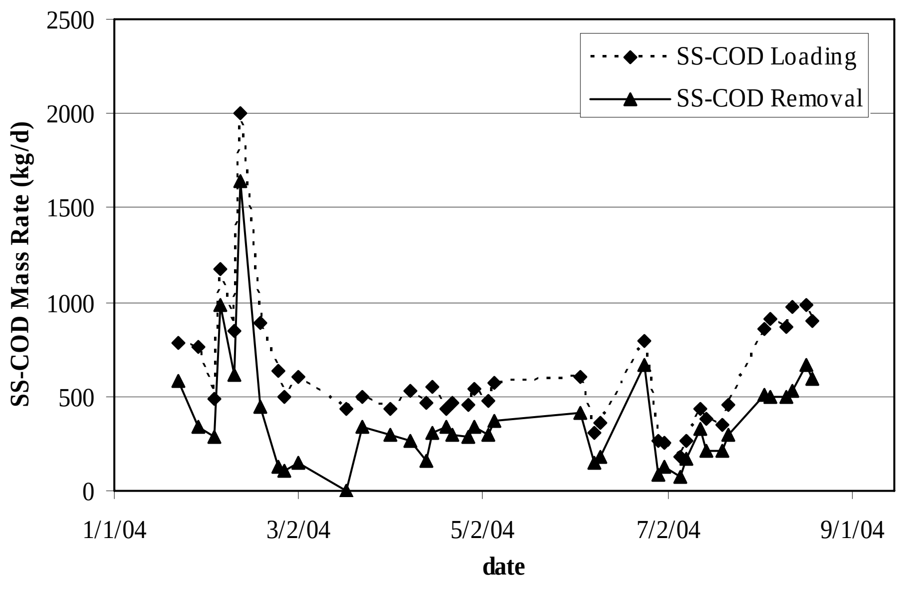

Figure 28. Mass flow of suspended COD in the SBR system

Removal Rates and Removal Efficiencies

Removal rates considered wasted biosolids (from the mixed liquor) as well as effluent solids. Removal rates were very low when the system was not operating properly following the spike loading in February. At other times, removal efficiency averaged 60% (Figure 29). Since the calculation of removal did not include the wasted biosolids as being removed, removal of suspended solids from the treatment system resulted from the solids staying in the reactor long enough to be broken down into soluble parts, which become part of the soluble COD fraction.

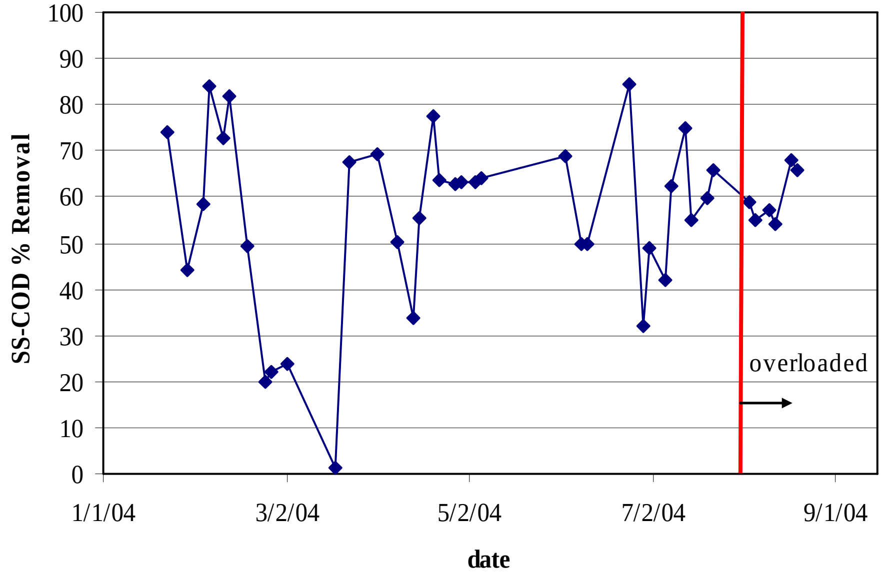

Figure 29. Removal efficiency (%) of suspended COD from the SBR system

Removal, Loading Rate, BSRT

Considering only operation of the system at normal COD loading rates, the removal rate corresponded well to the mass loading rate (Figure 30) with an average removal of 60%. Removal efficiency increased slightly with increased mass loading (Figure 31).

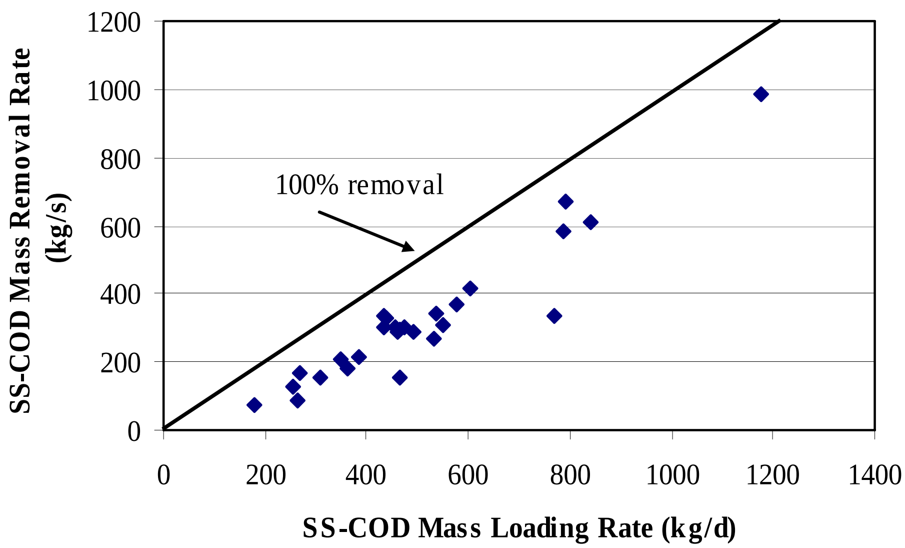

Figure 30. Suspended COD mass removal as a function of suspended COD mass loading

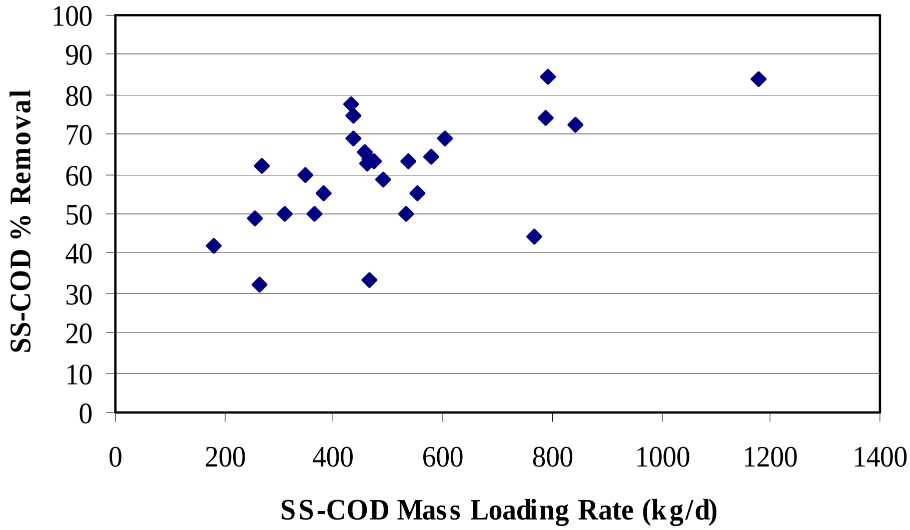

Figure 31. Suspended COD removal efficiency as a function of suspended solids mass loading

5.3 Treatment Efficiency with Planned Wasted biosolids Handling and Disposal

Although not installed as part of the evaluation at the Hunt farm, biosolids handling is an important part of a wastewater treatment system. This is especially true for phosphorus and metals because, unlike nitrogen, COD or suspended solids, there are no known microbial transformations of oxidized phosphorus or metals to other forms and there are no volatile forms. Therefore removal occurs when these constituents accumulate in the particulate fraction, which can be removed from the effluent stream by settling and biosolids handling.

To evaluate the removal of wastewater constituents by the SBR system if a biosolids separation and handling were included, removals were calculated assuming the biosolids handling system could produce a liquid stream with the same constituent concentration as the effluent stream. The planned biosolids separation system would have to remove 80% of the COD from the biosolids stream to achieve the same COD concentration as in the effluent; for nitrogen, the system would have to remove only 66% of TKN to achieve the same concentration as in the effluent.

5.3.1 Phosphorus Removal

Concentrations: inflow, lagoon, effluent, waste (ML)

A large proportion of the influent total phosphorus (TP) was in the form of soluble orthophosphate (o-PO_4). Average percentage of o-PO_4 was 74%, and approximately 26% of the TP was particulate. These percentages varied considerably over the evaluation period (Figure 32).

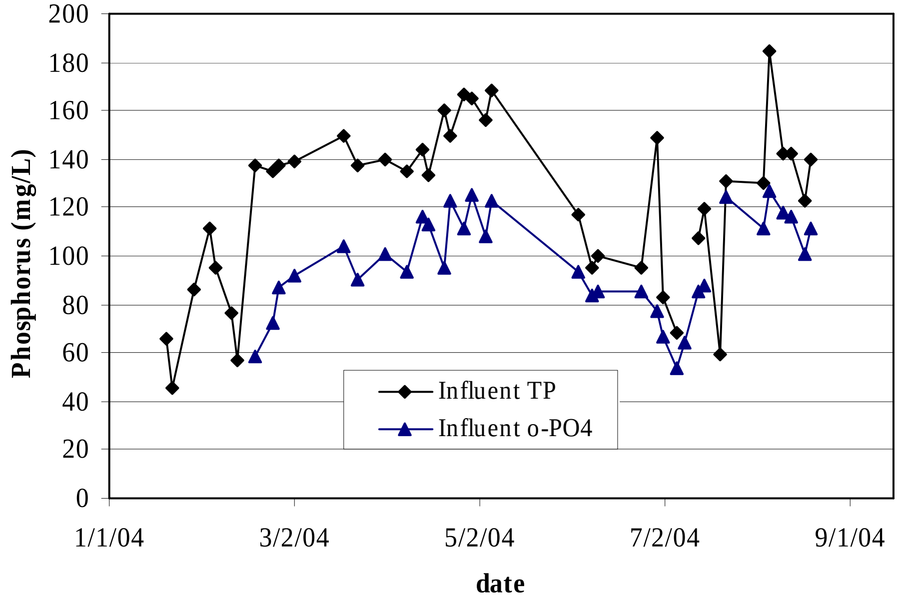

Figure 32. Influent phosphorus partition

Lagoon concentrations of TP were typically lower than effluent concentrations until the last third of the evaluation period. At the end of the study, effluent concentrations were relatively low while concentration in the waste liquor was very high, indicating that phosphorus had been removed from the liquid into the biomass fraction (Figure 33).

