APPLICATION OF ANOXIC/AEROBIC (A/A) BIOLOGICAL TREATMENT TO SWINE WASTEWATER

A Thesis

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Dale G. Frederick

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ABSTRACT

Residential expansion into traditionally rural areas, environmental issues and increasing integration and farm sizes, have placed steadily increasing pressure and demands on the modern pork producer. Waste management and odor control have become important priority issues.

In this research, a controllable field scale biological treatment system was designed, constructed and investigated. The anoxic/aerobic (A/A) system consisted of an anoxic reactor, which receives the raw swine waste, in series with an aerobic reactor. The design of the system requires the heterotrophic bacteria in the anoxic reactor to oxidize the organic carbon-to-carbon dioxide utilizing nitrate as the terminal electron acceptor and producing nitrogen gas through denitrification. Also, in the aerobic reactor autotrophic bacteria oxidize the ammonia to nitrate and a recirculation stream is fed back to the anoxic reactor to supply the needed nitrate.

Over the course of the investigation, the hydraulic retention times of the anoxic and aerobic reactors were increased from 35 and 36 hours to 105 and 108 hours, respectively, in order to establish steady state conditions. A recirculation ratio of 1 was maintained throughout the experiment. Chemical Oxidation Demand (COD), ammonia-N and nitrate-N were tracked through the system during the study.

At steady state, COD was reduced from 10,163 to 5,023 mg/L; ammonia-N was reduced from 1,209 to 633 mg/L; and nitrate-N held steady at 95 mg/L, which was the sample detection limit. It is believed that partial nitrification was achieved in the aerobic reactor, which supplied nitrite as opposed to nitrate to the anoxic reactor for organic decomposition resulting in the unexpected low nitrate-N results. An acceptable 67% of the overall 51%

COD reduction was accomplished in the anoxic reactor. These results show the field scale system reduced both the organic carbon and ammonia in the swine wastewater and prove the feasibility of the system. The reduction in ammonia indicates that the A/A system may have potential to address odor related problems of swine wastewater. Further research and study to optimize the controlling parameters and achieve more efficiency from the system is warranted and will be easily implemented utilizing the effective controls built in.

INTRODUCTION

Modern pork producers face numerous environmental and public nuisance problems. New technological and research advancements have allowed expansion of production operations to more than 50,000 head of hogs. In 1998, the National Pork Producers Council reported that 0.2% of producers in the U.S. produced 36.8% of the nations pork with operations having 50,000 and greater head of hogs, greatly increasing waste management, environmental and odor emission problems in those areas (NPPC Pork Facts, 2000/2001, www.nppc.org/PorkFacts/pfindex.html). Many of these operations are concentrated in localized areas in the U.S., which compounds the problems.

When a pig is raised, there is more than just meat produced. There are many co-products generated that are used in the medical industry such as replacement heart valves, skin grafts for burn victims, insulin for diabetics, and in making many food and industrial products including gelatin, plywood adhesive, glue, plastics, cosmetics (NPPC Pork Facts, 2000/2001, www.nppc.org/PorkFacts/pfindex.html). By far, the largest volume co-product associated with swine production is manure. Because of this, greater importance on research and development of waste treatment systems is needed. Miner states, “The development and implementation of proper land application systems is extremely important to protecting surface water, groundwater, and air quality standards. Improved feed-ration design, manure solids separation for composting, and biological digestion are becoming increasingly important steps in the treatment sequence culminating in land application” (Miner 1995). When handled properly and adequate land acreage is available, land application of swine wastewater can be an effective, low cost source of nutrients for crops and pastures. But, when adequate land acreage is not available, an effective and efficient waste treatment system that minimizes odorous gas release is necessary.

Many existing confined hog production systems utilize an under-slat storage pit, which holds the excrement, food and liquid wastes generated by the hogs. Generally, the waste is then gravity discharged to an anaerobic lagoon where it is treated and periodically applied on available pastureland to provide nutrients and prevent direct discharge to surface waters. This method has proven to be the most economical of waste treatment methods since no aeration is needed and maintenance requirements are low, but unfortunately it is the cause of most of the offensive odors associated with swine waste. Current design standards of anaerobic lagoons target a two-thirds reduction in influent COD utilizing a 60-day hydraulic retention time (NEH-AWMFH, 1992). For additional treatment, it is necessary to use tertiary treatment stages.

These odors have been a major source of irritation and confrontation between pork producers and their rural/suburban neighbors. Odor emissions have escalated over the years to a point where it is a major concern to pork producers throughout the United States. Many producers have expressed concern over the complaints they have received from citizens related to odors and the lawsuits that have arisen based on the law of common nuisance (Prosse, 1955; Trevett, 1900). The law of common nuisance generally states that every person has the right to the enjoyment of his/her property without unreasonable interference. In several instances, odors have been considered important enough to be judged a nuisance (Miner, 1995.). This becomes an increasingly more sensitive issue when urban encroachment onto historically rural farmland is a factor.

Alternative treatment systems utilizing sequential nitrification/denitrification, such as the Modified Ludzack and Ettinger (MLE) system (Ludzack and Ettinger 1962; Grady, Lim and Daigger 1999) can be utilized to eliminate anaerobic digestion, thus effectively reducing formation of noxious, odorous gases while maintaining a high level of efficient biodegradation of organics and greatly reducing the amount of nitrogen in the effluent. A lab scale anoxic/aerobic (A/A) system designed and operated to treat swine wastewater was effective at reducing organic carbon and nitrogen concentrations (Pan and Drapcho, 2001). The system consists of two biological reactors in series, one anoxic and one aerobic, and achieves a high degree of denitrification that reduces the concentration of organic carbon and nitrogen in the effluent. Three objectives for this research study were:

1) Design and install a field scale A/A system into an existing swine finishing house based on lab scale design. The design must include the capability to manipulate important parameters that affect system performance for future research.
2) Determine system performance with respect to organic carbon and nitrogen reduction and offensive odor indicator of ammonia.
3) Compare results to lab scale research.

LITERATURE REVIEW

The total number of hogs on farms in Louisiana in 1999 was 29,000 head (NPPC Pork Facts, 2000/2001, www.nppc.org/PorkFacts/pfindex.html). Using an average live weight of 102 Kg/hog brings the total weight of hogs to 2.9 million Kg. Hogs can produce 63.4 g/d/Kg (NEH-AWMFH, 1992) of waste, as excreted, bringing the total waste production from hogs in Louisiana to 187,644 Kg/day. Hog production for 1999 in the U.S. was 59.4 million head with an average live weight of 118 Kg/hog reported (NPPC Pork Facts, 2000/2001, www.nppc.org/PorkFacts/pfindex.html). Therefore, there was a total weight for the U.S. of 7.0 billion Kg and a total as excreted waste of 446 million Kg per day. Table 1 shows an analysis of hog waste as characterized in the Agricultural Waste Management Field Handbook (NEH-AWMFH, 1992).

Table 1 – Concentrations of As Excreted and Under-slat pit Hog Waste (18-100 kg)

Component	Units	Under-slat Pit	As Excreted
Volume	L/d/Kg		.062
Weight	g/d/L		1022.6
Moisture	%	91.0	90.0
Total Solids	% w.b.	3.0	10.0
Total Solids	g/L		102.3
Volatile Solids	g/L	67.48	87.1
Fixed Solids	g/L	12.0	15.2
Chemical Oxidation Demand	g/L		97.7
Biological Oxidation Demand	g/L		33.5
Nitrogen	g/L	3.0	6.8
Phosphorus	g/L	1.2	2.6
Potassium	g/L	2.1	3.5
Carbon:Nitrogen ratio		3.0	7

Offensive odors associated with swine production facilities are generated predominantly during manure decomposition. Odor from freshly excreted manure is generally regarded as less offensive than odor released when manure undergoes anaerobic treatment (Miner and Barth, 1979). Many existing confined hog production systems utilize an under-slat storage pit, which holds the excrement, food and water wastes generated by the hogs. The waste in the under-slat storage pit is usually more dilute than that of as excreted waste due to wasted drinking water, cooling misters and wash down water (Table 1).

During storage or treatment, the organic compounds in swine waste undergo degradation by microorganisms that are either originally present in fresh swine waste or from the environment (Paca, 1980). The organic nitrogen and insoluble phosphorus concentration decreases with storage (McGill and Jackson, 1976). Up to 50% of crude protein nitrogen in fresh swine waste can be degraded to non-protein nitrogen during storage (Spoelstra, 1997; Miner, 1969). The content of ammonia and soluble phosphorus in swine waste increased with storage (McGill and Jackson 1976). The temperature, pH and oxygen concentration of swine wastewater affect the strains of microorganisms present and thus the rate of degradation of organic compounds in swine waste (Paca, 1980).

Fresh swine waste may also contain a variety of mineral salts, the major ones include calcium, magnesium, sulfur, and iron (Taiganides and Hazen, 1966; Paca, 1980). Relatively high concentrations of copper salts and antibiotics may also be present in the waste originating in the feed as supplements. High concentrations of these compounds have been shown to decrease the growth rate of microorganisms and slow the rate of organic degradation (Ariail et al., 1971; Robinson et al., 1971; Robinson et al., 1977). Both copper and antibiotics have been considered potentially toxic compounds for the metabolic activity of microorganisms (Paca, 1980).

