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Evaluation of an attached growth organic media bioreactor for swine waste treatment and odor abatement

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EVALUATION OF AN ATTACHED GROWTH ORGANIC MEDIA

BIOREACTOR FOR SWINE WASTE TREATMENT

AND ODOR ABATEMENT

by

Allison Paige Kirkpatrick

A Thesis
Submitted to the Faculty of
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THE EVALUATION OF AN ATTACHED GROWTH ORGANIC MEDIA

BIOREACTOR FOR SWINE WASTE TREATMENT

AND ODOR ABATEMENT

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The objective of this study was to determine if an organic media attached growth
bioreactor could effectively be used as a means of odor control for swine waste. The
pilot-scale attached growth bioreactor system was evaluated against a standard pit
recharge system, which served as the control. Performance was based on water quality
testing, odor assessments by a human sensory panel, and air phase measurements of
ammonia and hydrogen sulfide. The affect of aeration on the system was also evaluated,
along with various types of organic media (kenaf, hardwood mulch, and corncobs).
Overall, the bioreactor systems were effective in reducing orthophosphate, COD, volatile
acids, and phenol concentrations as compared to the control. The bioreactor systems
were not effective in reducing the conductivity, ammonia or total solids concentration of
the wastewater. With the exception of the corncob media, all bioreactor systems
significantly reduced the overall odor intensity and the fecal characteristic of the
wastewater as compared to the control system.

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CHAPTER 1

INTRODUCTION

The swine industry has changed dramatically in the past few decades. Production techniques have shifted from extensive outdoor production to intensive, confined housing and feeding practices. While these changes have brought about rapid growth and increased efficiency, they also generate large amounts of liquid and solid waste that are often associated with odors. These odors are often perceived to be a nuisance. As the production moves into larger units and the surrounding residents have a less direct relationship to animal-based agricultural activities, odor will become an increasing concern for the swine industry. In recent years, odor complaints have increased in severity and number, especially for larger facilities located in areas experiencing urban sprawl. Odor is no longer considered to be an inconvenient by-product, but has become a valid concern for livestock producers (NPPC, 1995).

Odors from these facilities can have a considerable impact on a person's physiological and psychological well-being. A study by Schiffman et al. (1995) found that persons living near an intensive swine facility experienced more tension, more depression, more anger, less vigor, more fatigue, and more confusion than control subjects as measured by the Profile of Mood State. Wing and Wolf (2000) also found that people living near swine facilities have reported decreased health and quality of life. Reports of headache, runny nose, sore throat, excessive coughing, diarrhea, and burning

eyes were more frequent from residents in the vicinity of a swine operation than from residents of a community without a swine operation. A study conducted by Kirkhorn and Garry (2000) reported that a significant percentage of agricultural workers have clinical symptoms associated with long-term exposure to organic dusts and animal confinement gases. In particular, swine confinement operations have contributed to the increased intensity and duration of exposure to indoor air toxins. Respiratory diseases and syndromes such as hypersensitivity pneumonitis, organic dust toxic syndrome, chronic bronchitis, mucous membrane inflammation syndrome, and asthma-like syndrome can result from acute and chronic exposure to organic dust and gases.

Survival of the swine industry in industrialized countries may depend on the reducing the emission of offensive odorants to levels tolerable by surrounding communities (Zhu, 2000). In fact, public concern with odor and water quality has prompted several states to place moratoriums on the construction of new confined animal feeding operations. In 1997, North Carolina was the first state to place a ban on any new hog operation planning to house more than 200 animal units. Maine placed a ban (expired in September, 1999) on hog operations with 500 or more animals. In 1998, Mississippi placed a two-year moratorium on new operations housing 200 or more hogs. Since 2000, Mississippi has not issued additional permits, citing a need for more information regarding health concerns. In 1999, Kentucky placed a ban on new operations so it could assess and update relevant laws and regulations (Glenn, 1999).

Numerous technologies have been developed and/or are currently under development to control or eliminate odors. However, many of these technologies are not

considered to be technically or economically feasible for most livestock operations. They are expensive and energy intensive, lack flexibility, and have substantial management requirements. Further research and development of cost-effective alternatives are needed.

These factors resulted in a research effort by the Mississippi Agricultural and Forestry Experiment Station (MAFES) at Mississippi State University (MSU) to develop a cost-effective biological treatment system for swine wastewater. An attached growth bioreactor system using organic media was designed by a research team headed by Dr. Timothy N. Burcham with the primary goal of reducing odor associated with large-scale swine production. The system uses attached growth biological treatment to reduce the formation of odor compounds and utilizes plant fiber as the attached growth medium. Bench-scale models by Jones (2000) were used to determine loading rates and potential odor reduction for the attached growth system. Water quality analyses indicated that the attached growth system was effective in reducing biochemical oxygen demand (BOD_5), chemical oxygen demand (COD), total solids (TS), volatile solids (VS), and other nutrients in the swine wastewater. A human olfactory panel evaluated the treatments for odor reduction. The panel indicated that the attached growth treatment changed the odor associated with swine waste from a highly intense, acrid odor to an odor that was primarily "earthy" in character. Based on these findings, a pilot-scale attached growth bioreactor system was installed at the MAFES Swine Physiology Barn on the MSU campus.

Objectives

The primary objective of this study was to determine the applicability of using an attached growth bioreactor system to biologically treat and therefore reduce the odor associated with swine waste. The specific objectives of this research are as follows:

1. To determine if an attached growth bioreactor packed with organic media could effectively be used as a means of odor control as measured by water quality testing, odor assessments by a human sensory panel, and air phase measurements of ammonia and hydrogen sulfide,

2. Determine if aeration of the collection pits and/or bioreactor vessel improves the performance of the attached growth bioreactor system, and

3. To evaluate the performance of various types of organic packing media such as kenaf, hardwood mulch, and corncobs.

CHAPTER II

REVIEW OF LITERATURE

The Problem with Odor

Odor is perhaps the most critical issue facing the swine industry today. Odors considered to be offensive can be generated from manure during collection, handling, storage, and spreading (Mackie et al., 1998). Odors have become a valid concern of producers as the industry has evolved into larger and more intense units (NPPC, 1995). Therefore, accurate methods to quantify odors and to estimate when potential problems may occur are needed. The fact that there is no universally accepted definition of an objectionable odor complicates the matter. The producers do not have a set of conditions that requires them to reduce the level of odors generated from their facilities. Due to the difficulty in defining and initiating an odor regulation, most states have not adopted odor guidelines (NPPC, 1995; Mackie et al., 1998). Many factors can contribute to odor nuisance conditions making determination of an acceptable level of odor difficult. Livestock odors are often sporadic and can result from barely detectable levels of odorant compounds. The human nose has extremely sensitive detection capabilities and is capable of recognizing odorants in the parts-per-billion range or less. The extreme variability of odor sources, environmental conditions, and human response to various odorants all contribute to the difficulty of measuring and determining objective limits for livestock odors (NPPC, 1995).