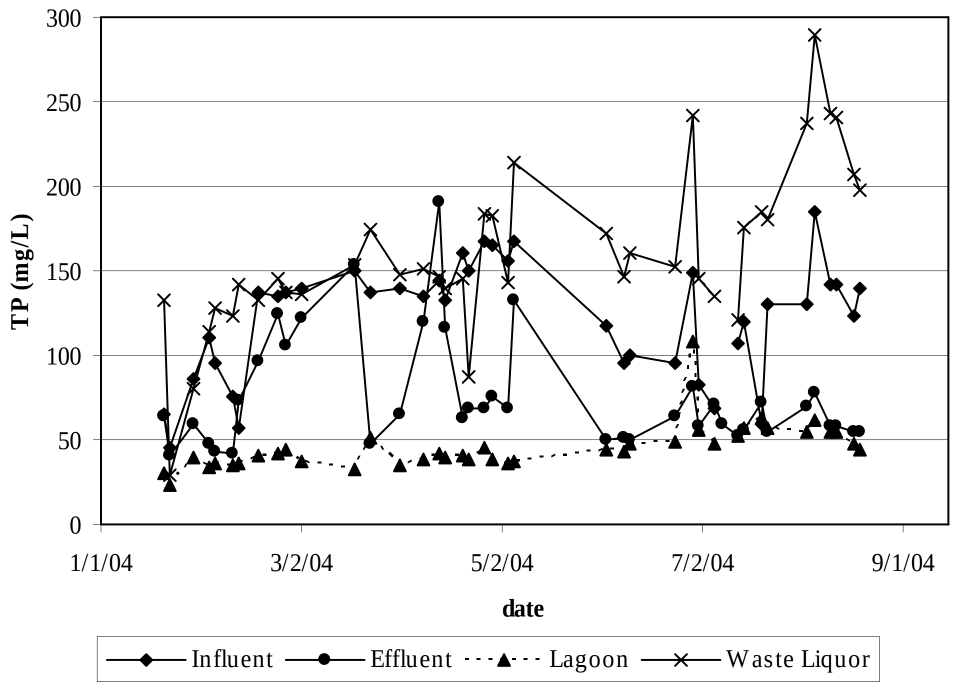

Figure 33. Total phosphorus concentrations in SBR system

Total Phosphorus Loading (animals plus flush water)

The proportion of the phosphorus in the inflow that came from manure and from flush water was estimated using the manure and flush water flow rates calculated using nitrogen data. Percent of P from manure ranged from 76% for smaller pigs to 82% for larger pigs (Table 3).

Table 3. Estimated phosphorus contributions from manure and flush water

Date	Mass of Pigs (kg)	Manure P (kg P/d)	Inflow TP (mg P/L)	Lagoon TP (mg P/L)	P (flush) / P (total)	P (manure) / P (total)
2/16/04	119,635	10.4	137	40.2	0.24	0.76
2/23/04	135,025	8.5	135	41.8	0.24	0.76
3/1/04	149,667	9.8	139	37.2	0.20	0.80
4/19/04	274,527	18.0	160	41.2	0.18	0.82
4/26/04	287,500	17.5	167	45.1	0.18	0.82

Removal Rates and Removal Efficiencies

Over the entire evaluation period, the mass removal rate increased (Figure 34). The mass removal rate generally followed the mass loading rate, indicating the potential for phosphorus removal is high. This effect is seen in no change over time of the phosphorus removal efficiency (Figure 35). Phosphorus can be released by biomass as well as taken up, as seen from the occasional negative removal rates caused by the effluent concentration being higher than the influent. The average TP removal efficiency was 35% (36% during times of normal loading).

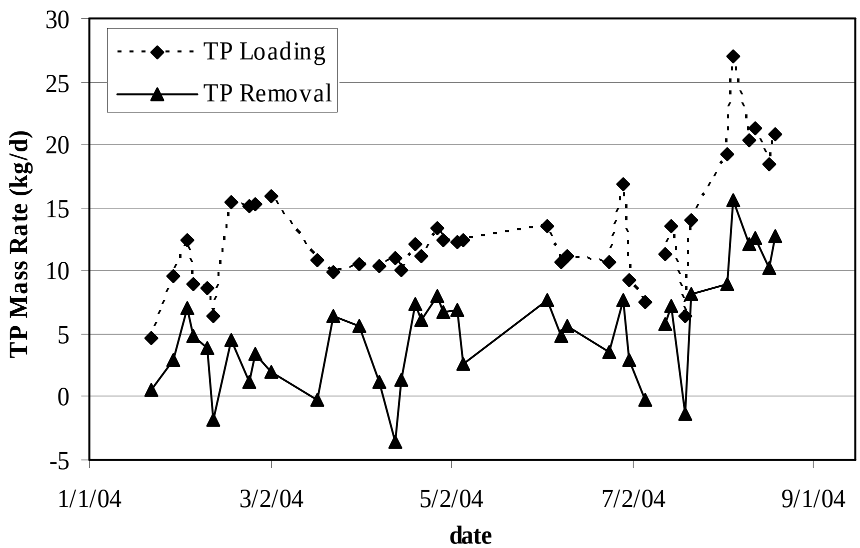

Figure 34. Mass flow of total phosphorus in the SBR system

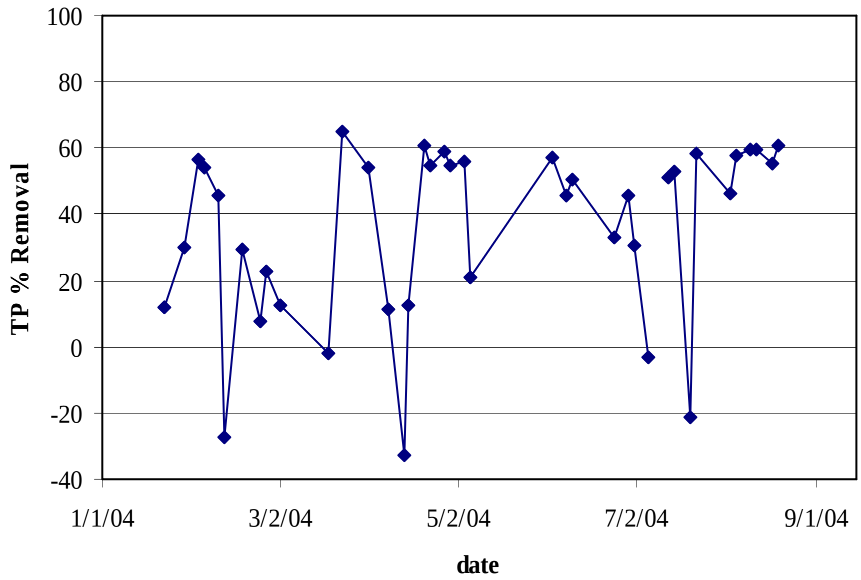

Figure 35. Removal efficiency of TP in the SBR system

Removal, Loading Rate, BSRT

The mass of phosphorus removal seemed to be related to the mass loading rate, especially at loading rates above 15 kg/d (Figure 36). There was no apparent relationship between phosphorus removal and BSRT (data not shown). If phosphorus is a critical issue at a specific installation, very high removals are possible with aluminum sulfate and other compounds.

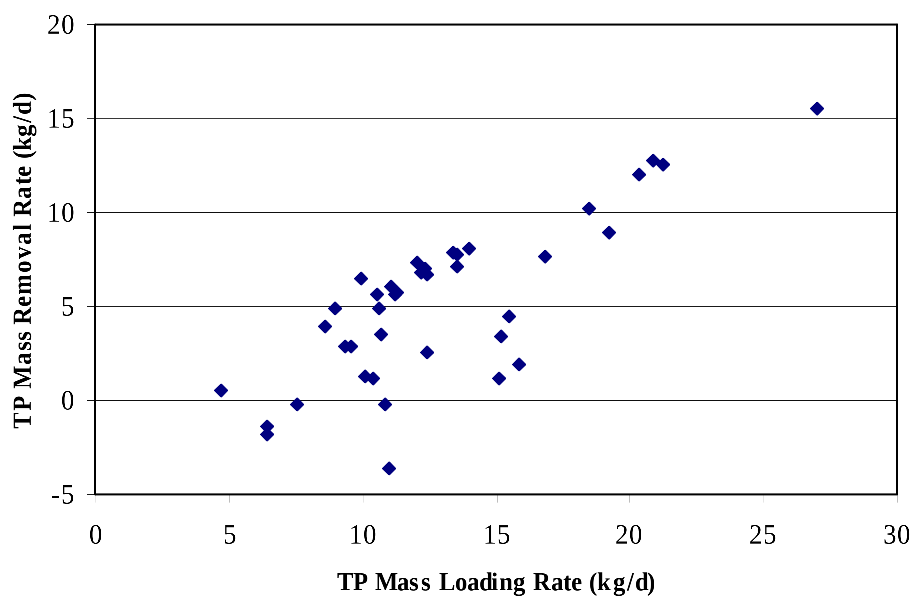

Figure 36. Phosphorus removal as a function of phosphorus mass loading

5.3.2 Copper and Zinc Removal

Concentrations: inflow, lagoon, effluent, waste (ML)

Copper (Cu) concentrations in the influent were fairly low at the beginning of the evaluation and increased steadily during the last half of the evaluation period (Figure 37). Zinc (Zn) influent concentrations were more consistent throughout the evaluation, although some variation did occur. Concentrations of both metals were highest in the waste liquor, indicating that the metal tended to accumulate in the biosolids (Figure 38 and Figure 39). Relatively high concentrations in the effluent stream early in the evaluation are consistent with this observation, as during that time problems with settling occurred due to inadvertent overloading, and the effluent stream contained more suspended solids than later in the evaluation.