The most common conventional method of treating swine waste from confinement production systems is by anaerobic lagoons, with subsequent land application of lagoon supernatant and sludge for nutrient utilization and eliminating point source discharge. This method has proven to be the most economical of waste treatment methods since no aeration is needed, but unfortunately it is the cause of most of the offensive odors associated with swine waste. The production of many odorous compounds is a result of the biological fermentation process that becomes more concentrated during anaerobic decomposition (Miner, 1995; Veenhuizen, 1998; Spoelstra, 1997; Williams and Evans, 1981).

During anaerobic fermentation, heterotrophic bacteria decompose the organic compounds in the waste to carbon dioxide and methane, releasing odorous compounds such as volatile organic acids, phenolic and amine gases. The organic nitrogen and sulfur compounds are hydrolyzed to soluble ammonia and sulfide compounds. The formation of these noxious gases as well as other volatile organic compounds under anaerobic conditions has been cited as the cause of offensive odors emanating from swine production facilities (Spoelstra, 1997; Hartung and Phillips, 1994; Williams and Evans, 1981). Most of these compounds are produced only in anaerobic conditions or their concentrations increase under anaerobic conditions (Spoelstra, 1997; Williams and Evans, 1981; Veenhuizen, 1998). Slow organic degradation is also inherent to anaerobic systems.

Alternative odor control methods have been proposed that deal with the problem after the odorous gases are formed such as permeable covers for manure storage containers that are designed to biologically oxidize the odorous gases as they diffuse through the cover material (Miner, 1995; Veenhuizen, 1998), or chemical and biological additives. Improvements to the anaerobic process have also been introduced such as the use of algae or nitrifying bacteria to remove nutrients after anaerobic treatment (Boopathy, 1998; Zhang et al., 1997; Canizares and Dominguez, 1993; Gantar et al., 1991; Boopathy and Sievers, 1991; Blouin et al, 1990).

Since these designs still utilize the anaerobic fermentation process, the problem with noxious, odorous gas production remains.

Aerobic treatment systems have been used to minimize the production of odorous compounds (Evans et al., 1975). During aerobic digestion organic compounds are oxidized to carbon dioxide and water without the formation of organic acids associated with anaerobic fermentation. Advantages of aerobic treatment include rapid organic decomposition due to faster bacterial growth and production of odorless compounds (Day 1966). Further, ammonia nitrogen is oxidized to nitrate and hydrogen sulfide to sulfate. However the cost associated with aerating an entire lagoon makes them unpopular and cost prohibitive. Another deficiency in a strictly aerobic system is limited nitrogen removal through ammonia volatilization, which becomes an issue if the producer does not have enough land to apply the treated effluent. In addition, nitrate in drinking water is associated with methemoglobinemia, which affects infants less than three months old (Halling-Sorensen and Jorgensen, 1993).

An alternative biological treatment system based on the Modified Ludzack and Ettinger (MLE) system (Ludzack and Ettinger 1962; Grady, Lim and Daigger 1999) was investigated at the bench scale for swine wastewater treatment (Pan and Drapcho, 2001). In the A/A system the anoxic reactor receives the influent of raw swine waste and heterotrophic bacteria biodegrades the organic material. In the anoxic reactor, nitrate is utilized as the electron acceptor, as opposed to oxygen in aerobic systems, and the nitrate is converted to nitrogen gas (denitrification) effectively reducing nitrogen within the system. Also, hydrolyzed organic sulfur compounds, mainly hydrogen sulfide, are oxidized to sulfate. The aerobic reactor receives the effluent of the anoxic reactor and autotrophic nitrifying bacteria oxidize the ammonia to nitrate (nitrification). A portion of the wastewater from the aerobic reactor is re-circulated to the anoxic reactor to provide nitrate for the heterotrophic bacteria which maintains the anoxic state in that reactor. In this system the majority of the organic input in the system is degraded in the anoxic reactor. The aerobic reactors main purpose is to oxidize the ammonia to nitrate to supply the anoxic reactor with the needed nitrate and not for organic degradation. In this manner effective organic waste degradation and denitrification is achieved and the end products are odorless, non-toxic compounds. Summarized results of the lab experiment are shown below in Table 2 (Pan and Drapcho, 2001).

Table 2 – Results of Lab Scale A/A Research

Observed concentration (mg/L)	Influent wastewater	Treated effluent
Soluble organic matter, COD	9,243	856
Particulate organic matter, COD	1,236	2,435
Sulfide	25	<0.1
Ammonia-nitrogen	1410	209
Nitrate-nitrogen	<0.1	620

These results constitute a removal of 70% organic matter, 85% ammonia and 100% of total sulfide and validate the need for a field trial experiment. The potential advantages of the A/A system for swine waste treatment are as follows:

1. Anoxic treatment will oxidize organic compounds in the waste while reducing the concentration of odorous compounds associated with anaerobic treatment.
2. Oxygen will be required only for ammonia oxidation and not for organic degradation so energy costs should be less than that of a totally aerobic system.
3. A significant portion of the nitrogen contained in the waste will be removed, decreasing land area requirements for supernatant application and lessening concerns over nitrogen contamination of surface and groundwater.

MATERIALS AND METHODS

Description of Existing Swine Finishing House

This study was conducted at an existing swine finishing house at LSU AgCenter's Ben Hur Research Station. The finishing house is a closed end, double-curtain sided building with under-slat containment pits. There are two animal holding areas with stalls and slatted concrete floor, with the under-slat pits below. The animal stalls are separated by a walk aisle and an enclosed feed storage area is located at one end. Each animal holding area is 30.48 m long and 3.3 m wide. The under-slat pits have a 1% slope to a corner drain area. The depth of the pits range from 40.6 cm at the shallow end to 71.1 cm at the drain area (Figure 1), and are periodically drained to a waste collection lagoon for storage until land application (Figure 2). For this experiment one animal holding area and under-slat pit was utilized.

The facility is equipped with twenty automatic misters, ten on each side, which cool the pigs on hot summer days. The misters come on at a programmed high temperature of 29°C. An intermittent timing schedule, 3 minutes on and 10 minutes off, is activated until the ambient temperature drops below 29°C. The intermittent schedule helps minimize wastewater volume and conserve fresh water supply while keeping the swine as cool as possible. Mister output was measured and found to be 4.5 L per mister over the 3 minute on cycle. Thus, wastewater input on each side of the house from the misters can be as much as 208 L for every hour the ambient temperature is at or above 29°C. For a day where misters are activated for 9 hours the water input to one side of the swine house is 1,870 L which is 6.9% of total working volume and 4 times the measured per day input from the pigs.

During this experiment the number of pigs held in the targeted holding area ranged from 28 to 50. The pigs were brought into the barn weighing approximately 49.9 kg and removed at market weight which is approximately 113.4 kg. The breed of hogs produced at the LSU AgCenter Swine Research Facility consists of a Yorkshire, Landrace, Duroc crossbreed. Virtually all hogs marketed today are crossbreeds of nine major purebred seed stock breeds consisting of Yorkshire (or Large White), Duroc, Hampshire, Landrace, Berkshire, Spotted, Chester White, Poland China and Pietrain. Producers crossbreed these lines to take advantage of heterosis or hybrid vigor, which is the biological phenomenon in which the offspring of two separate breeds or lines performs better than the average of their parents (NPPC Pork Facts, 2000/2001, www.nppc.org/PorkFacts/pfindex.html).