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Definition of Odor

Odor is defined as something that stimulates the olfactory system or sense of smell. Each compound has a characteristic smell, and humans are known to be able to detect over 10,000 odors despite being able to name only a few of them (Mackie et al., 1998). Despite this acute sense of smell, it is often difficult to describe the smell of a compound, and each individual differs in his or her perception of odor. The human nose can detect and discriminate odors at concentrations even lower than those detectable by gas chromatography. Also, a mixture of odorants may smell different from the unmixed compounds and in general, pleasantness decreases as intensity increases. Many factors influence olfactory sensitivity, but none so much as individual variability. Therefore, establishing a universally accepted definition of an objectionable odor has proven difficult (Mackie et al., 1998).

Measurement of Odors

Odor nuisance can generally be defined by four factors: frequency, intensity, duration, and offensiveness. Frequency is the number of times an odor occurs. Intensity is an indication of the strength of the odor. Duration is length of time the odor is encountered.   Offensiveness refers to the unpleasantness of the odor. The intensity of the odor has been given the most consideration with regard to odor nuisance problems for both research and regulatory purposes.   Therefore, a variety of methods have been developed for measuring an odor's intensity. The methods can be classified into two categories: direct and indirect. In direct (also known as sensory or olfactometric) methods the human nose is used as a detector, usually in the form of a panel of trained observers.

Indirect methods work by measuring concentrations of volatile odorants or particles in the air. The measurements are then correlated to direct observations (NPPC, 1995; Mackie et al., 1998).

Direct methods can be divided further into two major categories: scaling and dilution. Scaling involves either rating the intensity of the odor on an arbitrary scale or against a standard of known intensity. Scaling techniques are simple, easy to use, and do not require complex equipment. Dilution methods, however, are more objective. In dilution methods, the samples are diluted with odor-free air to determine the odor threshold or detectability. The use of a reference, useful in both scaling and dilution methods, is advised to help in comparing values from different panelists. Using this approach the panelists compare the intensity of an odor with a series of different concentrations of a reference odor to determine if the intensity of the odorous sample is less than, greater than, or equal to a given concentration of the reference odor (NPPC, 1995; Mackie et al., 1998).

All dilution methods involve presenting the panelists with a range of dilutions of the odorous sample in liquid or vapor form, which allows for the determination of a detection threshold. The detection threshold refers to the lowest concentration at which odor can be positively detected. Results of dilution methods are expressed as a dimensionless ratio representing the volume of odorous and odor-free liquid or vapor to the volume of odorous liquid or vapor at the dilution representing the detection threshold. Liquid dilution has primarily been used in the assessment of odors in water and wastewater treatment effluents (NPPC, 1995; Mackie et al., 1998).

Scentometers and dynamic olfactometers have been used in the evaluation of ambient odors originating from livestock wastes. They allow for direct field measurements to determine the threshold dilution. The scentometer is a small, hand-held device that consists of an activated carbon filter, two nasal ports, and a series of graduated orifices. Varying amounts of the odorous and filtered air are introduced to the individuals nose through the two nasal ports. The individual can then indicate which ratio of odorous to filtered air is detectable. This ratio becomes the threshold dilution (NPPC, 1995; Mackie et al., 1998).

However, there are a number of limitations to using sensory methods for measuring odor intensity. These include rapid saturation of olfactory senses by some odorants, individual variation in sensitivity to different odor, fatigue as a result of adaptation, and changes in climatic variables when measuring odors under field conditions, as well as effects of age, gender, health and personal habits on the sense of smell of individual panelists (Ritter, 1981; NPPC, 1995; Mackie et al., 1998).

Therefore, there is a need for alternative methods for measuring odors. Several indirect methods that separate, identify, and quantify the odorous compounds have been developed. These methods offer several advantages such as automated sampling and measurement. Gas chromatography (GC) is the technique most commonly applied to separate and identify volatile and gaseous samples. The odorous compounds can be separated by injecting an odorous air sample onto specific columns. The columns separate compounds according to their vapor pressure and solubility. The individual components can be identified using nonspecific detectors such as thermal conductivity

flame ionization or electron capture. The peak areas and heights can then be used to quantify the concentration of each component. The use of a mass spectrometer, a specific detector, improves the certainty with which compounds may be identified. This technique enables the odorous compounds to be "profiled or fingerprinted" based on their ionized molecular fragment patterns. However, this technique is mainly used in research rather than routine monitoring due to the cost (Chen et al., 1994; NPPC, 1995; Mackie et al., 1998). Correlating the concentrations of odorous compounds with direct sensory methods is very important. However, mixtures of odorous compounds may be additive, subtractive, synergistic, or counteractive, making correlating concentrations to odor intensity difficult. Although, indirect methods have been and are being developed for odor evaluation, none of the methods have gained acceptance over using the human nose and sensory methods (Barth et al., 1984; NPPC, 1995; Mackie et al., 1998).

<u>Key Odor Components</u>

Microbial activities are normally considered to be responsible for the odor generated from stored swine manure. Manure is subject to anaerobic degradation under a variety of conditions, which results in the generation of odorous volatile compounds. The odorous volatile organic compounds (VOCs) are the normal end products or intermediate products of the degradation of fecal substances by anaerobic bacteria. (Zhu and Jacobsen, 1999; Zhu, 2000). When manure is exposed to the atmosphere, volatile products and intermediates can be emitted into the environment. These odorous compounds absorb to particulate matter (dust), building surfaces, and clothing. Not only are these compounds responsible for malodors, but they can also affect the comfort,

health, and production efficiency of animals as well as the human workers. The

principal odorous compounds can be divided into four different chemical classes: volatile

fatty acids, indoles and phenols, ammonia and volatile amines, and sulfur-containing

compounds (Mackie et al., 1998; Zhu and Jacobsen, 1999; Zhu, 2000).