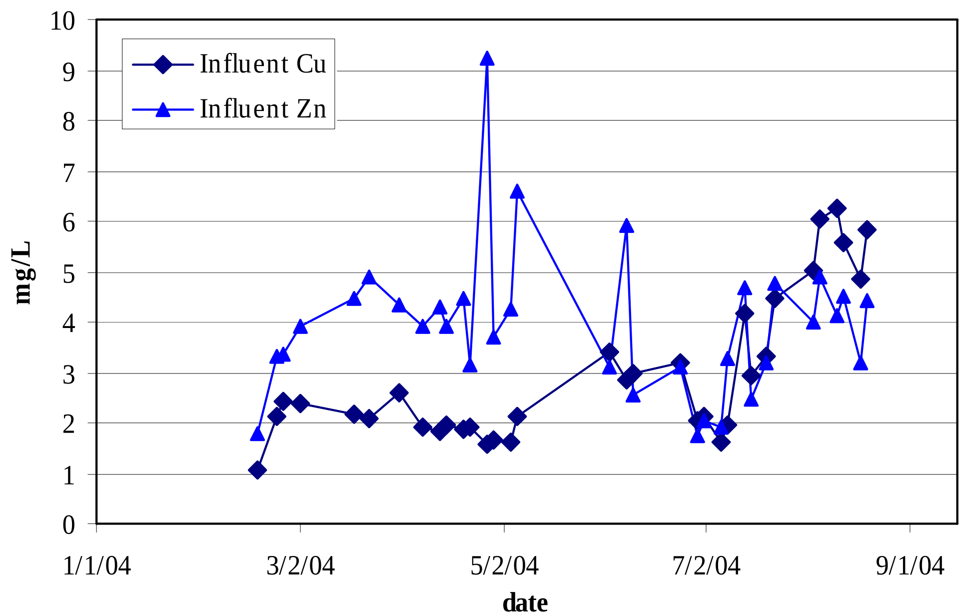

Figure 37. Influent concentrations of copper and zinc

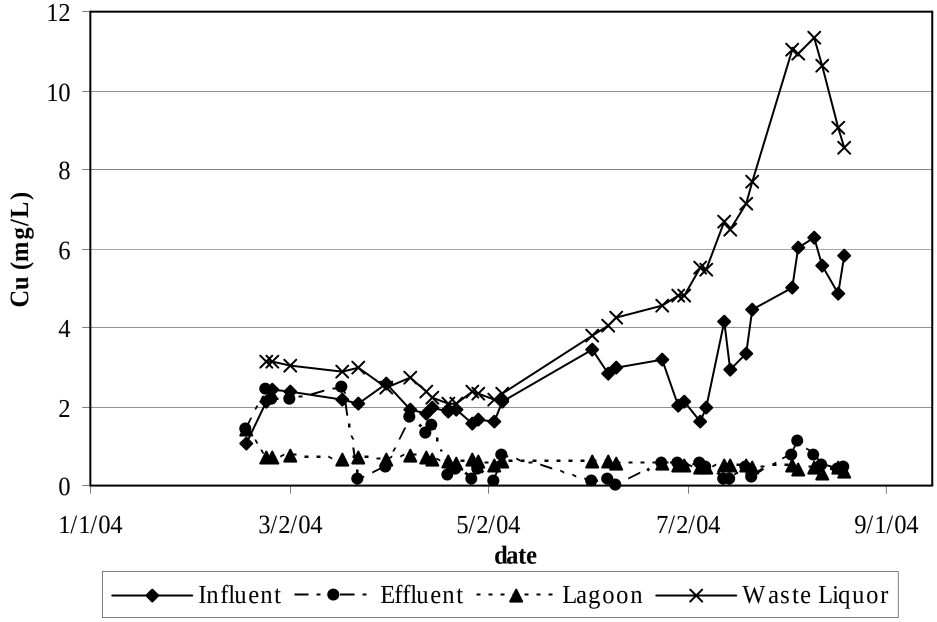

Figure 38. Copper concentrations in the SBR system

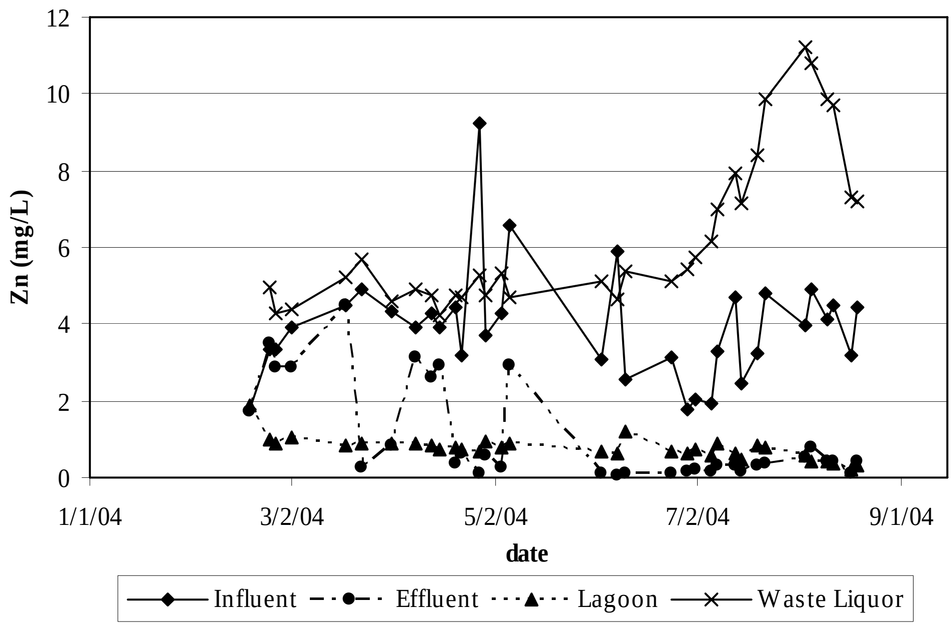

Figure 39. Zinc concentrations in the SBR system

Removal Rates and Removal Efficiencies

As with phosphorus, metals are not transformed by biological or chemical/physical reactions. Therefore, removal occurs by accumulation of the constituent in the biosolids and subsequent removal of the biosolids from the effluent stream. Average removal efficiencies for Cu and Zn were 69% and 75%, respectively (76% and 81% under normal loading). Early in the evaluation, Cu and Zn concentrations were relatively high in the effluent, and removal efficiency was low (Figure 40). After mid-April, effluent concentrations were generally very low and removal efficiencies were high. Increases in Cu removal efficiency after this time were mostly due to increased concentration in the influent rather than decreased concentration in the effluent.

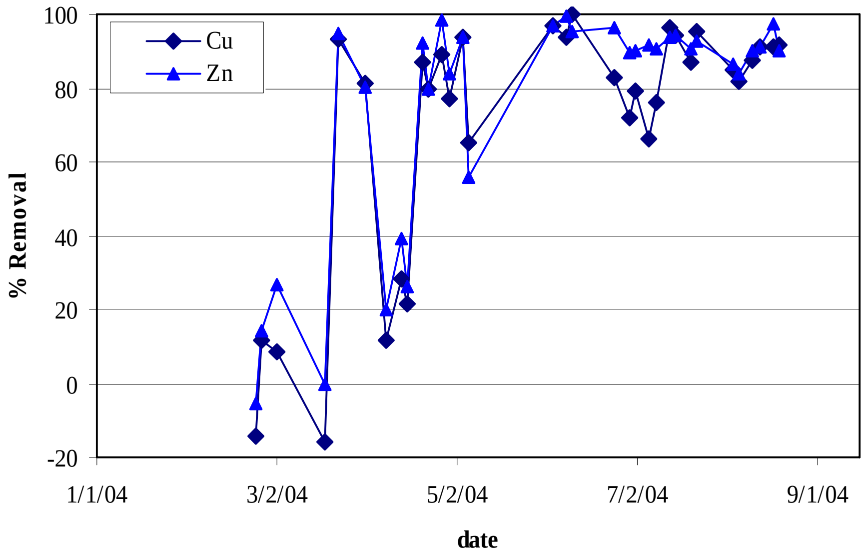

Figure 40. Removal efficiency (%) of copper and zinc from the SBR system

5.3.3 Nitrogen Removal

Average removal efficiency during periods of normal loading was 90% (Figure 41), compared to 83% when wasted biosolids were not disposed of off site (Figure 14). Although this represents an improvement in performance, there is an associated cost in equipment, land for application, and management to include the biosolids separation and handling.