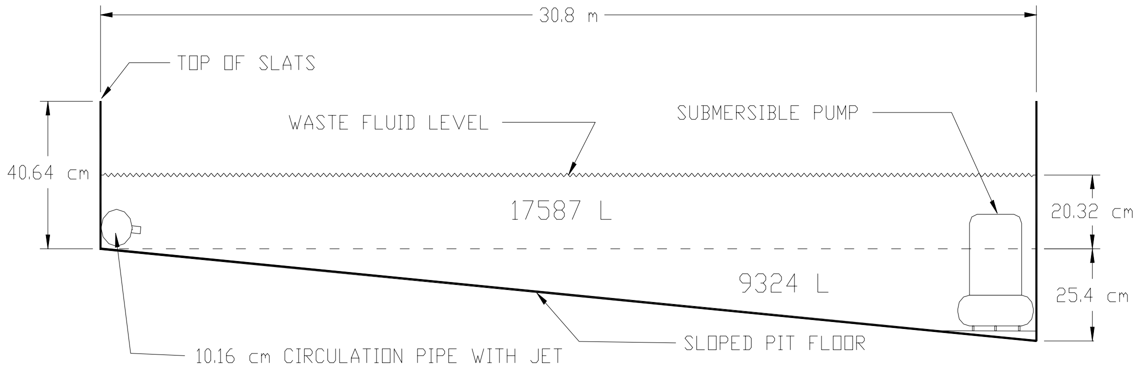

Figure 1 – Cross Section of Under-slat Pit

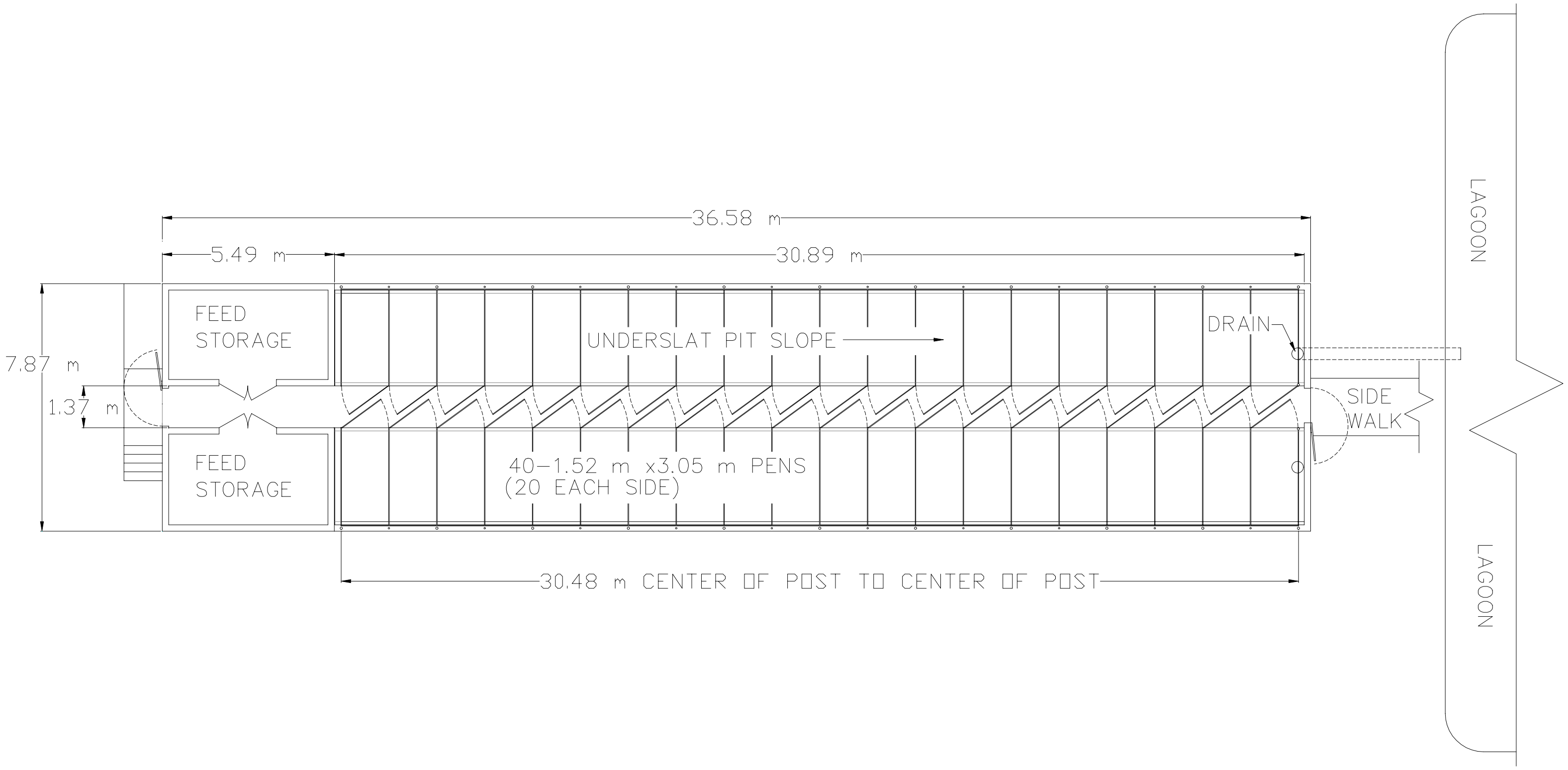

Figure 2 – Finishing House Layout

The following table lists the general balanced diet make up for the finishing hogs at the Swine Unit.

Table 3 - Composition of Swine Diet During the Finishing Phase

Item	Percentage (kg/100 kg feed)
Corn	85.93
Soybean meal (48% CP)	10.42
Monocalcium phosphate	0.93
Limestone	1.09
Sodium bentonite	0.5
Salt	0.5
Lysine-HCl	0.15
LSU vitamin mix:	0.375
Vitamin A – 1,000,000 IU	
Vitamin D3 – 3000,000 IU	
Vitamin E – 8,000 IU	
Vitamin B12 – 5.5 mg	
Vitamin B6 – 400 mg	
Vitamin C – 10 mg	
Menadione – 750 mg	
Roboflavin – 1,200 mg	
D-pantothenic acid – 4,500 mg	
Niacin – 8,000 mg	
Folic acid – 300mg	
Thiamine – 400 mg	
Biotin – 40 mg	
LSU mineral mix:	0.1
Ca, % min. – 2.75	
Ca, % max. – 3.75	
Fe - 12.7%	
Zn – 12.7%	
Mn – 2.2%	
Cu – 1.27%	
I – 800 ppm	
Se – 300 ppm	
Calculated composition:	
Crude protein	12.39
Lysine	0.65
Tryptophan	0.12
Threonine	0.44
Total Sulphur Amino Acid	0.45
Calcium	0.6
Phosphorus	0.5

Wastewater Samples and System Monitoring

To monitor the systems progression, swine wastewater was collected three times a week from the under-slat pit (system influent), anoxic, and aerobic reactors. The following field data was recorded and monitored to track performance of the A/A system.

1. Under-slat, anoxic and aerobic liquor levels
2. Flow rates of the influent and recirculation waste streams
3. Dissolved oxygen, pH and temperature readings in the influent, anoxic and aerobic tanks

Analytical Methods

Sample analysis at the Biological and Agricultural Engineering Department: Chemical oxygen demand was determined using micro COD vials (Bioscience, Inc.) following Method 5220 D of Standard Methods. Soluble COD was determined by filtering sample through glass fiber filters (Gelman, A/E, effective pore size = 1μm) prior to COD analysis. Soluble COD was used as a measure of soluble organic substrate concentration.

Sample analysis at the Agricultural Chemistry Department: Concentrations of ammonia and nitrate- nitrogen were determined by the semi-automated colorimetric procedure using EPA Method 351.2.

SYSTEM DESIGN

Design Overview

Design of the field scale system involved the following components.

1) Mixing system for under- slat pit to suspend solids and provide uniform influent wastewater.
2) Selection of appropriate retention time and reactor volume for anoxic and aerobic reactors to achieve specified level of treatment based on lab scale model results.
3) Mixing and distribution piping system for anoxic and aerobic reactors.
4) Aeration system for aerobic reactor.
5) Automated control and valve system to maintain desired flow rates.

Table 4 lists and defines the terms affecting the system as described herein and shown in Figure 3.

Table 4. Definition of Terms

Term	Definition
S_S	Soluble organic substrate concentration, mg/L COD
S_{NO}	Soluble nitrate concentration, mg/L NO_3-N
S_{NH}	Soluble ammonia concentration, mg/L NH_3-N
τ	Hydraulic retention time, hr
α	Recirculation ratio, Q_R/Q, dimensionless
V	Reactor volume, L
Q	Volumetric flow rate, L/hr
Subscript	Identification
AN	Anoxic
AE	Aerobic
I	Influent
O	Outflow (effluent) from system
R	Recirculation
M	Maximum
T	Total