Volatile Fatty Acids

Volatile fatty acids are produced from the fermentation of structural

carbohydrates and in the deamination and decarboxylation of amino acids. The majority

of the volatile fatty acids produced are acetic, propionic, butyric, valeric, caproic, and

capric acids. Bacterial genera involved in these activities normally include *Bacteroides*,

Prevotella, *Selenomonas*, *Lachnospira*, *Eubacterium*, *Fusobacterium*, *Clostridium*,

Peptostreptococcus, *Streptococcus*, *Acidaminococcus*, and *Bifidobacterium* (Mackie et

al., 1998; Zhu and Jacobsen, 1999; Zhu, 2000).

Indoles and Phenols

The production of indoles and phenols results from amino acid metabolism. The

degradation of tyrosine and phenylalanine in the intestinal tract can result in the

formation of phenolic compounds such as phenols and p-cresols (Spoelstra, 1977;

Ishaque et al., 1985; Mackie et al., 1998; Zhu and Jacobsen, 1999; Zhu, 2000).

Tryptophan metabolism results in the production of indoleacetate, which is subsequently

converted into skatole (3- methyl indole) and indole. The bacterial genera responsible for

these compounds include *Propionibacterium*, *Escherichia*, *Eubacteria*, and *Clostridium*,

Bacteriodes, *Lactobacillus*, and *Bifidobacterium* (Mackie et al., 1998; Zhu and

Jacobsen, 1999; Zhu, 2000).

Ammonia and Volatile Amines

Volatile amines include putrescine, cadaverine, methylamine, and ethylamine.

During the storage of fresh manure, amino acids undergo decarboxylation to produce

putrescine, cadaverine, and ammonia. Bacterial genera involved in this activity include

Streptococcus, *Peptostreptococcus*, and *Bacteroides*. In addition to amino acid

deamination, urea hydrolysis is another source of ammonia (Mackie et al., 1998; Zhu and

Jacobsen, 1999; Zhu, 2000).

Volatile Sulfur-Containing Compounds

Anaerobic bacteria produce sulfur compounds by sulfate reduction and through

the metabolism of sulfur containing amino acids. Sulfate reduction can occur by either

assimilatory or dissimilatory pathways. In the first process, bacteria produce enough

reduced sulfur for cell biosynthesis; while in the second process, sulfate is utilized as

terminal electron acceptor and large quantities of sulfide are produced. Bacterial genera

involved in this activity include *Megasphaera*, *Desulfobivrio*, *Veillonella*, and the

enterobacteria (Mackie et al., 1998; Zhu and Jacobsen, 1999; Zhu, 2000).

<u>Major Odor Indicators</u>

Extensive research has been conducted to determine the major odor indicators for

swine manure. Merkel et al. (1969) found alcohols were unimportant in determining the

nature of swine odor, and major odor constituents were from amine and sulfide groups

(Zhu et al., 1999; Zhu and Jacobsen, 1999; Zhu, 2000). Barth et al. (1974) reported

that the volatile organic acids correlated best with the odor intensity. Ammonia was

thought to be useful as an indicator for malodor, but in spite of the relatively high

concentrations and easy determination, it was proven to be a poor parameter in evaluating

odor intensities (Lunn and van De Vyver, 1977; Barth et al., 1974; Williams, 1984;

Riskowski et al., 1991; Zhu et al., 1999; Zhu and Jacobsen, 1999; Zhu, 2000). A study

by Spoelstra (1977) showed indole and skatole could not be recommended as indicators

for malodor because concentrations might decline during storage (Zhu et al., 1999; Zhu

and Jacobsen, 1999; Zhu, 2000). Spoelstra (1980) reported in another study that both

ammonia and hydrogen sulfide were not suitable indicators for odor. It was concluded

that the VFAs seemed to be useful indicators to test whether an effect had occurred in

odor-abatement methods (Zhu et al., 1999; Zhu and Jacobsen, 1999; Zhu, 2000).

Williams (1984) found that the supernatant BOD_5 correlated with offensiveness during

both aerobic treatment and post-treatment storage; and therefore, could be the most

widely applicable indicator. He also concluded that VFAs, total organic acids, as well as

indoles and phenols correlated with offensiveness during post-treatment storage and

limits of acceptability could be defined during aerobic treatment. Sulfide is a misleading

indicator during aerobic treatment, but is a useful indicator during post-treatment storage.

He also found that ammonia is of no value as an indicator (Zhu et al., 1999; Zhu and

Jacobsen, 1999; Zhu, 2000). A study conducted by Zahn et al. (1997) reported that the

volatile organic acids with carbon numbers ranging from two to nine demonstrated the

greatest potential for the malodor. They exhibited the highest transport coefficients and highest respective airborne concentrations (Zhu and Jacobsen, 1999; Zhu, 2000).

The research literature indicates that volatile fatty acids may be a good indicator for measuring odor potential from swine manure because VFAs always tend to be produced in the processes that are known to produce swine odors. However, the measurement of total VFAs has not been shown to be highly correlated to offensive odors. This contradiction may be explained by the fact that all VFAs may not contribute equally to the sensation of offensive odors. It may be that only the long chain VFAs (C4-C9) are highly offensive, so future research may need to concentrate on these acids (Zhu et al., 1999).

Odor Control Technologies

Anaerobic Processes

A number of different anaerobic digestion processes have been developed for the treatment of high strength organic wastes. Many of these processes are applicable for treating swine wastewater. Anaerobic digestion is the breakdown of organic and inorganic matter in the absence of oxygen. During anaerobic digestion, organic matter is biologically converted into a variety of end products, namely carbon dioxide and methane (Metcalf and Eddy, 1991).

The anaerobic digestion of organic matter is thought to occur in three steps hydrolysis, acidogenesis, and methanogenesis. A consortium of bacteria is responsible for the anaerobic digestion of organic waste. One group of organisms hydrolyzes organic

polymers and lipids to basic structural building blocks. A second group ferments the products into simple organic acids. They are often referred to as acidogens or acid formers. Finally, a third group of microorganisms, methanogens, convert the organic acids into methane gas and carbon dioxide (Metcalf and Eddy, 1991). Maintaining a balance between the last two groups is instrumental in the prevention of malodor. The production of the acids must equal the consumption of acids by the methanogens. Malodor can result when the production of acids exceeds the consumption. The methanogens are considered the working force in the anaerobic decomposition process. Therefore, whether an anaerobic treatment process can function well depends largely on the performance of the methanogens (Zhu, 2000).