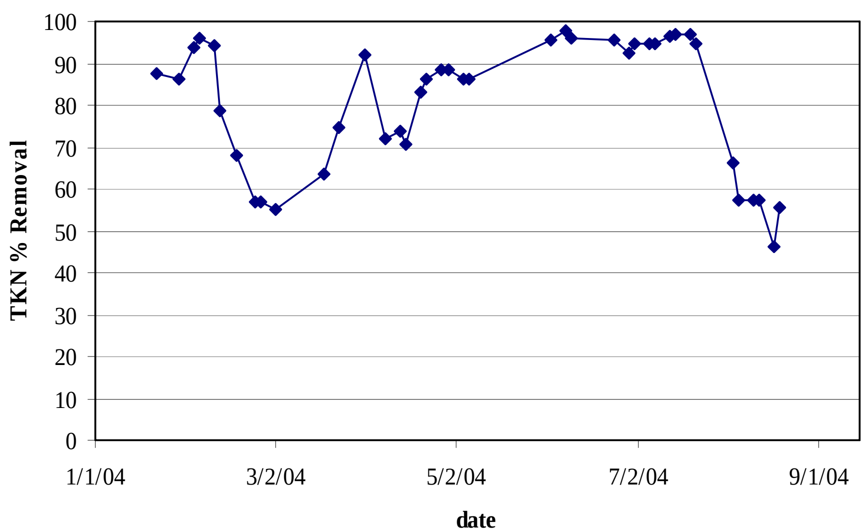

Figure 41. Removal efficiency (%) of TKN with planned wasted biosolids handling and disposal

Effluent water quality from a biological treatment system is controlled by the BSRT of the reactor. The relationship of removal efficiency with BSRT using the effluent concentration (rather than the effluent plus wasted solids stream, as discussed earlier) has a good basis in the theory of microbial metabolism. The relationship is evident for TKN and TAN under normal loading conditions (Figure 42 and Figure 43). Removal efficiencies increased with increasing BSRT, to the point where increasing BSRT no longer increased removal (between 25 and 30 days). The removal efficiencies observed during overloaded conditions (in August) did not fit the same relationship for both TKN and TAN. Nitrogen oxidizing microorganisms were more seriously oxygen limited during this time, resulting in lower removal efficiencies. During the time when the normal loading was split into two feedings per day, the BSRT was very high and removal efficiencies were extremely good. The BSRT may have been higher during this period as a result of higher average dissolved oxygen concentrations resulting in ideal microbial populations and better settling.

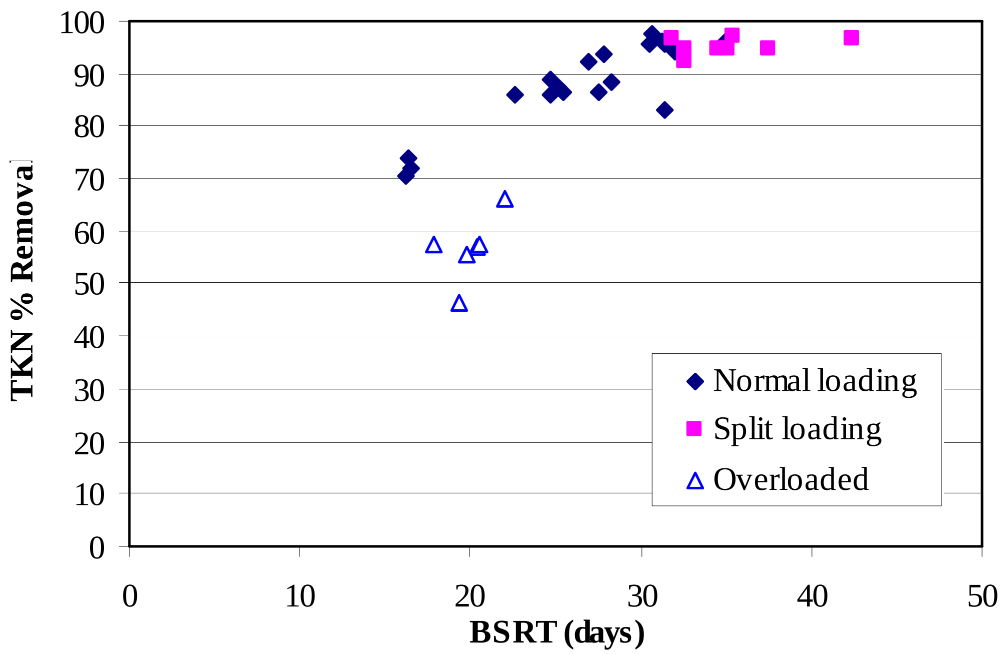

Figure 42. Removal efficiency of TKN as a function of biosolids retention time (BSRT)

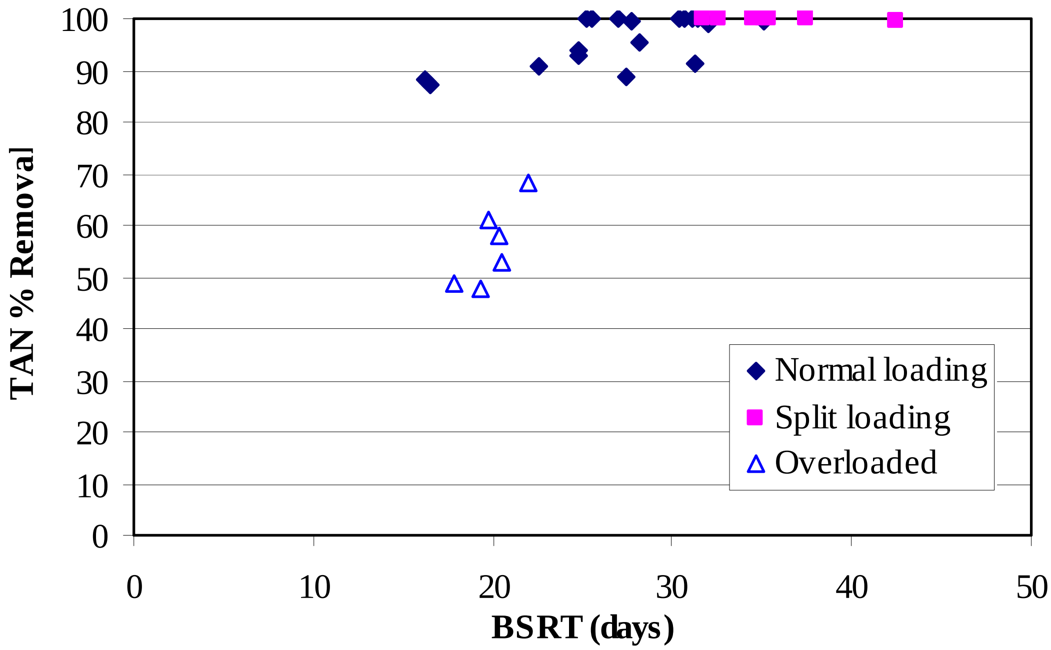

Figure 43. Removal efficiency of TAN as a function of biosolids retention time (BSRT)

5.3.4 COD and Suspended COD Removal

Average removal efficiency during periods of normal loading was 84% (Figure 44), compared to 64% when wasted biosolids were included in the effluent (Figure 24). Suspended solids removals were similar to COD removal because a large fraction of the COD was in the form of suspended solids. Average removal during normal loading periods was 90% (Figure 45). As discussed for nitrogen removal, the increased performance in COD removal comes at a cost of equipment, land for application, and management to include the biosolids separation and handling.

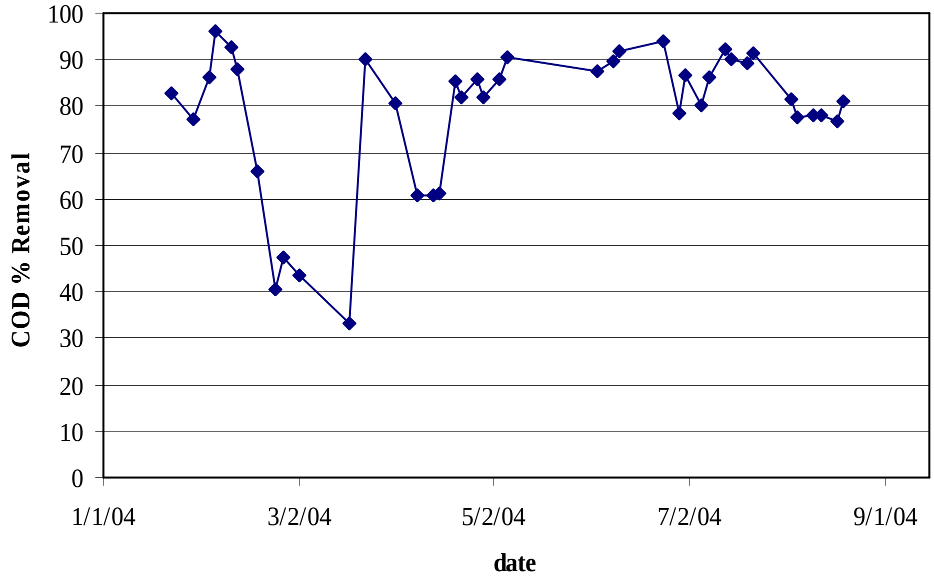

Figure 44. Removal efficiency (%) of COD with planned biosolids separation

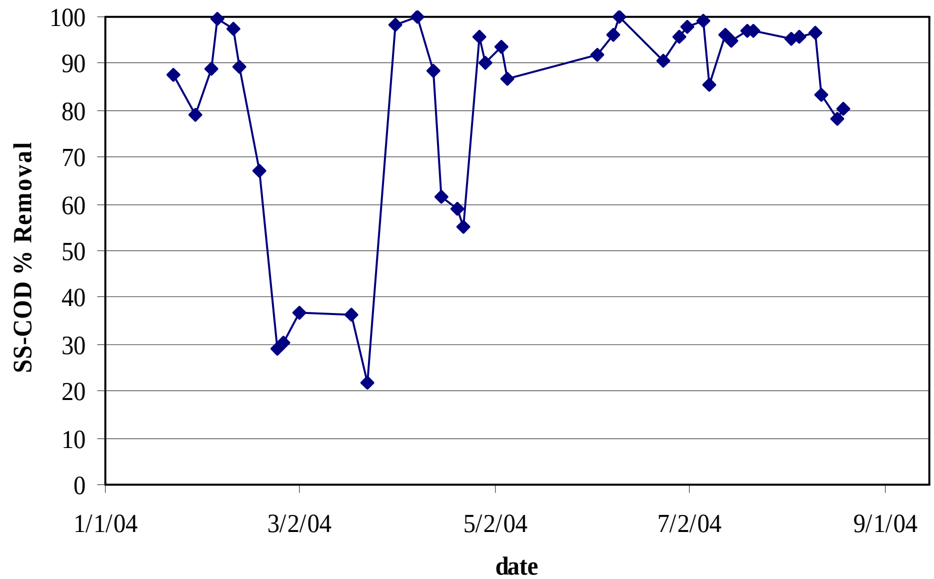

Figure 45. Removal efficiency (%) of suspended COD with planned biosolids separation

The removal efficiency of COD based on effluent concentrations was also clearly related to the BSRT (Figure 46). As with nitrogen, COD removal efficiency increased with increasing BSRT until a maximum removal was reached. Unlike the case of nitrogen, the removal efficiency of COD in the overloaded condition fit the same relationship as the normal loading condition. This result occurs because heterotrophic microorganisms are not as sensitive to oxygen limitation as nitrogen oxidizers, and the heterotrophic organisms grow faster and tend to overwhelm the nitrogen oxidizers in overloaded conditions.