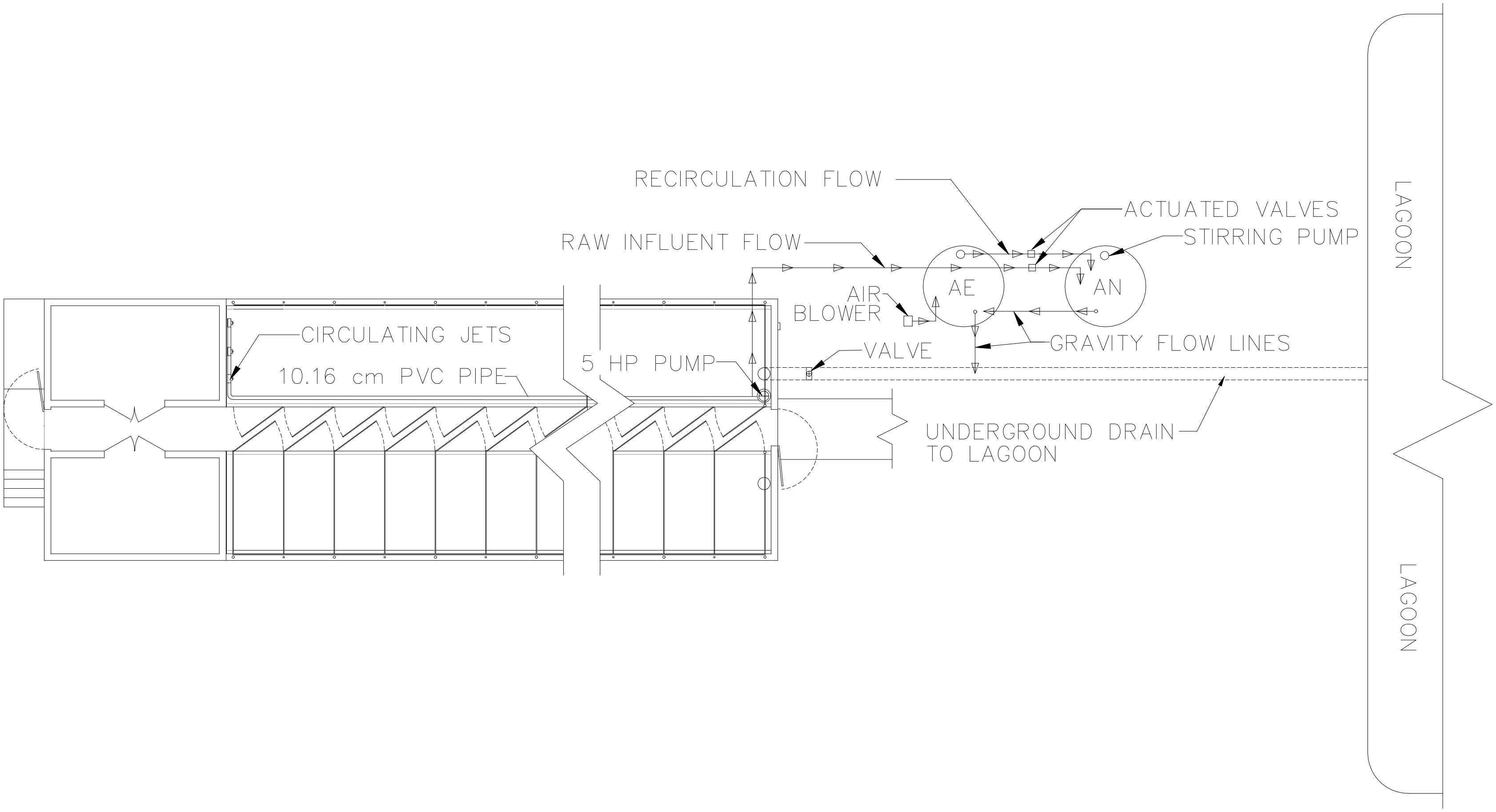

Figure 3 – A/A System Layout

Under-slat Pit Stirring System

In the bench scale lab experiment the influent swine wastewater was collected from the under-slat pit which was not agitated and had an average retention time of 30 days. This allowed for partial anaerobic degradation of organics and settling of solids to occur. Therefore, field design needed to incorporate a means of mixing the under-slat pit. To calculate the waste fluid volume, the volume of the sloped floor section was first determined (Fig. 1). At the deeper end of the pit, the floor was constructed in a manner that channels the waste to the drainpipe in one corner for more efficient and complete dumping. Because of these irregularities in the floor, the volume was determined by timing the fill up of the sloped floor section using a 5.08 cm hose flowing at 2.8 L/s. The time to fill up the sloped floor section was 55 min and 30 sec. Thus;

3,330 s * 2.8 L/s = 9,324 L

Total sloped floor volume was calculated to be 9,324 L. The pit width is 2.81 m and length is 30.8 m. This translates into a volume of 865.5 L/cm above the sloped floor section. Using an average working fluid level of 20.32 cm measured from the highest point of the sloped floor section, the volume of this part of the pit was calculated to be:

20.32 cm * 865.5 L/cm = 17,587 L

Thus, total working volume was calculated to be (Figure 1):

17,587 L + 9,324 L = 26,911 L

Due to economical and practical constraints it was decided that complete (100%) suspension of all solids within the under-slat pit would not be feasible. The goal was to circulate the total working volume three times in one hour utilizing scouring jets at the shallow end of the pit to aid in particle suspension. The stirring pump size and selection as well as distribution pipe size was based on the following calculation for minimum flow rate needed:

$$26.9\ m^3 * 3 = 80.7\ m^3/hr$$

To achieve a minimum of 80.7 m^3/hr of flow in the pit, head loss through the distribution system was calculated. Initial calculations using a 10.16 cm PVC distribution pipe yields a flow velocity of 2.74 m/sec at the desired flow rate. Using Hazen Williams equation and design roughness constant C = 130 for new PVC pipe, head loss was calculated to be 2.3 m through the 32 m length of pipe (Lindeburg, 2001). This flow velocity is at the high end of optimum velocities for pipe flow but considering its short length and the added advantage of keeping solids in suspension the 10.16 cm PVC pipe was selected.

Minor losses were calculated using Eq. 1 which is the product of the sum of the loss coefficient K, associated with each fitting, and the velocity head (Roberson, John A., Crowe, Clayton T, 1993).

$$h_m = \Sigma K * V^2/2g \qquad \text{(eq. 1)}$$

Total minor losses through fittings and reducers were calculated to be 5.7 m. Thus, total head loss through the mixing system was 8 m. The selected pump must achieve a minimum of 80.7 m^3/hr working against 8 m of total head loss. To select the correct pump the performance curves of different pumps were compared. The selected Goulds pump output is 93.1 m^3/hr at the calculated total head of 8 m. The minimum necessary was calculated to be 80.7 m^3/hr. The actual output is greater than minimum which in effect achieves a better than expected stirring action within the pit.

The under-slat pit of the finishing house was retrofitted with the Goulds model no. 3888D4, 5 HP 3 phase submersible pump and mixing distribution system. In addition to flow rate, the maximum solids size handling capability of the pump was considered. This particular pump can handle spherical solids up to 7.94 cm in diameter. The mixing distribution system consisted of 10.16 cm PVC pipe and fittings with reducers for three jets to suspend solids and create a homogenous liquor. Different sized jets were installed and observed. The combination of one 2.54 cm, one 3.175 cm, and one 3.81 cm jets was chosen based on agitating performance and distance of jets throw.

A 2.54 cm PVC pipe was installed at a Tee in the 10.16 cm PVC pipe at the output of the pump to supply the raw swine waste influent Q_I to the A/A system. The 8 m of head at the pump discharge is equivalent to 78,200 Pa mixing system working pressure and would be more than sufficient to supply the A/A system with its required influent waste flow, eliminating the need for another pump.

Anoxic Reactor

In a full field scale design the volume of the anoxic and aerobic reactors would be calculated by the following relationship with terms defined in Table 4:

$$\tau = V / Q_M \qquad \text{(eq. 2)}$$

with $Q_M = 2.34\ m^3/d$ given as the total maximum wastewater output from the swine finishing house. This value is the sum of $1.87\ m^3/d$ input from the misters calculated at a nine hour 29°C or greater day and $0.47\ m^3/d$ input from the pigs. Input from the pigs was determined from a seven day waste accumulation test run on the finishing barn; no other input was introduced for the duration of this test. This waste flow would require $V_{An} = 3{,}412$ L and $V_{AE} = 3{,}510$ L using the hydraulic retention times of 35 hr and 36 hr respectively, determined in the lab scale study (Pan and Drapcho 2001). Due to financial constraints, standard 1060 L round fiberglass tanks were used as reactors and approximately 28% of the total swine wastewater flow was treated. For the purpose of this pilot scale study a round 1.2 m diameter by 0.9 m deep, 1060 L fiberglass tank was chosen. The anoxic reactor influent flow rate (Q_I), from the under slat pit, was set to theoretically remove 93% of the soluble organic substrate (Ss) contained in the raw swine waste. This was based on the results generated by the lab scale research by Pan and Drapcho (2001). From Table 2, the raw swine waste collected for the lab scale study contained 9243 mg/L soluble COD, therefore an effluent soluble organic substrate (Ss) concentration of 856 mg/L COD was anticipated. Utilizing the model generated by Pan and Drapcho, it was determined that a hydraulic retention time (τ_{AN}) of 35 hr was needed to achieve that effluent (S_S) concentration.

The stirring system for the anoxic reactor consisted of a 1/5 HP Tsurumi OMU-2 submersible pump and a PVC manifold with drilled holes. This system was used to achieve complete mixing and minimize aggressive agitation to limit oxygen diffusion at the air/liquid interface.

An adjustable 5.08 cm PVC stand pipe designed to extract the waste liquor at approximately mid-depth of the reactor was attached to a gravity flow line into the aerobic tank. Using the stand pipe the depth of the waste liquor could be set, thus controlling the volume of the reactor. The effluent of the anoxic reactor, through the stand pipe, served as the aerobic reactor's influent flow.

Aerobic Reactor

The hydraulic retention time of the aerobic reactor (τ_{AE}) was calculated using a targeted 90% ammonia oxidation efficiency of ammonia-nitrogen ($S_{NH,AE}$) resulting in an effluent concentration of 140 mg/L (Pan and Drapcho, 2001). The hydraulic retention time was determined to be 36 hr. Comparing τ_{AN} and τ_{AE} reveals a small difference in hydraulic retention times, thus the same size fiberglass tank as the anoxic reactor was used and the retention times will be achieved by controlling the volume in each reactor with the adjustable stand pipes on the gravity flow effluent lines.

The aeration system for the aerobic reactor was designed based on Recommended Standards for Sewage Works also known as “The Ten States’ Standards” (Great Lakes, 1997). As published in the Ten States Standards, the amount of air required for an aerobic waste treatment reactor is 131.1 m^3 air/kg BOD. To obtain the required oxygen demand in kg BOD it was first necessary to convert the obtained test results in COD (mg/L) to BOD (mg/L). Correlated BOD/COD ratios among gross measures of organic content in untreated waste have been found to vary from 0.4 to 0.8 (Metcalf and Eddy,1991). The most conservative value of 0.8 and recorded values of influent S_s, instead of treated effluent S_s (Table 2), were used to ensure sufficient air blower sizing for this and future research projects using this system. Substituting the influent S_s value for COD in the ratio equation yields a BOD value of 7394 mg/L. To calculate the BOD loading rate the following equation was used:

$$Q\ (m^3/d) * BOD\ (mg/L) * 0.001 = BOD\ (kg/d) \qquad \text{(eq. 3)}$$

At the time the lab scale experiment was conducted the misters in the finishing house were not functional so values in Table 2 do not reflect any dilution from them. Thus, for this calculation, a value of $Q = 0.47\ m^3/d$ was used, which is the total waste input from the pigs and the maximum wastewater output from the swine finishing house at that time. Using the maximum wastewater output for this calculation sized the aerator for the maximum influent flow rate into the A/A system, and not necessarily the influent flow rate used for the study. The result of eq. 3 was 3.48 kg BOD/d. Thus, the amount of aeration needed for this system was:

$131.1\ m^3$ air/kg BOD * 3.48 kg BOD/d * 1 d/24 hr = 19 m^3/hr

Airflow resistance within the system is 7,500 Pa from the average depth of the coiled diffuser hose from the liquid waste surface, plus approximately 3,500 Pa from the diffuser hose which yields a total resistance of 11,000 Pa. The performance curves for the selected Gast Regenair model no. R3105-12, 1/2 HP blower indicates available free air of 32 m^3/hr at 11,000 Pa which should be more than adequate for this systems needs.