The use of anaerobic lagoons is perhaps the most common method of wastewater storage and treatment used in the swine industry today. Within many of the swine facilities, the swine waste is collected from slotted floors and stored in a liquid form in 16 to 24-inch underfloor pits. The underfloor pit is drained periodically by gravity to a lagoon and recharged with new liquid. By draining the pit, much of the manure solids are removed therefore reducing the amount available for gas production. Also, the liquefaction of the solids that settle provides for easier removal at the next draining interval. As the frequency of draining and recharging increases, more manure solids will be removed, reducing gas generation potential. In order to achieve the goal of reduced odor and gas levels, studies have shown that flushing needs to occur every five to seven days. Fresh water can be used for the pit recharge; however, most facilities will recycle lagoon liquid to cut down on the use of fresh water and to lessen the capacity of the

lagoon. A relatively high-quality lagoon effluent is required for recharging.

Insufficiently treated lagoon liquid may contribute to the odor and gas generation within

the underfloor pits (Muehling, 2001)

Unfortunately, many of these lagoons are overloaded and not functioning

properly, which can result in the generation of odors (Zhu, 2000). The lagoons are

designed so that bacteria (methanogenic and non-methanogenic) decompose the organic

compounds in swine manure under anaerobic conditions. These bacteria grow best in

either mesophilic or thermophilic temperature ranges depending upon genera. In

operating lagoons, the storage temperature of wastes usually ranges from 10° to 20° C

depending on the season. This temperature range is generally lower than the optimum

mesophilic temperature range (Zhu, 2000). Lower temperatures, along with excess

ammonia and volatile acids concentrations, and insufficient bicarbonate alkalinity can

prevent methane fermentation from being the dominant activity resulting in an upset in

the acid formation/consumption balance (Donham, 1985). Once the balance is upset,

little methane will be formed and strong offensive odors can be generated by the lagoon

(Zhu, 2000).

A number of studies using other anaerobic digestion processes for the treatment of

swine wastewater have been reported (Zhang et al., 1997). Continuously stirred tank

reactors (CSTR) and plug-flow reactors are also used in animal waste treatment. The

hydraulic retention time (HRT) and solids retention time (SRT) are equal in both of these

reactors. In other words, the liquid and solids travel through the reactor at the same

retention time. However, the retention time must be long enough to satisfy the growth

requirements and ensure a sufficient amount of functioning anaerobic bacteria.

Typical retention times for CSTR and plug-flow reactors are 15 to 30 days, depending on

strength of the wastes. However, several types of anaerobic reactors have been

developed that allow the separation of the SRT from the HRT. Separation of the

retention times (decreased HRT) allows for the cost effective treatment for dilute wastes,

such as flushed swine waste (Zhang et al., 1997).

Other anaerobic reactors used are the anaerobic contact reactor, upflow anaerobic

sludge blanket reactor (UASB), anaerobic biofilter, fixed film reactor, and fluidized bed

and expanded bed reactors (Zhang et al., 1997). The first two are known as suspended

growth reactors, while the latter as attached growth reactors.

In the anaerobic contact process, untreated waste is mixed with recycled sludge

solids and digested in an anaerobic reactor. After digestion, the mixture is separated and

the supernatant is released as effluent and the settled anaerobic sludge is returned and

mixed with untreated sludge. This allows the solids to have a longer retention time than

the liquid (Metcalf and Eddy, 1991).

In an UASB reactor, the waste enters in the bottom of the reactor and flows

upward through a sludge blanket composed of biologically formed granules or particles

(Metcalf and Eddy, 1991). Lo et al. (1994) used two hybrid upflow anaerobic sludge

blanket reactors to treat screened swine wastewaters. Operating at moderate organic

loading rates, over 57% of the chemical oxygen demand (COD) was removed and 0.7

liters methane per liter reactor day were obtained during the study. Sanchez et al., (1995)

found that 40% of organic matter was removed in the UASB reactor with a similar

range of organic nitrogen and phosphorus (PO_4^{-3}) removal.

Another reactor technology is the anaerobic suspended particle attached growth

(SPAG) reactor (Bolte et al., 1986). This technique combines characteristics of attached-

growth reactors with conventional complete-mixed reactors. Active bacterial masses are

fixed onto lightweight highly porous support particles. These particles are suspended in

the reactor liquor by mechanical agitation. Bolte et al. (1986) concluded that SPAG

reactors appear to be "well-suited" for conversion of medium strength animal wastes to

methane gas. Hill and Bolte (1986) determined that operating and performance

characteristics of SPAG reactors were superior to conventional reactors at the same

HRT's with regard to alkalinity and ammonia (NH_3) levels, VS and COD reduction, as

well as gas quality and specifically methane production.

The anaerobic sequencing batch reactor system developed at Iowa State

University (US Patent No. 5,185,079) is a suspended-growth, biomass-retaining reactor.

The ASBR system works in a batch mode with 4 distinct cycles: feed, react, settle, and

decant. Mixing is provided intermittently during the feed and react phases. The substrate

concentration and the biogas production is at its highest in the feed and react phases,

which results in internal gas mixing. During the settle and decant phases, the substrate

concentration and biogas production is at its lowest providing conditions for biomass

settling. The settle phase allows biomass solids to be kept within the reactor extending

the SRT and improving the organic removal efficiencies. Zhang et al. (1997b) found that

the ASBR is effective in treating dilute swine manure at 35° C with a HRT as short as three days over a wide range of volatile solids (VS) loading rates (0.9 to 5.5g VS/L day).

Zhang et al. (1997) evaluated the effects of anaerobic treatment on odor control of swine and dairy manure using laboratory scale, two-stage anaerobic sequencing batch reactor (ASBR) systems. Using gas analysis, they were able to conclude that the anaerobic treatment systems reduced the generation of sulfur gases during manure storage. The raw dairy and swine manure exhibited strong offensive odors with high hydrogen sulfide (H_2S) and mercaptan concentrations detected in the headspaces of storage jars. However, the treated manure showed little residual odors and during many tests, H_2S and mercaptans were not detectable.