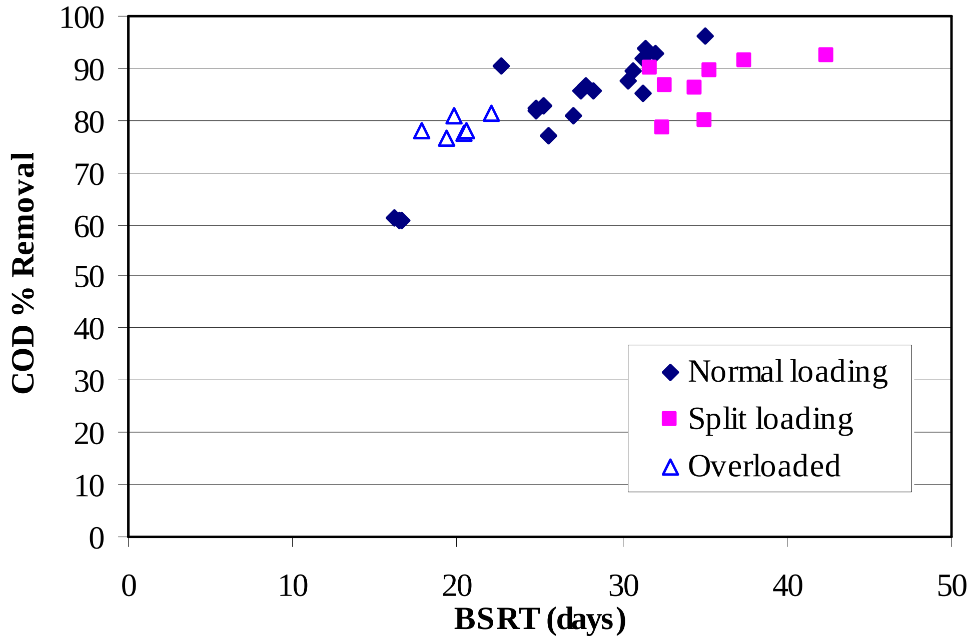

Figure 46. Removal efficiency (%) of COD as a function of biosolids retention time (BSRT)

Table 4 summarizes the performance under normal operating conditions. Performance with and without biosolids separation are shown. Table 5 summarizes the performance under increased loading conditions. Comparing results in the two tables shows higher loading rates makes little difference in the removal of COD and SS-COD. Nitrogen removal decreases as with the higher loading rate but is still near or above 50%. Phosphorus removal seems to increase substantially with the higher loading rate but may be due to the short operation under these conditions. The fluctuation seen earlier in the evaluation period (Figure 35) was not seen during the short period of increased loading conditions.

Table 4. Average influent concentrations, mass loading, and percent removal under normal loading conditions

Parameter	Concentration (mg/L)	Mass Loading Rate (kg /d)	% Removal
SBR System as Tested			
Total Kjeldahl Nitrogen (TKN)	862	79.8	83.0
Total Ammoniacal Nitrogen (TAN)	637	58.6	96.8
Chemical Oxygen Demand (COD)	7310	687	63.7
Suspended COD (SS-COD)	5400	506	60.4
SBR with Planned Wasted Biosolids Handling and Disposal			
Total Phosphorus (TP)	118	11.0	36.5
Ortho-Phosphate-P (o-PO4)	96	8.82	34.6
Copper (Cu)	2.46	0.242	76.1
Zinc (Zn)	3.94	0.362	81.4
Total Kjeldahl Nitrogen (TKN)	862	79.8	90.0
Chemical Oxygen Demand (COD)	7310	687	84.0
Suspended COD (SS-COD)	5400	506	89.7

Table 5. Average influent concentrations, mass loading, and percent removal under increased loading conditions

Parameter	Concentration (mg/L)	Mass Loading Rate (kg /d)	% Removal
SBR System as Tested			
Total Kjeldahl Nitrogen (TKN)	913	135	48.7
Total Ammoniacal Nitrogen (TAN)	619	91.5	56.2
Chemical Oxygen Demand (COD)	8860	1310	63.6
Suspended COD (SS-COD)	6200	916	59.9
SBR with Planned Wasted Biosolids Handling and Disposal			
Total Phosphorus (TP)	144	21.2	56.5
Ortho-Phosphate-P (o-PO4)	114	16.8	51.6
Copper (Cu)	5.59	0.826	88.1
Zinc (Zn)	4.18	0.618	89.8
Total Kjeldahl Nitrogen (TKN)	9.13	134.8	56.6
Chemical Oxygen Demand (COD)	8860	1310	78.8
Suspended COD (SS-COD)	6200	916	88.2

5.4 Operational Considerations

5.4.1 Shock Loading

Any biological system is susceptible to sudden changes such as temperature, pH, oxygen availability or food availability. The SBR system experienced a significant shock loading of suspended COD, probably in the form of spilled feed, in February. The system received at least two days of elevated COD loading of 1,400 kg/d and 2,100 kg/d rather than the design value of 1,100 kg/d. Total COD concentration in the influent, generally near 8,000 to 9,000 mg/L, was as high as 19,000 mg/L. As described above, this disrupted the biological system, which affected the quality of the effluent from the system and required operational adjustments to bring the process back into control. The system recovered in about a month but during that time, some of the influent was diverted to the existing lagoon; the schedule of pumps, blowers and mixers was adjusted; and the system was operating poorly in terms of biomass settling and COD and nitrogen removal. These effects are not unexpected given the magnitude of this event. Although farm operators try to prevent such events, sometimes unexpected things do happen and facilities must be flexible enough to accommodate some of them.

A larger equalization tank may have been able to help manage this event by providing storage capacity and allowing the COD to be fed to the reactor at a more measured pace. Even with adequate storage, proper management would have required time, attention and specialized knowledge of biological waste treatment systems.

5.4.2 COD Control

A related problem is that, unlike municipal wastewater treatment plants, the waste contribution by growing animals naturally increases over time. Pigs in any given barn in modern swine production facilities are usually the same age. Depending on the preferences of the producer or integrator, a farm may have a wide or narrow range of ages on site at any given time. If the range of animal ages is relatively large, the overall loading to the waste treatment system will be near a long term average value, simplifying the waste treatment system operation. If, however, the animals are all relatively close in age, the mass rate of COD loading will gradually increase as the pigs grow. The lack of COD in the influent when houses are empty or filled with new weanling pigs can also be a problem for biological waste treatment systems. This condition was controlled in this case by adjusting the duration of influent pumping so the mass loading of COD was near the design rate. Because flow into the system must match flow out of the system, each adjustment of the influent pumping duration required a corresponding adjustment to the duration of the wasting stage or the effluent stage or both. A full scale installation of an SBR system would be able to absorb some variation in loading without operational adjustments. When the system was intentionally overloaded by 30% near the end of the evaluation, the system continued to operate with some changes in performance (Table 4, Table 5). In general, management of the system may require time, attention, and specialized knowledge to achieve optimum results.

5.5 BIOSOLIDS SEPARATION MODULE

5.5.1 Summary of Performance

Although not installed as part of the evaluation at the Hunt farm, biosolids handling is an important part of a wastewater treatment system that can be done in a variety of ways. A screw press solid separator (Somat Waste Reduction Technology, Coatesville, PA) was tested at the SBR site using the waste liquor from this system. The SBR evaluation team was not involved in that testing, but the report submitted by the company was included in this report (**Appendix A**) because of the potential importance of this component as part of a total treatment system. The one day test conducted near the end of the evaluation period demonstrated that polymer addition can do a very good job of floc formation and removal. The report gives a percent capture of biosolids of approximately 83%, leaving 17% of the biosolids in the liquid portion of the wasted mixed liquor stream. The Somat report did not include dissolved solids in the solids capture calculation because the technology was only designed to capture suspended solids and it would not be representative to show this as a failure of the technology.

5.5.2 Biosolids Production and Recovery

During normal loading of the SBR system, an average of 27.5 m^3/d (7260 gallons per day) were wasted from the system with an average suspended solids concentration of 5250 mg/L. Assuming 83% solids capture from this stream (as reported in Appendix A), 120 kg/d of dry biosolids would be produced from the biosolids separator, or 690 kg/d of wet biosolids. Analysis of the biosolids cake at NCSU gave 7.68% N and 3.12% P based on dry weight. Therefore, for the average flow for this system, 9.22 kg/d of N and 3.74 kg/d of P would be contained in the biosolids fraction from the biosolids separator. These amounts represent 67% and 43% of the total effluent N and P, respectively.

The total expected production of biosolids from six houses cannot be calculated with the data collected in this evaluation, as the total waste stream from the six houses was not always treated.

5.6 COMPARISON TO PILOT SCALE SYSTEM

Bicudo et al. (1999) evaluated a pilot scale SBR system designed to treat 1.5 m^3/d of flushed swine wastewater. The pilot scale loading rate (0.72 kg COD / m^3 – d) was similar to the loading rate at the Hunt farm installation but the BSRT was higher at 35 days. The pilot scale installation included biosolids separation so the comparison is based on performance of the Hunt farm system with the planned biosolids handling component. Performance of the Hunt farm system was similar to that of the pilot scale, as shown in Table 6.