The supply air was piped through 3.2 cm PVC to the bottom of the tank and diffused through 18.3 m of soaker hose coiled and secured near the bottom of the tank. The soaker hose was used to break the air stream into tiny bubbles allowing for maximum oxygen transfer into the waste liquor.

Stirring in the aerobic reactor was achieved by the aggressive agitation of the aeration system and a bypass on the recirculating pump.

The recirculaton pump consisted of an identical 1/5 HP Tsurumi OMU-2 submersible pump as that used for stirring in the anoxic reactor and is capable of 13.2 m^3/hr output. This output was determined to be sufficient to supply any re-circulation flow to the anoxic reactor that may be needed. Since the re-circulation flow was intermittent it was necessary to install a bypass to allow flow through the pump when the actuated valve was closed. This bypass line was also used in assisting the stirring and mixing of the reactor.

An adjustable 5.08 cm PVC standpipe was used to set the desired depth of the reactor, which allowed control of the volume. The gravity flow effluent from the aerobic reactor standpipe was directed into an existing drainpipe, used to drain the under slat pit, which drained into an existing anaerobic lagoon (Figure 3).

System Controls

To achieve the desired flexibility of this system it was necessary to control the influent flow rate, recirculation flow rate and the reactor volumes. The automated metering system used consisted of a programmable Intermatic controller model no. ET70215CR, two Dynaquip model no. 6CX18, 2.54 cm positive closing, electric actuated ball valves and two 2.54 cm manual ball valves.

The controller consisted of a two load, microprocessor time switch which allows for flexible 24 hour, 7 day programming. It included a pulse feature that could be programmed for 1 to 127 second duration. This pulse feature was used to open the ball valves for a set duration of time allowing a calibrated amount of waste to flow on an intermittent basis, thus metering the flow rates. The controller also included a convenient keypunch override feature used for sampling and flow rate measurements. Retention times and recirculation rate in the reactors were adjusted by changing the program of the controller.

The electric motor driven actuated ball valves were chosen because of their durable construction and high closing torque development that was necessary in the harsh, high solids liquid.

The manual ball valves were installed in line with the actuated ball valves and used for fine adjustments to the flow rates.

The adjustable 5.08 cm PVC standpipes in each reactor were used to change the reactor volume. Changing the reactor volume was another means of adjusting the retention time and also allowed for fluid level adjustments found to be necessary once the system was running, such as lowering the aerobic reactor level because of foaming.

System Parameter Settings

For this experiment the same recirculation ratio (α) and initial hydraulic retention times (τ_{AN} and τ_{AE}) as the lab study were used.

To determine the necessary Q_I, Q_R and V to achieve the desired retention times in the reactors, a working level for the anoxic reactor was set at 81 cm. The tanks used have a volume to depth ratio of 11.6 L/cm, which results in a working volume of 940 L.

Using the predetermined retention time $\tau_{AN} = 35$ hr, $V_{AN} = 94$ 0 L and $\alpha = 1$ (indicating the recirculation flow rate and influent flow rate were equal) the flow rates can be determined using the following equations with terms defined by Table 4 and Figure 4.

$$\tau = V / Q_T \qquad \text{(eq. 4)}$$

Where,

$$Q_T = Q_I + Q_R \qquad \text{(eq. 5)}$$

and

$$Q_R = \alpha * Q_I \qquad \text{(eq. 6)}$$

With $\alpha = 1$ then $Q_R = Q_I$ so,

$$Q_T = 2 * Q_I \qquad \text{(eq. 7)}$$

Eq. 4 then becomes,

$$\tau_{AN} = V_{AN} / 2 * Q_I \qquad \text{(eq. 8)}$$

Substituting, $Q_I = 13.5$ L/hr, $Q_R = 13.5$ L/hr, $Q_T = 27$ L/hr, and $\tau_{AE} = 36$ hr, V_{AE} is calculated to be 972 L and subsequently a working fluid level of 84 cm was needed in the aerobic reactor.

In order to more evenly distribute Q_I and Q_R over time, to achieve a near constant flow rate, the flow rates were divided by six and 2.3 L was metered in every 10 min.

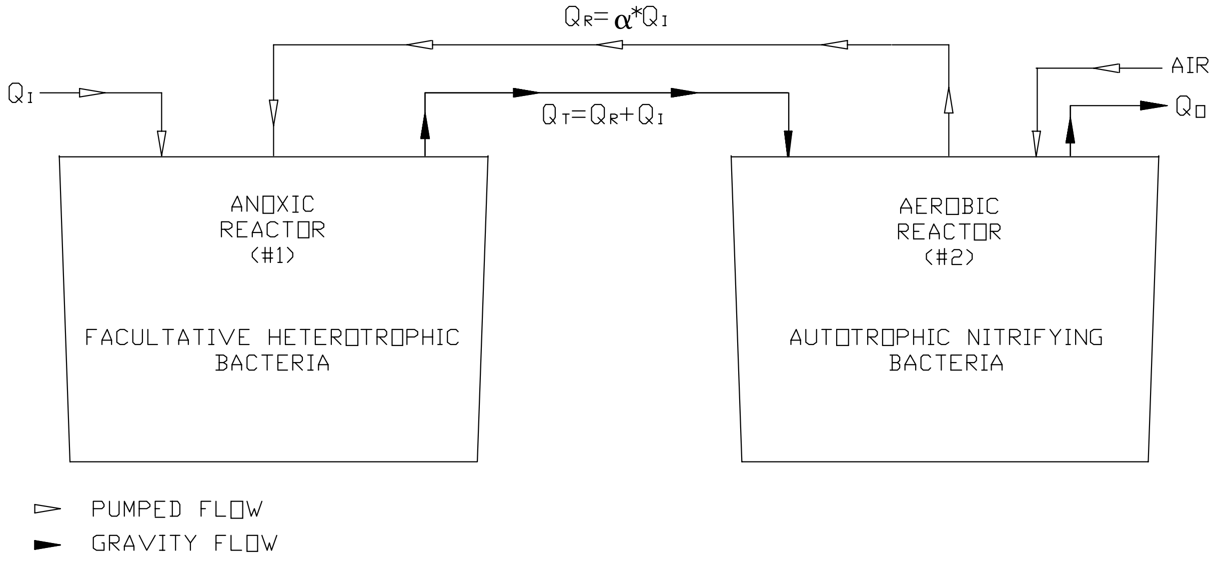

Figure 4 – A/A System Schematic

System Construction

A 3 phase electrical service with meter was installed at the finishing house dedicated to the A/A system. The meter will allow for future economic studies to be performed on the system and comparisons made. The necessary electrical outlet placements were determined and installed.

The under-slat pit of the finishing house was retrofitted with the selected submersible pump and PVC mixing system.

The two fiberglass tanks were fitted with necessary bulkhead fittings, valves, 5.08 cm flow lines and standpipes for gravity flow discharge and installed outside the finishing house to serve as the reactors. Elevations of the tank site and the existing under-slat pit were determined. Final reactor tank elevations were set to maintain a head differential of 10.16 cm between the anoxic and aerobic tanks and included the flexibility to utilize the under-slat pit as a reactor with complete gravity flow through system, without pumping influent waste, for future research. Tank site was excavated and system installed, ensuring unimpeded gravity flow through the system.

The aerator, distribution and diffusion system in the aerobic reactor were installed. The automated metering system was installed and tested. One 1/5 HP submersible pump and distribution system was installed in each reactor. The pump in the aerobic reactor was piped through one of the actuated valves to meter the recirculation flow into the anoxic reactor.

Upon system start-up the reactors were filled with raw swine waste to the set levels of 81 cm for the anoxic and 84 cm for the aerobic. Fluid flow rates through the influent and re-circulation lines were calibrated and controller programming was determined. Initial programming for the system "pulsed" the influent actuated valve open for 6 sec and the recirculation valve for 9 sec to achieve the desired Q_I and Q_R. The program was initiated and the influent flow from the under-slat mixing pump and the recirculation flow from the aerobic reactor were metered into the anoxic reactor, through the aerobic reactor and then out to the existing lagoon (Figures 3 and 4).

RESULTS AND DISCUSSION

Operational Progression and System Adjustments

After installation of the under slat pit stirring system, the waste in the pit contained an average organic concentration of 43,900 mg/L COD (average of six samples in May 2001, Figure 5) which is 4.7 times greater than the values obtained in the lab scale research (Table 2).

By May 2001, mechanical portion of the system was working well. The flow through system was unimpeded and automated valves functioning as intended. DO measurements in the aerobic reactor were very low, approximately 0.1 mg/L and COD values throughout system remained very high indicating no treatment taking place (Figure 5). Since the aerator for the aerobic reactor was sized using the lab scale influent COD value, these results indicate that the oxygen transfer to the aerobic reactor was insufficient to allow for conversion of NH_3 to NO_3 due to the extremely high COD of the influent waste.

On June 2, 2001, hydraulic retention times (τ) were increased by 25% from $\tau_{AN} = 35$ hr to 44 hr, $\tau_{AE} = 36$ hr to 45 hr by decreasing influent flow rate to Q = 11.4 L/hr to allow establishment of the autotrophic nitrifying bacteria in the aerobic reactor.