Welsh et al. (1977) studied the effect of anaerobic digestion on the odor of swine manure using a series of odor panels. Undigested manure samples, along with samples from digesters of various SRTs, agitation rates, and operating temperatures were tested. The results indicated that anaerobic digestion was effective in reducing odors, but that some negative quality in the odor remained. Both digested and undigested manure samples had "sulfide-like" and/or "rotten egg" odor characteristics. Ammonia, sour, fermented, moldy, and musty were descriptive terms commonly used. "Manure" was the major descriptive term given by the panelists. It was concluded that the type of odor was not significantly altered, but the intensity of the odor had been modified. Hedonic ratings on an 11 point scale (0-10) indicated that the anaerobic digested swine manure reduced the presence and offensiveness of swine manure odors from a rating of 6.5 for undigested manure to 4.6 for digested manure.

Aerobic Processes

Several studies have been conducted to determine the effect that aerobic treatment has on the control of odor from swine operations. The characteristic odors of slurries of animal wastes are largely due to the release of volatile organic compounds from the fermentative degradation of fecal residues. As stated earlier, these compounds are the normal end products of catabolism by anaerobic bacteria. They are, however, readily degradable by aerobic bacteria (Evans et al., 1986).

Evans et al. (1986) studied aeration and control of slurry odors by heterotrophic bacteria. During continuous-culture aeration, heterotrophic activity varied with treatment time and temperature, but was unaffected by the level of dissolved oxygen (DO) as long as it exceeded 1 % saturation. He concluded that treatment times must normally exceed seven days and redox potential during treatment must be higher than -200mV if the rapid regeneration of odorants after treatment is to be avoided.

Chen et al. (1994) confirmed that aeration is an effective method of odor control for swine wastewater. Under aerobic conditions, malodorous volatile fatty acids, phenol, p-cresol, and skatole were degraded. A headspace sampling GC technique was used to monitor and quantify the changes in the concentrations of certain malodorous compounds during the aeration of swine wastewater within the laboratory.

Williams et al. (1989) performed pilot scale (500 L) continuous-culture experiments to determine the oxygen requirements for controlling odor from pig slurry. The offensive odors of untreated, separated pig slurry were controlled by aerobic treatment, at 28° to 35° C with residence times of 1 to 4.8 days and with an aeration rate

that maintained redox potential at +13 mV Eh and above.   The minimum oxygen requirement for controlling odors from separated pig slurry containing 14 to 39 kg/m^3 of total solids was 0.11 kg/pig place•day.

Sequencing batch reactors (SBR) have gained acceptance for BOD and nutrients removal from both municipal and industrial wastewaters (Bicudo et al., 1999). Bicudo et al. (1999) monitored a pilot scale SBR unit with capacity to treat up to 1.5 m^3/day for 7 months at a swine farm in North Carolina. It operated with a solids retention time of 35 days. Higher removals of total nitrogen (N) (75%-95%) and total phosphorus (P) (15%-70%) were observed when the SBR was operated with 10 days HRT and short aerating/non-aerating periods (aeration one hour on, one hour off) than with other conditions. The SBR was also able to significantly reduce odor intensity and irritation intensity as evaluated by an odor panel using liquid influent and effluent samples. The biosolids had higher odor and irritation intensity than the treated effluent, but were significantly less intense than the flushed swine manure (influent).

Bicudo and Svoboda (1995) studied a farm scale activated sludge treatment plant treating pig slurry for one year. Four different aeration cycles were tested. The performance was not significantly affected by 60% reduction of aeration times, from 20 hours per day to 12 hours per day. High removal rates could be achieved through the intermittent operation of the aerator. Operating at a very long sludge age resulted in almost complete removal of soluble biodegradable matter and up to 90% removal of soluble COD. The energy input to the system was estimated to be 9 kWh/m^3 of slurry.

Zappi et al. (2000) studied the effects of aerating and adding an activated sludge seed to swine wastewater in order to prevent the formation of odor compounds. Three different systems were evaluated in a pilot-scale swine facility: aeration of the wastewater collection pits, aeration with bioaugmentation, and standard pit recharge system serving as the control. The aeration with bioaugmentation had the highest BOD_5 removal efficiency and the lowest levels of organic volatile acids of all the systems tested. The preliminary olfactory evaluation of the wastewater samples indicated that the aeration of the pits does improve the odor as compared to the control treatment. The results indicated that there was a benefit to the aeration strategies as compared to the anaerobic control.

Attached Growth Biological Processes

Attached growth biological treatment is usually used to remove organic matter found in wastewater. It can also be used to support nitrification. The attached growth processes can include trickling filters, rotating biological contactors, and fixed-film nitrification reactors (Metcalf and Eddy, 1991).

In an attached growth reactor, organic material present in the wastewater is degraded by a population of microorganisms (aerobic, anaerobic, and facultative) growing attached to the filter media (Metcalf and Eddy, 1991). The microorganisms form a biological film or slime layer on the filter media. Organic material from the liquid is adsorbed onto the biological film or slime layer. Within the outer portions of the biological slime layer, aerobic microorganisms degrade the organic material. As the microorganisms grow, the thickness of the slime layer increases, and the diffused oxygen

is consumed before it can penetrate the full depth of the slime layer. Therefore, an anaerobic environment is established near the surface of the media. As the slime layer increases in thickness, the adsorbed organic material is metabolized before it can reach the microorganisms near the media face. The microorganisms near the media face have no external organic source available and therefore enter into an endogenous respiration. This causes the microorganisms to lose their ability to cling to the media and the liquid washes the slime layer off the media. This phenomenon is called "sloughing" and a new slime layer will begin to form (Metcalf and Eddy, 1991).

Chui et al. (1996) studied the removal efficiency of nitrogen (N) and organic matter in an anoxic/aerobic upflow fixed bed filter. The effects of aeration, hydraulic loading rate, and COD/N ratio on nitrogen removal and carbon oxidation were studied. A synthetic wastewater was used in the study with COD and N concentrations of 1250 and 250 mg/L, respectively. The filter was constructed out of a 2 m acrylic column with inside diameter of 140mm. The column was packed with 15 and 25 mm diameter Siporax porous glass rings. For volumetric loadings of up to 1 kg N/m^3•day, between 41% and 86% of the nitrogen was removed. COD removal efficiency was consistently above 95% even at a high loading rate of 5 kg COD/m^3•day and a bulk liquid dissolved oxygen level as low as 1.1 mg/L.

Westerman et al. (1998) evaluated an aerobic fixed-media attached growth bioreactor for the treatment of flushed swine manure. A pilot plant treating up to 8 m^3/day of flushed swine manure was monitored for 12 months. The system consisted of two upflow aerated attached growth reactors connected in series and two polishing tanks.