Table 6. Percent removal by SBR system at Hunt farm and pilot scale system

Parameter	Hunt Farm[1]	Pilot (I)[2]	Pilot (III)[3]
Chemical Oxygen Demand (COD)	84	93	65
Total Kjeldahl Nitrogen (TKN)	90	97	85
Total Ammoniacal Nitrogen (TAN)	97	99	99.9
Total Phosphorus (TP)	36	70	44
Ortho-Phosphate-P (o-PO4)	35	62	38
Copper (Cu)	76	NA[4]	41
Zinc (Zn)	81	NA[4]	65

[1] Hunt farm loading rate was 960 g COD $m^{-3}d^{-1}$

[2] Condition I from pilot scale (Bicudo et al., 1999); loading rate was 820 g COD $m^{-3}d^{-1}$; 10 d HRT

[3] Condition III from pilot scale (Bicudo et al., 1999); loading rate was 720 g COD $m^{-3}d^{-1}$; 5 d HRT

[4] Analysis results not available

6.0 CONCLUSIONS

The installation at the Hunt farm did not include a biosolids handling system so the excess biomass was sent to the primary lagoon for land application as was the clarified wastewater. Without removing biosolids, the SBR system was able to consistently achieve 83%, 64%, and 60% removal of TKN, COD, and suspended solids, respectively, under normal loading conditions. If wasted biosolids handling and disposal is added to the SBR system and is assumed to remove all the settled biosolids, TKN, COD, and suspended solids removal would be expected to increase to 90%, 84%, and 90% respectively.

There was good evidence that the loss of TKN from the system was mostly due to nitrification / denitrification rather than volatilization. Nitrate and nitrite concentrations in the effluent and alkalinity consumption both indicate substantial conversion of reduced nitrogen.

The system operated well when operated within design loading parameters. It was subject to severe upset following extreme spike overloading (~100%) and operated well but less efficiently under consistent (deliberate) overloading of 30%. Monitoring and management for loading rate will be required for normal operation.

If wasted biosolids are separated and disposed of differently than the effluent liquid, removal of phosphorus, copper and zinc are also achieved with this system. Since these constituents are associated with the suspended solids, removal efficiency is closely tied to the settling properties of the mixed liquor in the SBR tank. When good settling occurred, 80% - 90% removal of the metals was typical. Removal of up to 60% of phosphorus was observed, but this was less consistent, as the soluble forms of phosphorus are more mobile than are the metals.

7.0 ACKNOWLEDGEMENTS

This is but one of many evaluation projects undertaken by North Carolina State University under the umbrella of the North Carolina Attorney General's agreement with Smithfield Foods, Premium Standard Farms, and Frontline Farmers. The authors wish to thank the many individuals in and out of state government whose vision and persistence made these evaluations possible. In particular, we thank Dr. C. M. Williams for his commitment and hard work in managing this enormous endeavor. Ms. Lynn Worley-Davis of the North Carolina State University Animal & Poultry Waste Management Center was invaluable in managing the communications and logistics, from construction through evaluation. We thank the staff of the Biological and Agricultural Engineering Department at North Carolina State University for their help in installing equipment, collecting samples, analyzing samples, and organizing data, especially Mr. Doug Williams, Ms. Rachel Huie, Ms. Tracey Whiteneck, Ms. Heather Morell, and Mr. Hiroshi Tajiri. We also thank Dr. C. Douglas Goldsmith and Mr. Thomas Smith of Alternative Natural Technologies for their perseverance and commitment to this project.

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9.0 APPENDICES

APPENDIX A: SOMAT WASTE REDUCTION TECHNOLOGY: SOLIDS DEWATERING REPORT

SOMAT

DEWATERING PILOT

TEST REPORT
AHA FARMS
WILSON, NORTH CAROLINA

On June 1, 2004, the Somat mobile dewatering system traveled to AHA Farms, in Wilson, NC to support ANT Inc., and their pilot wastewater treatment project at this pork producing facility. This project is a search for alternative methods of wastewater treatment in the agricultural industry. The staple of wastewater treatment in this industry, for decades, has been the lagooning process, which has been deemed environmentally undesirable.

The prototype wastewater treatment systems is a modification of an aerobic sequencing batch reactor (SBR). The system generates approximately 8,000 gallons of aerobic sludge daily. Our mission was to dewater this sludge into a sludge cake that was as dry as possible, thusly generating a commodity from the process suitable for soil conditioning.

We encountered a mechanical problem during setup, which required replacement of a mechanical shaft seal. This problem was resolved without impacting the scheduled dewatering operations.

The solids concentration in the raw Waste Activated Sludge (WAS) was anticipated to be quite low, and it was deemed appropriate to decant this material to a slightly higher concentration prior to dewatering. An old chemical tanker trailer was used for this decanting process. After decanting, the remaining thickened WAS was circulated to keep the solids in suspension, ensuring a constant solids percentage in the feed sludge during dewatering operations.

Bench scale testing prior to this field test, suggested that the recommended flocculant for this application is a cationic emulsion polymer, manufactured by Ciba Specialty Chemicals; product ID – Zetag 7879FS40.

Dewatering operations began, and after a short period of tweaking the flow rates of sludge, dilution water, neat polymer, and press speed, the system was generating a very nice dry crumbly sludge cake, with a fairly clean pressate. During the day, the various flow rates were varied to generate the best possible performance. Samples were collected, to be analyzed for total solids, and to document the system performance.

When observing the pressate samples, a notable transparent tint to the free water was seen. This suggested a significant level of colloidal and dissolved solids. Solids of this nature are not “capture-able” through mechanical dewatering processes. Because of this observation, the solids percentage of the supernatant of the pressate was also measured and considered in the Solids Capture calculation.

The results of analysis of all these samples, and other raw data, are shown below.

RAW DATA

Parameter and Units	Sample Set #1	Sample Set #2
Raw WAS Total Solids (%)	0.65	0.65
Feed Sludge Total Solids (%)	0.8	0.8
Sludge Cake Total Solids (%)	17.0	17.6
Pressate Total Solids (%)	0.46	0.47
Pressate Supernatant Total Solids (%)	0.40	0.40
Feed Sludge Flow Rate (gallons per minute)	15	20
Neat Polymer Flow Rate (gallons per hour)	0.15	0.21
Polymer Dilution Water Flow (gallons per minute)	1.5	1.5
Polymer Type (Ciba Specialty Chemicals)	7879FS40	7879FS40
Polymer Activity (%)	50	50
Press Speed (rpm)	3	4

CALCULATIONS

	Sample Set #1	Sample Set #2
Solids Capture (%)*	82.5	85
Polymer Usage on Solids Basis – (lbs polymer per Ton of Dry Solids)**	21.2	21.5
Polymer Usage on Volume Basis – (Gallons of Polymer Per 1,000 gallons of Raw WAS)	0.14	0.16
Solids Generated Daily (Tons of Dry Solids)	0.22	0.22
Volume Reduction (%)	96	96

*Note 1- The colloidal and dissolved solids content is pertinent and considered in this calculation
**Note 2 – The polymer activity (50%) is considered in this calculation.

It should also be noted that in the above calculations, some uncertainty is presented into the results due to errors while decanting the feed sludge. In spite of this uncertainty, it can be confidently stated that both solids capture and polymer usage would improve if sludge of higher solids concentrations were fed to the dewatering system. These values could improve by as much as 20% if the sludge was allowed to thicken to 1.25%, or higher, before mechanical dewatering began. The presence of the colloidal and dissolved solids also injects some uncertainty in these calculations. Some solids may have become dissolved between the time of sample collection and sample analysis.

The cost of the polymer can vary widely. In my dewatering travels, I have seen this product range in cost from $1.20 per pound to $2.00 per pound. This cost variance depends largely upon purchase volumes and suppliers.

In summary, this was a very good application of Somat dewatering technology. Once the various flow were determined, the system operated hands off. The sludge cake quality was excellent. Solids capture was very good, but could be improved with higher feed sludge solids percentage.

Steve Eno
Manager of Research
& Development
Somat Co.

APPENDIX B: PHOTOGRAPHS OF SYSTEM

Aerial view of the R.C. Hunt farm.

SBR system under construction

SBR reactor under normal operating conditions

SBR settling test

Somat Waste Reduction Technology dewatering test unit

APPENDIX C: DATA

C1: Concentrations in SBR Influent
C2: Concentrations in SBR Effluent
C3: Concentrations in Secondary Lagoon
C4: Concentrations in SBR Wasted Biosolids