On July 17, 2001, due to lack of system response to increase in hydraulic retention times, sodium nitrate was added to the anoxic reactor on a schedule of 9.1 kg twice a week. The temporary addition of the supplemental sodium nitrate was used to supply the necessary nitrate to facilitate heterotrophic bacteria growth and "jump start" organic degradation via denitrification. The reduction in COD entering the aerobic was predicted to allow autotrophic bacteria growth in the aerobic reactor and allow nitrification.

By August 2001, the system slowly responded to the adjustments made as shown in Figure 5. The lower aerobic and anoxic COD values as compared to the influent values indicate treatment taking place. The large fluctuation in influent values may be attributed to the heterogeneous nature of samples and the varying amounts of flaking from build up in the systems piping when collecting samples. Subsequent charts will reflect a weighted average of the influent data which will aid in showing the trend over time.

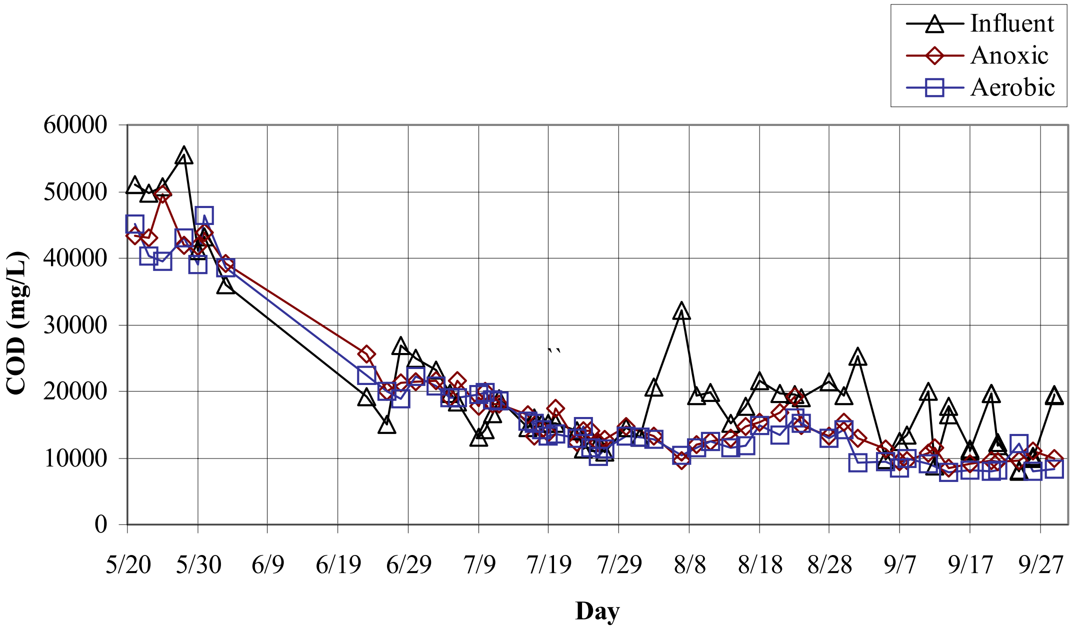

Figure 5 – COD Data (5/21/01 to 9/29/01)

By October 2001, the DO level in the aerobic reactor increased and COD values in both reactors were generally lower than the influent, indicating treatment was taking place (Figure 6). To stabilize the system and increase COD reduction, the hydraulic retention times were increased to τ_{AN} = 70 hr, τ_{AE} = 72 hr by reducing influent flow rate to Q = 6.6 L/hr.

By November 2001, the downward trend of anoxic and aerobic COD values coincide with increased hydraulic retention times and indicate an increase in organic degradation (Figure 6). The addition of sodium nitrate was suspended on 11/14/01 and the downward trend in COD for the aerobic and anoxic reactors leveled out but remained constant. At this point the system was operating on its own without supplemental assistance (Figure 6).

On December 1, 2001, the hydraulic retention times were increased to τ_{AN} = 105 hr, τ_{AE} = 108 hr and Q = 4.5 L/hr in preparation for upcoming cold weather. As temperature decreased, bacterial growth in the reactors also decreased with a subsequent increase in effluent COD concentration (Figure 6) starting approximately 12/19. During the period of increasing COD concentration, non-steady state condition, organic degradation was taking place as shown by the difference in influent and effluent COD concentrations.

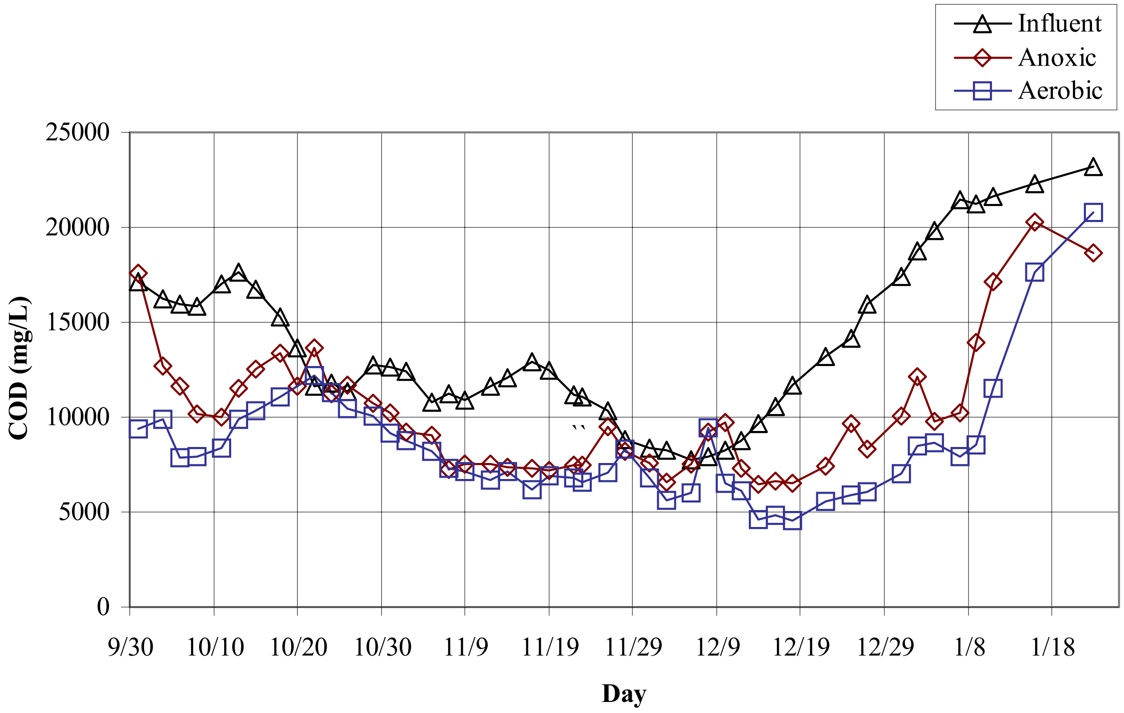

Figure 6 – COD Data (10/1/01 to 1/23/02), 5 Day Weighted Average - Influent

The daily ambient low temperatures for the time period 10/1/01 to 1/24/02 show an extended cold period from about 12/17/01 to 1/22/02 (Figure 7). Comparing the ambient temperature during this time frame to the wastewater temperature (Figure 8), a downward trend in wastewater temperature is evident and coincides with the increasing COD values in the anoxic and aerobic reactors observed in Figure 6.

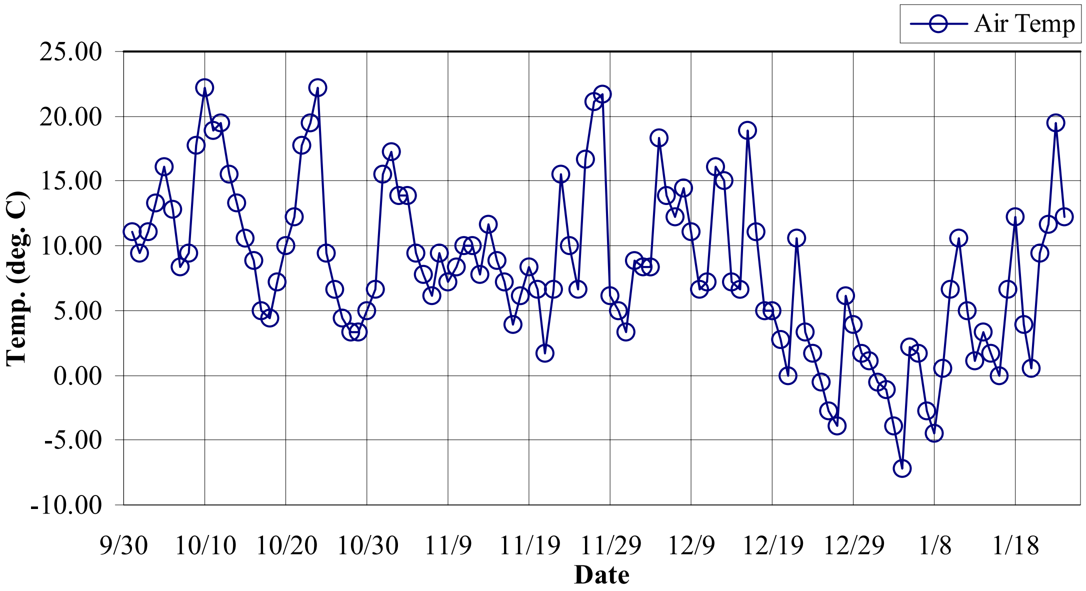

Figure 7 – Daily Ambient Low Temperatures (10/1/01 to 1/24/02)