The reactors had a total volume of 1.76 m^3 and were packed with plastic media. The average loading was 6.6 kg COD/day per m^3 of media. Reductions were 72% for COD, 57% for VS, 76% for suspended solids (SS), 72% for total Kjeldhal nitrogen (TKN), 82% for NH$_3$-N, 49% for Total N, and 26% for Total P. Reductions were affected by temperature, with higher reductions observed during the warmer months. An odor panel evaluated liquid samples on four different occasions. Significant reductions in odor intensity from about 5.5 to 2, and odor irritation from about 4.5 to less than 2 were reported.

Szogi et al. (1997) constructed a media filter to treat swine wastewater. The filter consisted of a tank filled with marl gravel. The flow rate was 606 L/m^{2}day and TKN load was 198 g/m^{2}d. The filter removed 54% of COD, 50% of total suspended solids (TSS), and removal efficiencies for Total P ranged from 37 to 52%.

Amal Raj and Murthy (1999) investigated the use of a cross-flow trickling filter for treatment of a synthetic dairy wastewater. The reactor consisted of a column of cross section 15 cm x 15 cm and a height of 180 cm. It was packed with six modules of cross flow PVC medium placed using a zigzag layout. Hydraulic loadings of 5, 9, 13, and 17 m^3/m^2•d at influent COD concentrations of 427 to 1384 mg/L were evaluated in this study. COD removal efficiency decreased with increased hydraulic loadings and decreased influent COD concentrations. However, the COD removal rate increased with increases in influent COD concentration and hydraulic loading. The highest COD removal efficiency (91.4%) occurred at the 5 m^3/m^2•d loading rate with influent COD

concentration of 686 mg/L. COD removal efficiency decreased to 76.1% at the higher loading rate of 17 m^3/m^2•d.

Jones (2000) evaluated an attached growth reactor using organic media for treatment of swine wastewater. A ten-cell laboratory-scale bioreactor apparatus operating in a batch mode was used to determine water quality improvement and odor abatement of swine wastewater. Oxygen demand (both BOD$_5$ and COD) was reduced more than 90% from the influent value. Total solids and volatile solids were reduced by 50% and 70%, respectively. A human olfactory panel evaluated the bioreactor system for odor reduction. The panel indicated that the highly intense, acrid swine odor was transformed to a primarily "earthy" odor after treatment.

In the anaerobic filter, an attached-growth treatment process, anaerobic bacteria grow and are retained on the attachment media. As waste flows upward through the column, it is metabolized by attached bacteria (Metcalf and Eddy, 1991). Kaiser et al. (1995) conducted studies on the temperature-phased anaerobic biofilter (TPAB) process. The system includes a thermophilic biofilter connected in series to a mesophilic biofilter. Soluble and total COD reductions in excess of 97% and 90% were achieved for a synthetic milk substrate (2 to 16 g COD/L•d). The TPAB systems were observed to outperform single-stage anaerobic filters. Also, preliminary data from Hawkins and Raman (1999) suggest that downflow anaerobic filter system can also successfully remove organic matter from dairy and swine wastewater at low organic loading rates.

Sanchez et al. (1995) studied a downflow anaerobic fixed bed reactor (AFBR) packed with ceramic rings. Results indicate that the organic matter removal and organic

nitrogen decomposition were around 60% and PO_4^{-3} removal was about 40% with the AFBR. The organic volumetric loading rate was 5 kg $TCOD/m^3 \cdot day$ (TCOD – total chemical oxygen demand).

Other Treatment Processes

Surface aeration is a means proposed to reduce the odor emission from anaerobic lagoons. Surface aeration takes advantage of both anaerobic and aerobic degradation processes. The aerobic layer acts like a biological blanket over the odor producing anaerobic environment below. Within such a blanket, aerobic bacteria convert odorous gases and organic compounds into low odor gases before emission into the atmosphere. Laboratory testing by Zhang et al. (1996) concluded that continuous low-rate aeration to maintain the dissolved oxygen in the surface liquid layer (about 30 cm deep) at 0.5 mg DO/L was effective in controlling odor emissions from swine manure stored in laboratory lagoons. However, it was stated that "low rate aeration may cause high ammonia emission rates and is therefore not recommended for use in an underfloor pit due to concerns of reducing indoor air quality".

He et al. (2000) applied a thermochemical conversion (TCC) process to treat swine manure slurry for oil production and waste reduction. The process would serve dual purposes: reducing waste strength and producing renewable energy. Odor emission could also be reduced because of a shortened manure on-farm retention time. A TCC process is a chemical reforming process in which the depolymerization and reforming reactions of lignin-cellulosic compounds occur in a heated and oxygen-absent enclosure. The TCC process was successfully applied to the treatment of swine manure slurry to

produce liquid oil and reduce the waste strength. The oil yield was as high as 76.2% of the total volatile solids of the feedstock and the hydrogen to carbon molar ratio was 1.53. The COD in the post-processes water after the TCC process had been reduced as much as 75.4 %.

Sievers (1997) investigated the performance of constructed wetlands treating anaerobic swine lagoon effluents. Effluents from an anaerobic lagoon system treating flushed swine waste were loaded into two types of constructed wetlands: submerged flow and free water surface. Passing anaerobic lagoon effluents through the constructed wetlands resulted in the following average reductions in water quality parameters: biochemical oxygen demand (BOD_5), 18% to 50%; NH_3-N 17% to 41%; TSS, 34% to 48%; total P, 15% to 30%. The low reductions were primarily due to the lack of oxygen in the wetlands, which resulted in a continuous anaerobic environment. The oxidation potential was consistently in the facultative to anaerobic range. Dissolved oxygen was measured in the wetlands only during algae blooms and was not detected at other times. Effluents from the lagoons were too concentrated to achieve the wetland effluent criteria suggested by the National Resource Conservation Service.

Wood et al. (2000) quantified odor removal from swine wastewater in constructed subsurface-flow wetlands. The reductions of malodorous, dimethyl disulfide and p-cresol in wastewater were examined by GC analysis; and a human sensory panel was used to provide odor intensity and offensiveness ratings on a 0-5 scale. Gas chromatograph analysis indicated that planted wetlands removed 80% and 83% of dimethyl disulfide and p-cresol, respectively. Both untreated swine facility wastewater and organic filter

effluent had median odor intensity and offensiveness ratings of 4 (identifiable odor-offensive, but tolerable). Median odor intensity and offensiveness rating for wetland effluent were 1 (faint odor-non-identifiable, not offensive). These odor ratings were significantly lower than the odor ratings for the untreated wastewater and organic filter effluent.