C1 Concentrations (mg/L) of Analyzed Parameters in the SBR Influent

DATE	TKN	solTKN	NH3N	NO3N	TP	o-PO4	COD	solCOD	%TS	TSS	VSS	alkalinity	Cu	Zn
1/20/04	641	606	491	0.1	65.65		3810	2110	0.74	3178	2935	3400		
1/22/04	350	294	246	0	45.78		8714	1029	1.02	6980	6700	1800		
1/29/04	571	367	286	0	85.86		8040	1170	0.8	5633	5550	2100		
2/3/04	856	633	552	0	111		7640	3227	1.35	6171	6043	3000		
2/5/04	643	473	368	0	95.48		14840	2295	1	5888	5888	2300		
2/10/04	543	431	287	0	76.04		8700	1270	0.77	6063	1800	1800		
2/12/04	600	563	429	0	57.2		19200	1360	1.13	7100	6686	3100		
2/18/04	895	515	479	0	137	58.28	9420	1520	1.22	6338	6288	3100		
2/19/04	970	771	786	0	65.22		5760	1540	1.26	6925	6000	4700	1.07	1.79
2/24/04	1109	850	815	0	135	72.58	7740	2040	1.08	4310	4040	5400	2.12	3.34
2/26/04	1154	825	863	0	137	86.66	6830	2330	1.05	4367	4056	4900	2.44	3.36
3/2/04	1110	817	831	0	139	91.86	7390	2070	1.24	5419	4977	5400	2.38	3.9
3/18/04	1228	744	914	0	150	104	8300	2270	1.13	4725	4238	5200	2.16	4.48
3/23/04	1113		842	0	137	90.04	9240	2400	1.12	5570	5020	5200	2.08	4.9
3/24/04	1090	873	857	0	146		8480	1410	1.05	4820	4290	5500	1.96	4.16
4/1/04	1151	899	886	0	140	101	7650	1880	1.19	4790	4610	5500	2.6	4.32
4/8/04	1213	899	945	1.12	135	93.33	8980	2020	1.45	6040	5560	5400	1.92	3.9
4/13/04	1171	862	940	0	144	116	8480	2370	1.18	4700	4310	5500	1.84	4.28
4/15/04	1067	850	876	0	133	113	9390	2110	1.1	6085	2600	5569	1.96	3.92
4/20/04	1190	978	916	0.06	160	95.28	7710	1970	1.19	6867	5600	5983	1.86	4.46
4/22/04	1261	865	922	0	150	123	8480	2190	1.18	4650	4560	5600	1.9	3.16
4/27/04	1303	1018	987	0	167	111	8880	3160	1.21	6380	5730	5800	1.58	9.24
4/29/04	1278	926	920	0	165	125	9310	2150	1.22	5655	5245	5600	1.68	3.7
5/4/04	1120	845	869	0	156	108	8710	2670	1.23	5870	5530	4900	1.62	4.26
5/6/04	1181	960	880	0.01	168	123	10350	2530	1.25	5760	5300	5400	2.14	6.6
6/2/04	742	569	576	0.02	113		6740	2000	0.79	3350	3220	3400	2.94	2.54
6/3/04	797	587	568	0.03	117	93.61	7030	1830	1.01	5990	5020		3.42	3.1
6/8/04	798	571	612	0.04	94.82	83.72	4330	1580	0.79	3780	3090	3700	2.84	5.92
6/10/04	749	573	581	0.06	100	85.39	4940	1690	0.8	3480	3230	3400	3	2.56
6/24/04	756	630	631	0	94.77	85.02	8580	1530		5150	4990		3.2	3.12
6/29/04	699	491	508	0.015	149	77.63	3785	1440	0.665	2428	1913	3250	2.05	1.76
7/1/04	553	438	433	0	83.08	66.95	3800	1524	0.575	2050	2050	2650	2.14	2.06
7/6/04	601	478	459	0	68.52	53.8	2735	1090	0.57	1560	1555	3100	1.6	1.92
7/8/04	518	410	415	0		64.37	3770	1356	0.63	2140	2125	2600	1.95	3.27
7/13/04	671	479	446	0	107	85.25	6420	2274	0.755	3170	3015	2800	4.16	4.69
7/15/04	715	513	538	0.02	119.5	87.53	5190	1808	0.77	3030	2830	3300	2.94	2.47
7/20/04	706	561	537	0.005	59.5		4815	1596	0.75	2845	2590	3750	3.33	3.21
7/22/04	814	569	585	0	130.5	124	6135	1870	0.85	4745	3865	3600	4.46	4.78
8/3/04	855	591	624	0	130	111.5	8900	3094	0.925	4545	4175	3400	5.02	3.99
8/5/04	913	583	603	0	184.5	126.5	9360	3135	0.94	4800	4280	3600	6.03	4.89
8/10/04	925	599	616	0.095	142	117.5	8975	2885	1.005	5060	4485	3600	6.27	4.12
8/12/04	925	641	642	0	142	116.5	9490	3005	0.995	4805	4370	3600	5.58	4.51
8/17/04	844	625	610	0.01	123	101	7480	954	0.905	4145	3765	3700	4.84	3.19
8/19/04	1016	725	620	0.02	140	111.5	8940	2870	1.02	4950	4405	3950	5.82	4.41
average	896	663	654	0.04	121	97.1	7806	2014	1.00	4825	4285	4037	2.91	3.90
std dev	249	186	208	0.17	35	20.3	2852	616	0.22	1418	1377	1235	1.42	1.42

C2 Concentrations (mg/L) of Analyzed Parameters in the SBR Effluent

DATE	TKN	solTKN	NH3N	NO3N	TP	o-PO4	COD	solCOD	%TS	TSS	VSS	alkalinity	Cu	Zn
1/20/04	74.16	43.67	0.17	21.37	64.25		1450	810	0.65	990	775	1700		
1/22/04	43.48	10.21	0.31	32.26	40.3		1497	553	0.61	1102	856	1500		
1/29/04	77.91	18.06	0.38	0.17	59.85		1840	398	0.54	1578	1277	1200		
2/3/04	55.08	22.13	1.35	46.7	48.05		1040	544	0.54	529	448	1100		
2/5/04	24.49	23.93	1.77	9.5	43.54		560	480	0.51	141	100	1100		
2/10/04	32.07	20.33	1.39	0.58	41.47		633	430	0.47	204	183	1000		
2/12/04	128	27.21	8.98	1.13	72.96		2335	465	0.61	1997	1701	1100		
2/18/04	285	104	85.34	0.05	96.92	49.37	3190	585	0.69	3199	2713	1600		
2/19/04	153	136	129	0.06	45.6		3565	570	0.76	3517	3009	1600	1.44	1.74
2/24/04	480	277	242	0.83	125	43.55	4604	624	0.8	3463	2833	2500	2.42	3.52
2/26/04	495	310	300	0.37	106	53.41	3580	740	0.76	4367	3050	2700	2.16	2.88
3/2/04	499	280	244	1.39	122	46.12	4170	785	0.84	3434	3265	3000	2.18	2.86
3/18/04	450	162	141	0.56	153	62.62	5535	830	0.9	5318	3953	2300	2.5	4.48
3/23/04	281	277	238	1.13	48.1	74.17	930	805				2800	0.14	0.26
4/1/04	90.9	34.33	0.33	1.85	64.6	34.16	1473	808	0.7	986	803	2000	0.48	0.86
4/8/04	340	159	122	0	120	57.7	3517	827	0.84	2990	2690	2600	1.7	3.12
4/13/04	305	143	117	2.96	191	74.96	3310	804	0.86	2620	2440	2700	1.32	2.6
4/15/04	315	147	103	4.28	116	56.64	3655	385	0.86	2920	2500	2760	1.54	2.9
4/20/04	203	135	83	0.38	62.6	67.2	1130	884	0.69	287	273		0.24	0.35
4/22/04	176	99	59.4	1.4	68.2	57.8	1520	904	0.7	1101	869	2200	0.38	0.64
4/27/04	149	97.3	43.9	2.05	68.5	57.12	1270	900	1.23	532	469	2200	0.17	0.13
4/29/04	145	90	67.6	0.96	75.1	57.71	1690	748	0.71	1126	935	2400	0.38	0.59
5/4/04	153	126	99.7	0.86	68.7	63.39	1240	752	0.64	582	462	2400	0.1	0.27
5/6/04	165	124	86.2	0.06	133	63.41	1000	692		1554	1175		0.74	2.9
6/3/04	35.03	20.75	0.66	0.93	50.25	116	864	384	0.46	184	168	1200	0.11	0.1
6/8/04	18.95	10.58	0.55	0.07	51.6	49.97	448	332	0.47	187	163	1300	0.17	0.04
6/10/04	30.7	11.03	0.51	0.19	49.6	47.24	400	332	0.46	153	145	1300	0	0.12
6/24/04	34.45	20.2	0.4	53.05	63.7	49.75	520	452	0.49	207	192	1200	0.55	0.12
6/29/04	52.67	18.07	0.74	59.7	81.2	61.39	808	472	0.48	160	150	1200	0.58	0.18
7/1/04	28.5	25.6	0.51	34.15	57.57	63.98	512	424	0.47	165	148	1300	0.44	0.2
7/6/04	31.64	26.1	0.76	73.2	70.7	57.17	546	460	0.48	147	130	1000	0.54	0.16
7/8/04	26.57	15.22	0.51	55.3	59.45	58.26	516	448	0.44	168	148	1100	0.47	0.3
7/13/04	24.24	23.25	1.37	1.27	52.2	57.41	500	368	0.42	193	172	1200	0.16	0.3
7/15/04	22.57	16.88	0.99	0.08	56.24	48.66	512	348	0.42	194	163	1200	0.17	0.14
7/20/04	21.48	19.47	0.82	2.84	72.3	51.34	516	384	0.47	247	211	1400	0.44	0.3
7/22/04	44	21.35	1.02	0.05	54.7	56.52	532	388	0.49	218	195	1300	0.21	0.36
8/3/04	288	224	198	0.15	69.5	62.62	1656	688	0.58	1102	914	2100	0.75	0.53
8/5/04	391	291	254	0	78.1	64.74	2092	724	0.6	1491	1134	2300	1.11	0.79
8/10/04	395	308	290	0.06	57.8	55.47	1956	764	0.58	1522	1292	2300	0.77	0.41
8/12/04	395	334	328	0.05	57.8	53.03	2096	756	0.58	1641	1418	2600	0.5	0.4
8/17/04	454	357	316	0.08	54.9	49.66	1752	700	0.57	1201	1028	2400	0.43	0.08
8/19/04	453	340	237	0.2	54.7	45.56	1704	812	0.58	1208	1023	2500	0.47	0.44
average	187	118	90.7	9.82	74.5	57.9	1730	609	0.62	1340	1112	1834	0.76	1.03
std dev	166	115	109	19.6	32.9	13.3	1304	187	0.17	1340	1088	645	0.72	1.27