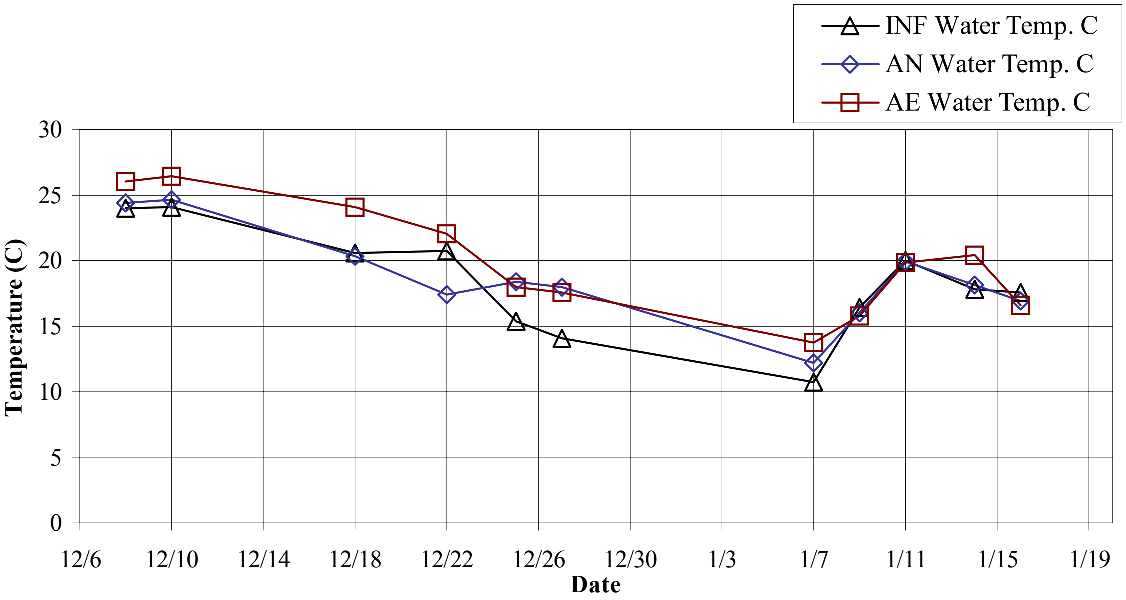

Figure 8 – Wastewater Temperatures (12/8/01 to 1/16/02)

An increase in influent COD during this period is also noted, this may be due to less water entering the under slat pit from the cooling misters during cold periods resulting in less dilution. Data collection was terminated for this experiment January 23, 2002.

Water Quality Data

In Tables 5, 6, and 7 influent values for COD reflects the 5 day weighted average values. These tables reflect three phases of operation, non-steady state (10/1/01 to 12/10/01); steady state (12/12/01 to 12/18/01) and second non-steady state (12/22/01 to 1/23/02).

Data in Table 5 indicate steady state had not been established but the overall decrease in effluent COD, as shown in Figure 6, indicates steady advancement being made.

Table 5 – Average Water Quality Data, for Non-Steady State Period 10/1/01 to 12/10/01

Component	5 day Mean Influent Conc.	Anoxic Effluent Conc.	Aerobic Effluent Conc.	Percent Removed
COD (mg/L)	12323	9814	8313	33
NH_3-N (mg/L)	1160	836	723	38
NO_3-N (mg/L)	173	806	1045	

A 33% COD reduction through the system also reveals the system was working. Hydraulic retention times were τ_{AN} = 70 hr and τ_{AE} = 72 hr and average daily ambient temperature was 16 °C. Overall ammonia reduction through the system indicates nitrification taking place and establishment of autotrophic bacteria in aerobic reactor. Thus, the addition of supplemental nitrate was terminated on 11/14/01. As indicated in Figure 9, an apparent residual of sodium nitrate had built up in the anoxic reactor which washed out over approximately two weeks after termination of the addition. The reported values of 95 mg/L is the sample detection limit. The high detection limit for the nitrate-N was due to diluted samples being analyzed. This also implicates the possibility of appreciable error in these reported results. From approximately 12/3/01 to the end of the experiment there was no measurable nitrate within the system.

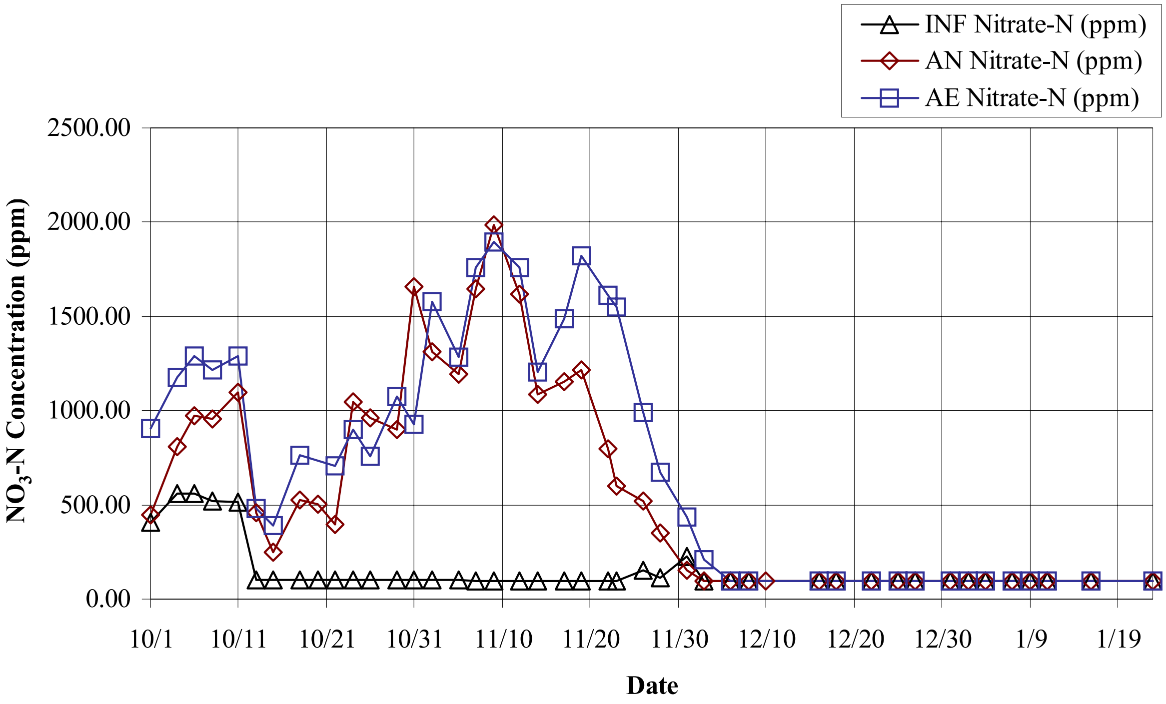

Figure 9 – Nitrate-N (10/1/01 to 1/23/02)

Table 6 shows average water quality data for the time period 12/12/01 to 12/18/01. Effluent COD and ammonia values, as indicated in Figure 6 and Figure 10, reveal steady state conditions were established and the system operating independently. Hydraulic retention times were τ_{AN} = 105 hr and τ_{AE} = 108 hr and average daily ambient temperature was 16 °C.

Table 6 – Average Water Quality Data for Steady State Period 12/12/01 to 12/18/01

Component	Influent	Anoxic Effluent	Aerobic Effluent	Percent Removed
COD (mg/L)	10163	6716	5023	51
NH_3-N (mg/L)	1209	850	633	48
NO_3-N (mg/L)	95	95	95	

Overall COD reduction through the system at steady state conditions was 51% and ammonia-N reduction was 48%. An acceptable 67% of the COD reduction was accomplished in the anoxic reactor. As the nitrifying bacteria were established in the aerobic reactor, ammonia reduction increased as the system approached steady state conditions (Figure 10). Ammonia-N was reduced by 576 mg/L and nitrate-N remained at the sample detection limit of ≤95 mg/L.

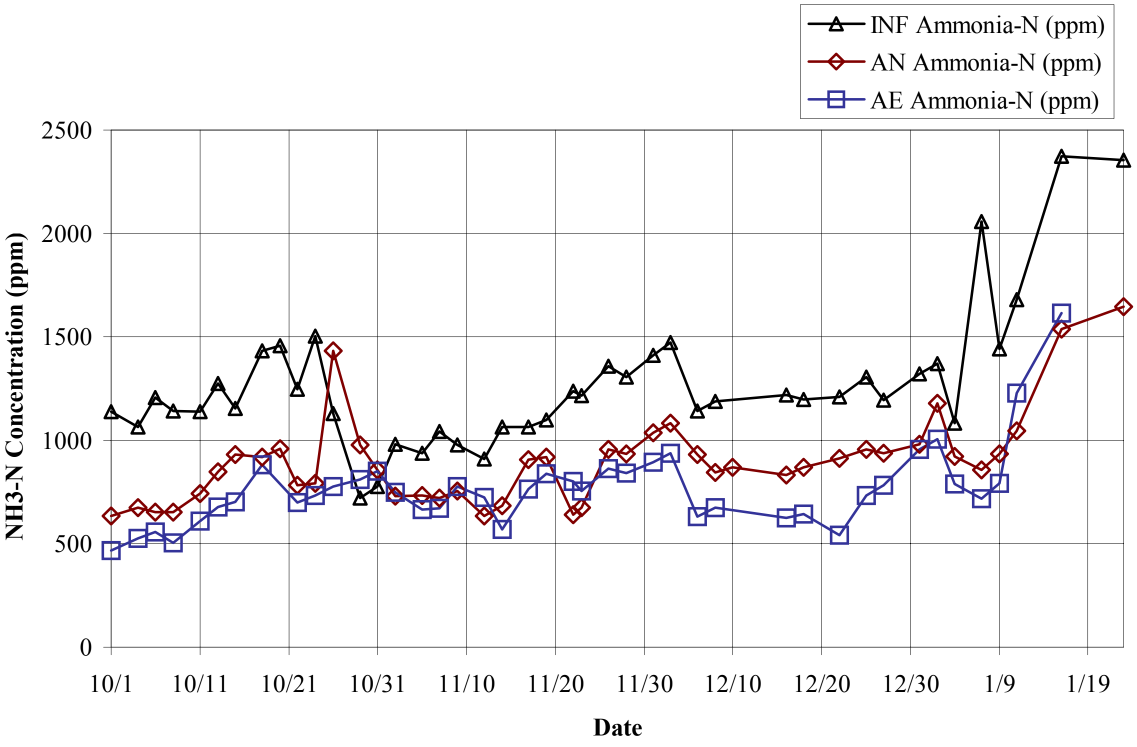

Figure 10 – Ammonia-N (10/1/01 to 1/23/02)

At steady state, overall COD reduction in the system was 51% compared to 69% reported by Pan and Drapcho (2001). Ammonia-N was reduced by 48% compared to 85% by the lab scale study (Table 7).