Watkins et al. (1997) investigated the use of ozone for the remediation of odorous compounds in liquid swine manure. Gaseous ozone was bubbled directly in to stored swine manure slurry in a continuously stirred batch reactor. Olfactometric determinations demonstrated a significant reduction in odors in ozonated samples as compared to raw and oxygenated samples. Volatile fatty acids, nitrate, phosphate and ammonia concentrations were unchanged by ozonation. However, the concentrations of odorous phenolic and indolic microbial metabolites were reduced to non-detectable levels by ozonation.

Gao et al. (1993) investigated the optimum dosage and the effectiveness of five different chemical treatments on low, medium, and high strength wastewaters. The chemicals tested in this study were ferric chloride, calcium hydroxide, aluminum sulfate, chitosan, and PERCOL 728, a copolymer of quaternary acrylate salt and acrylamide. For all wastewater strengths, a low dosage (25-50 ppm) of PERCOL 728 was the most effective. Removal efficiency of the PERCOL 728 was increased by 20 % when compared with the control. It was also effective in reducing the COD and BOD_5 of the wastewaters. However, the COD and BOD_5 of the wastewater were still quite high after treatment and further physical or biological treatment was necessary. PERCOL 728 was

less effective than the ferric chloride, calcium hydroxide, and aluminum sulfate with regard to phosphate removal. Chitosan was found to be ineffective in suspended solids, total solids, COD, BOD_5 and phosphate removal.

Al-Kanani et al. (1992) investigated the use of sphagnum peat moss (SM), monocalcium phosphate monohydrate (MCPM), elemental sulfur (S), calcium carbonate $(CaCO_3)$, and calcium oxide (CaO) in reducing odors from liquid hog manure. Amended and non-amended manure was incubated with and without aeration for periods ranging from 2 to 720 hr at 23 ºC. Aeration as a treatment, in general, resulted in a greater reduction of odor presence and offensiveness than non-aeration. In non-aerated treatments, SM at levels of 4% or 8% (w/w) or a combined treatment of 2% $CaCO_3$ plus 1% SM resulted in a significant reduction in odor and offensiveness. Little reduction was observed with H_2SO_4, H_3PO_4, MCPM, and CaO, and no odor reduction was found with elemental S.

Zhu et al. (1997) examined the effects of five commercial pit additive products (MPC, Bio-Safe, Shac, X-Stink, and CPPD) on the release of odorous and volatile compounds from swine manure. Results obtained from the study show that the emission of odor and volatile substances in swine liquid manure can be abated by using pit additives. All treatments reduced odor levels significantly by about 58% to 87%. MPC, Bio-Safe, and Shac showed significant reductions in volatile fatty acids (14%, 10%, and 23%, respectively). However, correlation analysis showed that the odor threshold did not correlated with volatile fatty acid concentration existing in the swine manure.

Chin et al. (1996) used a commercially available bacterial product to enhance the treatment of wastewaters containing high concentrations of organic wastes. The bioenhancer contained *Bacillus*, *Pseudomonas*, *Nitrosomonas*, *Nitrobacter*, *Cellulomonas*, *Aerobacter,* and *Rhodopseudomonas*. The dosage was around 2 mL/L of sewage treated. The bioenhancer was fed into the influent to the sewage treatment plant that consisted of an Imhoff tank followed by a conventional trickling filter packed with coral stones. The addition of the bioenhancers improved the treatment efficiency of BOD, COD, detergent, oil, and grease. The rate of sludge production and accumulation was reduced; and odor problems were minimized with the addition of the bioenhancers.

CHAPTER III

MATERIALS AND METHODS

The evaluation of the attached growth bioreactor was conducted at the MAFES Swine Physiology Barn located on the South Farm of Mississippi State University. Testing began in September 1999 and continued through November 2000. The primary research thrust involved the odor potential generated from a control pit versus a bioreactor enhanced pit system.

The control used in this study simulated conditions and procedures of a typical pit recharge system, as previously discussed in Chapter II. The pit-recharge system was selected as the control because it is the most popular waste treatment method for swine facilities in Mississippi and throughout the southeastern U.S.

Bioreactor System Description

The attached growth biological system was used for both odor abatement and limited wastewater treatment of organic waste streams. The bioreactor system is composed of three fundamental components:

1. A bioreactor designed to function as a modified attached growth biological reactor using plant fiber as the attached growth medium

2. A wastewater collection pit used to collect and store the wastewater

3.   A pump used to circulate the wastewater through the attached growth
        bioreactor

Wastewater (feces, urine, and process wastewater) was collected in the wastewater

collection pit. The wastewater was pumped from the collection pit to the top of the

bioreactor. After the wastewater trickled through the bioreactor, it was returned to the

collection pit.

Once the medium within the bioreactor became plugged (spent) with accumulated

solids or biological slimes, it was replaced with new medium. The spent medium was

removed from the bioreactor and allowed to dry. Once dry, the medium was either

composted or reused in the bioreactor. Composting provides a low-cost, low odor means

of stabilizing the spent medium (Metcalf and Eddy, 1991). Stabilized compost can be

used as a plant fertilizer or soil amendment. Because compost has a relatively low

moisture content and contains organically bound plant nutrients, it may be economically

feasible to transport the material offsite. This will become increasingly important as

restriction with regard to land application of animal manures continues to tighten.

Kenaf (*Hibiscus cannabis L.*) was the packing media used in the majority of testing.

It was chosen due to its physical characteristics and potential as an odor ad/absorbent.

The kenaf plant can grow up to 3.6 m (12 ft) and yields 13-22 metric tons per hectare (6-

10 tons per acre) in one growing season. Kenaf is composed of a stringy outer layer (bast

fibers) and a foam-like porous inner core. The bast fibers make up approximately 35% of

the kenaf plant and consist mainly of the outer fibrous bark, while the core fibers make

up the other 65% of the plant and are considered the inner woody core (Sellars et al.,

1999). Frost-killed kenaf plants were harvested in the spring using a standard forage

harvester adjusted to produce fiber and core material approximately 50.8 mm (2 inches)

in length. This length achieves relatively good primary filtration and biological treatment

characteristics, while minimizing plugging. After a killing frost, the kenaf is left standing

in the field for three to four months where it undergoes a process called dew-retting.