C3 Concentrations (mg/L) of Analyzed Parameters in the Secondary Lagoon

DATE	TKN	solTKN	NH3N	NO3N	TP	o-PO4	COD	solCOD	%TS	TSS	VSS	alkalinity	Cu	Zn
1/20/04	229	211	143	0.01	30.67		1740	1720	0.75	5400	4518	2700		
1/22/04	200	189	146	0	23.69		1640	1205	0.73	461	391	2700		
1/29/04	302	213	136	0	39.1		1637	1168	0.74	454	374	2500		
2/3/04	357	350	279	0	33.2		1847	1820	0.75	554	488	3300		
2/5/04	352	338	280	0	36.51		1763	1660	0.75	569	493	3100		
2/10/04	397	379	278	0	34.59		1847	1705	0.73	472	423	3100		
2/12/04	337	333	260	0.07	35.64		1767	1153	0.74	486	424	2900		
2/18/04	361	109	276	0	40.2	32.7	1790	1220	0.77	605	529	2900		
2/19/04	868	752	795	0	64.41		2683	1383	0.79	1436	1215	4900	1.44	1.9
2/24/04	377	324	261	0	41.78	56.52	1750	250	0.72	592	515	3100	0.73	0.98
2/26/04	381	358	275	0	44.52	30.68	1760	1157	0.72	624	579	3000	0.73	0.87
3/2/04	344	312	261	0	37.18	32.43	1790	1247	0.73	601	532	3000	0.74	1.05
3/18/04	314	255	238	0	32.98	31.62	1680	1267	0.65	557	470	2900	0.66	0.83
3/23/04	319	270	234	0	50.66	30.13	1683	1230	0.69	642	541	2900	0.73	0.87
4/1/04	324	279	247	0	34.71	30.77	1647	1290	0.7	517	437	2900	0.68	0.88
4/8/04	354	329	250	0.05	38.11	33.39	1730	1287	0.76	526	455	3100	0.75	0.91
4/13/04	285	236	220	0	41.8	33.75	1667	1260	0.69	458	390	3000	0.69	0.81
4/15/04	290	247	215	0	39	35.29	1640	1153	0.68	511	436	5500	0.65	0.75
4/20/04	276	252	213	1.22	41.24	32.25	1640	1170	0.68	405	372	2900	0.63	0.77
4/22/04	324	265	241	0.02	37.92	35.05	1730	1170	0.7	604	496	2800	0.57	0.71
4/27/04	270	266	194	0.01	45.14	35.19	1680	1140	0.69	538	469	3000	0.65	0.7
4/29/04	244	227	210	0	38.13	33.99	1660	1210	0.7	527	452	3000	0.61	0.96
5/4/04	249	204	186	0.01	36.08	36.11	1523	1477	0.63	470	394	2800	0.52	0.76
5/6/04	239	214	168	0.09	37.2	32.92	1497	1047	0.65	458	384	2800	0.6	0.91
6/3/04	208	178	110	0.03	44.21	33.59	1573	1150	0.69	543	440	2600	0.59	0.67
6/8/04	169	112	86.11	0.02	43.35	38.43	1473	1027	0.71	725	581	2500	0.61	0.62
6/10/04	172	105	81.28	0.07	47.75	37.68	1483	1047	0.7	397	331	2600	0.54	1.22
6/24/04	132	105	57.58	0	48.56	36.75	1453	1070	0.7	627	523	2300	0.57	0.67
6/29/04	119	106	49.13	0.02	108	39.26	1440	1080	0.68	446	316	2400	0.52	0.62
7/1/04	391	219	198	0	55.64	38.19	1417	1037	0.64	413	331	2800	0.49	0.74
7/6/04	228	203	158	0	47.69	45.95	1323	967	0.62	480	367	2600	0.46	0.55
7/8/04	196	172	144	0		43.93	1303	990	0.64	453	361	2600	0.44	0.89
7/13/04	234	220	159	0	52.48	44.13	1350	990	0.65	563	430	2700	0.53	0.61
7/15/04	225	217	143	0.18	56.95	44.95	1363	1007	0.63	520	407	2700	0.5	0.49
7/20/04	241	141	93.38	0.01	62.68	44.74	2473	1010	0.74	1732	1353	2600	0.53	0.81
7/22/04	191	164	115	0	57.21	44.98	1337	967	0.74	501	384	2600	0.48	0.76
8/3/04	253	236	190	0	54.51	44.67	1360	967	0.65	602	460	2800	0.51	0.59
8/5/04	287	212	181	0	61.4	48.34	1257	967	0.65	577	420	2800	0.38	0.42
8/10/04	241	187	165	0	54.09	46.17	1253	890	0.65	603	444	2700	0.44	0.41
8/12/04	241	181	156	0	54.09	44.63	1270	1080	0.64	607	487	2700	0.3	0.38
8/17/04	202	168	116	0.02	48.24	44.34	1040	727	0.55	483	378	2200	0.45	0.2
8/19/04	149	134	79.6	0.04	44.32	37.18	1063	887	0.58	483	380	2200	0.34	0.32
9/2/04	109	104	64.99	0.03	56.19	39.18	926	598	0.48	460		1700	0.24	0.33
average	279	234	194	0.04	46.0	38.6	1580	1136	0.69	690	575	2858	0.58	0.74
std dev	119	110	116	0.19	13.6	6.3	318	281	0.06	773	653	602	0.20	0.30

C4 Concentrations (mg/L) of Analyzed Parameters in the SBR Wasted Biosolids

DATE	TKN	solTKN	NH3N	NO3N	TP	o-PO4	COD	solCOD	%TS	TSS	VSS	alkalinity	Cu	Zn
1/20/04	251	4.89	0.05	8.89	133		5220	740	0.94	424	368	1800		
1/22/04	48.19	27.81	0.99	29.26	29.16		5080	520	1.08	6100	5460	1700		
1/29/04	154	23.63	0.52	30.54	79.78		11080	668		10280	9120			
2/3/04	249	27.56	3.66	4	114		6180	552	0.81	4395	4222	1400		
2/5/04	299	27.18	2.58	5.04	128		6960	532	0.86	4259	4035	1400		
2/10/04	320	26.83	5.07	0.15	123		7520	520	0.83	5360	4827	1100		
2/12/04	376	27.72	9.66	0.48	142		7660	660	0.96	6138	6000	1100		
2/18/04	394	303	88.13	0.02	133	51.52	8280	520	0.96	5167	5033	1500		
2/24/04	580	279	244	0	145	57.46	6840	680	1	4719	4416	2400	3.16	4.94
2/26/04	596	336	301	0.2	137	55.48	6040	660	0.88	3511	4293	2600	3.16	4.26
3/2/04	582	299	251	1.34	136	63.07	6530	720	0.95	4375	3989	2900	3.04	4.36
3/18/04	457	162	140	0.51	153	69.78	8680	716	1.05	6150	5550	2500	2.88	5.24
3/23/04	632	252	238	0.48	175	64.56	6830	660	1.06	5830	5080	2900	2.98	5.68
4/1/04	267	30.94	0.56	1.51	148	76.73	4810	650	0.95	4320	3780	2200	2.48	4.58
4/8/04	417	152	121	0.83	151	81.8	5800	760	0.99	4660	4070	2800	2.72	4.88
4/13/04	393	144	109	1.5	146	68.96	7350	800	1.06	4140	3710	2700	2.38	4.76
4/15/04	385	145	99.88	3.4	140	71.14	4930	1730	0.97	4470	3000	4030	2.24	4.2
4/20/04	378	140	80.57	0.31	145	67.47	4670	1620	1.01	5350	2800	4650	2.1	4.74
4/22/04	141	96.88	51.52	1.32	87.57	72.8	5510	664	1.07	4910	4410	2500	2.08	4.72
4/27/04	362	95.2	44.3	1.6	184	71.79	5990	710	1.05	5050	4430	2600	2.4	5.28
4/29/04	397	96	59.85	0.2	182	69.89	6020	720	1.06	5200	4500	2600	2.32	4.74
5/4/04	309	119	95.47	34.03	143	82.54	5770	740	1.05	5092	4530	2700	2.2	5.34
5/6/04	466	113	70.23	0.99	214	79.39	7130	656	1.02	5310	4840	2500	2.34	4.68
6/3/04	333	33.42	0.28	1.84	172	55.08	5420	376	0.84	5940	5450	1400	3.78	5.12
6/8/04	257	11.17	0.49	0.84	147	62.35	5340	328	0.86	5930	4740	1500	4.04	4.66
6/10/04	305	8.21	0.19	0.85	161	51.83	6520	340	0.84	5270	4650	1500	4.26	5.36
6/24/04	289	17.34	1.22	48.54	152	79.48	4750	420	0.8	4600	4150	1600	4.56	5.12
6/29/04	337	17.58	1.7	51.69	242	88.07	6050	480	0.95	5260	4760	1700	4.82	5.4
7/1/04	272	11.48	0.92	26.68	145	70.96	5020	432	0.84	4740	4191	1400	4.8	5.72
7/6/04	288	12.91	0.55	58.07	135	78.02	4450	448	0.78	4040	3550	1300	5.54	6.18
7/8/04	218	5.7	0.53	47.4		98.56	4280	436	0.78	4260	3740	1300	5.46	7
7/13/04	278	23.84	0.52	4.07	121	62.61	5390	352	0.8	4940	4240	1600	6.7	7.94
7/15/04	332	11.32	0.56	0.4	176	72.34	6150	352	0.84	5260	4490	1500	6.48	7.14
7/20/04	304	15.05	0.9	3.68	185	79.62	5890	408	0.88	5550	4710	1700	7.12	8.4
7/22/04	380	11.57	0.56	0.67	180	91.59	6580	368	0.93	6970	5440	1900	7.68	9.86
8/3/04	722	220	194	0.06	237	98.6	9330	940	1.15	8380	7060	2700	11.04	11.22
8/5/04	875	272	255	0	289	87.14	9830	680	1.19	8750	7390	3000	10.94	10.78
8/10/04	767	303	289	0.13	24.28	107	9080	648	1.3	9050	7570	2900	11.34	9.84
8/12/04	767	335	334	0	241	87.7	10450	788	1.16	7910	6580	3100	10.62	9.7
8/17/04	773	344	327	0.31	207	74.83	6990	676	1.07	7050	5990	2900	9.04	7.28
8/19/04	739	339	257	0.42	198	106	8000	916	1	7060	6170	2800	8.58	7.18
9/2/04	832	433	406	0.01	244	94.06	6870	780	0.86	8960		3700	9.12	7.48
average	417	127	97.3	8.86	157	75.2	6602	652	0.96	5598	4813	2246	5.13	6.29
std dev	202	128	121.0	16.52	53	14.7	1641	282	0.12	1755	1449	829	3.02	2.02