Table 7 – Water Quality Data Comparison at Steady State, Bench Scale vs. Field Scale

Component	Bench Scale (% Removed)	Field Scale (% Removed)
COD (mg/L)	69	51
NH_3-N (mg/L)	85	48

The reported nitrate-N values, especially in the aerobic reactor, were unexpected. The excellent COD reduction in the anoxic reactor and ammonia reduction in the aerobic reactor may be explained by partial nitrification being achieved in the aerobic reactor providing nitrite to the heterotrophic bacteria in the anoxic reactor for organic degradation. During the nitrification process, nitrite is an intermediary product which is further oxidized to nitrate in the complete process. In biochemical reactions, both nitrate and nitrite are important terminal electron acceptors (Grady, 1999).

Table 8 shows average water quality data for the non-steady state time period 12/22/01 to 1/23/02.

Table 8 – Average Water Quality Data for Non-Steady State Period 12/22/01 to 1/23/02

Component	Influent	Anoxic Effluent	Aerobic Effluent	Percent Removed
COD (mg/L)	19020	12507	9821	48
NH_3-N (mg/L)	1581	1083	837	47
NO_3-N (mg/L)	95	95	95	

From 12/22/01 to 1/23/02, increasing effluent COD values and decreasing reduction indicate non-steady state conditions (Figure 6). Dissolved oxygen (DO) levels in the aerobic reactor dropped to below 1 mg/L (Figure 11).

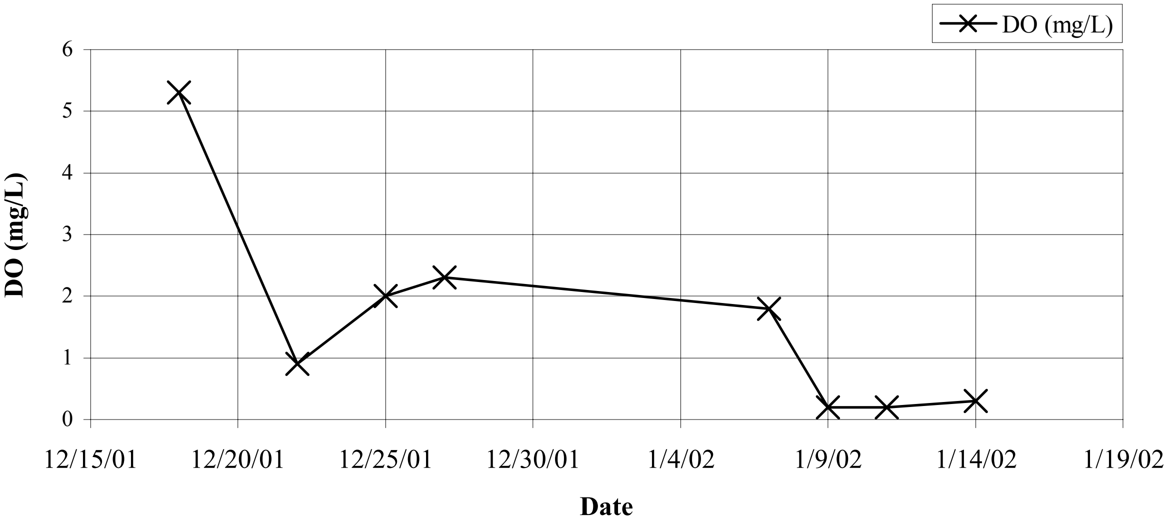

Figure 11 – Aerobic DO Levels (12/18/01 to 1/14/02)

Nitrate values remain at sample detection limit of 95 mg/L through the system. Concurrently, daily ambient low temperatures were at or near freezing for an extended period of time (Figure 7). Overall COD reduction through the system was 48%. Hydraulic retention times were τ_{AN} = 105 hr and τ_{AE} = 108 hr and average daily ambient temperature was 9 °C.

Field Measurements

Tables 9, 10 and 11 show averaged values of field data collected during each of the three time periods identified previously.

Table 9 – Field Data Averages for Non-Steady State Period 10/1/01 to 12/10/01

Component	Influent	Anoxic Effluent	Aerobic Effluent
pH	8.52	8.66	8.77
Water Temp, °C	24.0	25.0	27.3
DO, mg/L	1.1	1.1	3.3

Table 10 – Field Data Averages for Steady State Period 12/12/01 to 12/18/01

Component	Influent	Anoxic Effluent	Aerobic Effluent
pH	8.37	8.45	8.44
Water Temp, °C	20.6	20.3	24.1
DO, mg/L	0.2	0.2	5.3

Table 11 – Field Data Averages for Non-Steady State Period 12/22/01 to 1/23/02

Component	Influent	Anoxic Effluent	Aerobic Effluent
pH	8.49	8.66	8.75
Water Temp,°C	16.6	17.1	18.0
DO, mg/L	0.6	0.7	1.2

Comparing water temperature to DO levels in the aerobic reactor reveals decreasing dissolved oxygen concentration as temperature decreases. Figure 11 shows DO levels in the aerobic reactor in relation to date of sample. Comparing to Figure 6, a relationship between decreasing DO levels and increasing COD is apparent.

Conductivity was also measured over the time period 6/13/01 to 9/17/01 at which time readings were beyond the detection limit of the meter so collection of this data was suspended. Precipitation of salts was a problem in the system and periodic cleaning and maintenance was necessary to maintain proper operation. Table 12 gives the minimum, maximum and average readings collected at each sample point.

Table 12 – Conductivity Readings for the Time Period 6/13/01 to 9/17/01

Component	Influent (mS)	Anoxic Effluent (mS)	Aerobic Effluent (mS)
Minimum	7.8	8.0	7.7
Maximum	13.4	17.5	12.9
Average	10.5	11.8	10.9

SUMMARY AND CONCLUSIONS

The goal of this study was to design, construct, and operate a controllable field scale Anoxic/Aerobic (A/A) swine waste treatment system. The obtained results were evaluated and compared to expected results generated from the bench-scale experiment of Pan and Drapcho, 2001.

One recirculating rate, $\alpha = 1$, from aerobic reactor to anoxic reactor was investigated. Water quality parameters of temperature, pH, DO, ammonia, nitrate and COD were tracked through the system.

At steady state, overall COD reduction in the system was 51% compared to 69% reported by Pan and Drapcho. Ammonia-N was reduced by 48% compared to 85% by the bench scale study (Table 8).

These results show the field scale system reduced both the organic carbon and ammonia in the swine wastewater but was not as effective as the bench scale system. This could be in part due to the inherent difficulties of going from a controlled lab environment to field conditions and contending with the highly variable outside elements. The indication that partial nitrification was achieved in the aerobic reactor may also have attributed to the lower performance. Nitrite has a lower affinity level than nitrate as an electron acceptor in organic decomposition, reducing the efficiency. Also, as was revealed in the study by Pan and Drapcho, the heterotrophic bacteria kinetic parameters indicated that swine waste is difficult to biodegrade which this study proves. The reduction in ammonia indicates that the A/A system may have potential to address odor related problems of swine waste. The results prove the feasibility of the system and the need for further research and study to optimize the controlling parameters, such as retention times and recirculation rate, and achieve more efficiency from the system. This will be easily implemented utilizing the effective controls built into the system.

Observations and Recommendations

Swine waste offers an extremely harsh and challenging environment for all mechanical equipment installed. The corrosive nature of the waste, coarse abrasive build up of hair and rapid precipitation of salts promote premature wear on all pumps and valves installed. Any addition or replacement of system equipment should be researched and special attention given to this when selecting.

At startup of a new experiment, I recommend washing out the under slat pit and filling it to working level with water. This will begin influent into system at a very low COD level and allow bacteria time to acclimate and adjust as influent COD levels increase. In this manner the possibility of shock is reduced and a continuous and steady growth rate can be achieved.

The extreme variability in DO data of the aerobic reactor indicates some modification in the air distribution system may be necessary. My recommendation would be to try multiple, large diffuser stones or coil the diffuser hose in a layer spreading it out across more area of the tank and using a larger blower. This should maximize oxygen diffusion into the liquor and stabilize DO levels at acceptable levels.

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VITA

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