Dew-retting is the process by which the outer surface of the kenaf plant (non-fiber

components of the bark) is degraded by indigenous microflora on the surface of the plant.

A study by Zappi et al. (2000) determined that kenaf is resilient in an aqueous

environment for periods up to six months without enhanced bioactivity. Figure 3.1

presents a picture of the kenaf used within the bioreactor.

Figure 3.1. Kenaf Medium

Facility Description

Swine Physiology Barn

The evaluation of the attached growth bioreactor system was conducted at the

Swine Physiology Barn, a small swine research facility located on the Mississippi State

campus. Figure 3.2 presents a picture of the 88 m^2 (945 ft^2) barn. A concrete walkway

runs down the center of the barn separating two long, narrow pen areas (16 m x 1.9 m).

Figure 3.3 presents a picture of the inside of the barn. The pen areas have grated floors,

allowing waste (manure, urine, wasted feed, etc.) to enter underfloor flush alleys (pits).

Separate flush alleys, located directly beneath each pen area, have a 2% slope (0.3 m

deep at the shallow end, 0.7 m at the deep end) and empty into a concrete collection sump

located at the end of the alleys. The dimensions of the collection sump are 5 m x 0.7 m x

0.9 m (length x width x height). A drainpipe gravity-drains the collected water from the

collection sump to a small lagoon. A picture of the drainpipe and the lagoon is in Figure

3.4.

Figure 3.2. Swine Physiology Barn

Figure 3.3. Inside view of barn

Figure 3.4. Flushing of wastewater to the lagoon

The barn was originally designed to use a flush system for waste removal. Fresh

water from two 757 L (200 gallon) flush tanks (one per flush alley) was used to remove

manure and other materials from the flush alleys several times daily. Water from the flush tanks enters the flush alleys at the upper end of the barn, flows downslope to the collection sump and thus washes manure and other solids into the collection sump.

The flush alleys were modified to achieve a pit-recharge type system (as discussed in Chapter II) for both the bioreactor and control systems. The drainpipe in the collection sump was fitted with a plug to prevent drainage of the wastewater to the lagoon during testing. The plug could be easily removed and replaced to allow for the frequent filling and draining of the pits during this study (performed on 7 day cycles). Since both collection pits drained into the collection sump, a concrete wall was constructed that divided the collection sump into two separate independent collection sumps.

Bioreactor System Components

The pilot scale attached growth bioreactor system consisted of a 0.85 m^3 (30ft^3) bioreactor made from expanded metal with dimensions of 66 x 107 x 122 cm (depth, width, height, respectively). The bioreactor was placed over the shallow end of the collection pits at the upper end of the barn.   A 560-watt (¾ hp) Jacuzzi™ pump and 5.1 cm (2 in) PVC pipes were used to circulate the wastewater through the system. The intake of the pump was located near the bottom of the collection sump at the downslope-end of the pit. The wastewater was pumped from the collection sump to the bioreactor located at the upslope end of the pit. The bioreactor was fitted with a wastewater distributor to evenly apply the wastewater over the media. The wastewater distributor was constructed out of 1.9 cm (¾ in) PVC pipe. Numerous 0.5 cm (0.2 in) diameter holes were drilled in the bottom side of the PVC pipe to evenly distribute the wastewater

over the media within the bioreactor. Ball valves (5.1 cm {2 in}) and a re-circulation line

were installed to control flow to the distribution system. Wastewater was circulated

through the bioreactor at a rate of 22.35 L/min·m^3 (0.167 gpm/ft^3) for all experiments in

this study. Figures 3.5 and 3.6 present diagrams of the side view and top view of the

attached growth bioreactor system within the barn. A picture of the bioreactor and the

distribution system is shown in Figure 3.7.
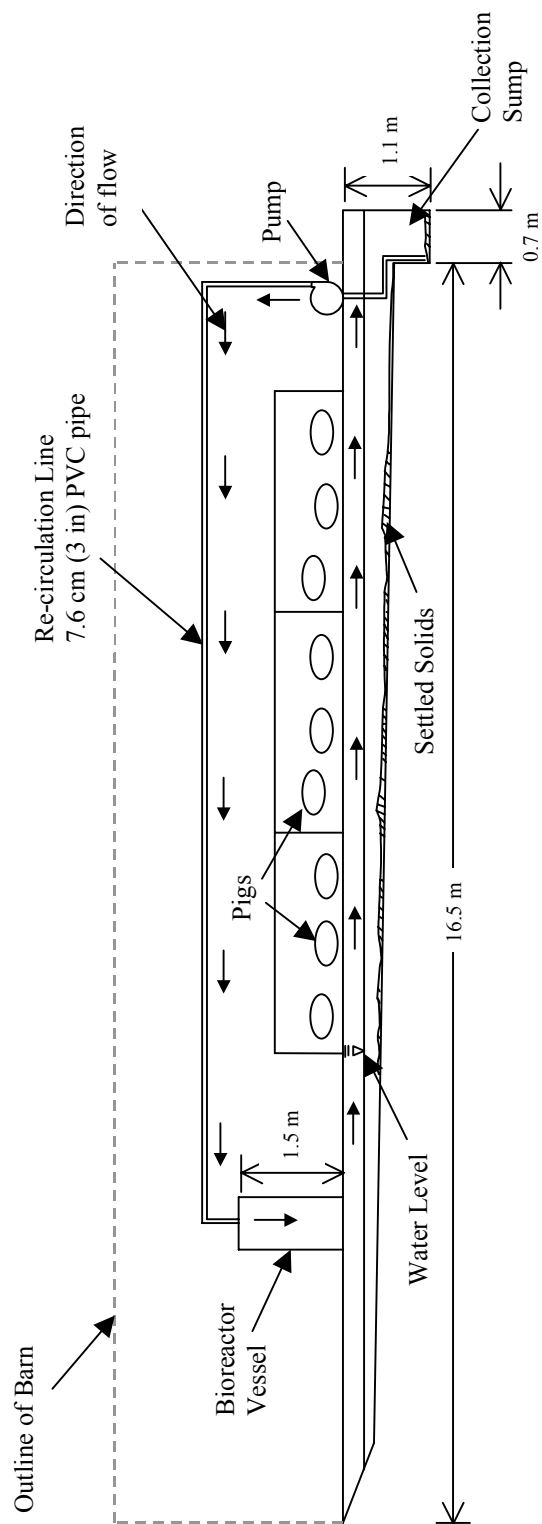
Figure 3.5. Schematic of barn (side view)
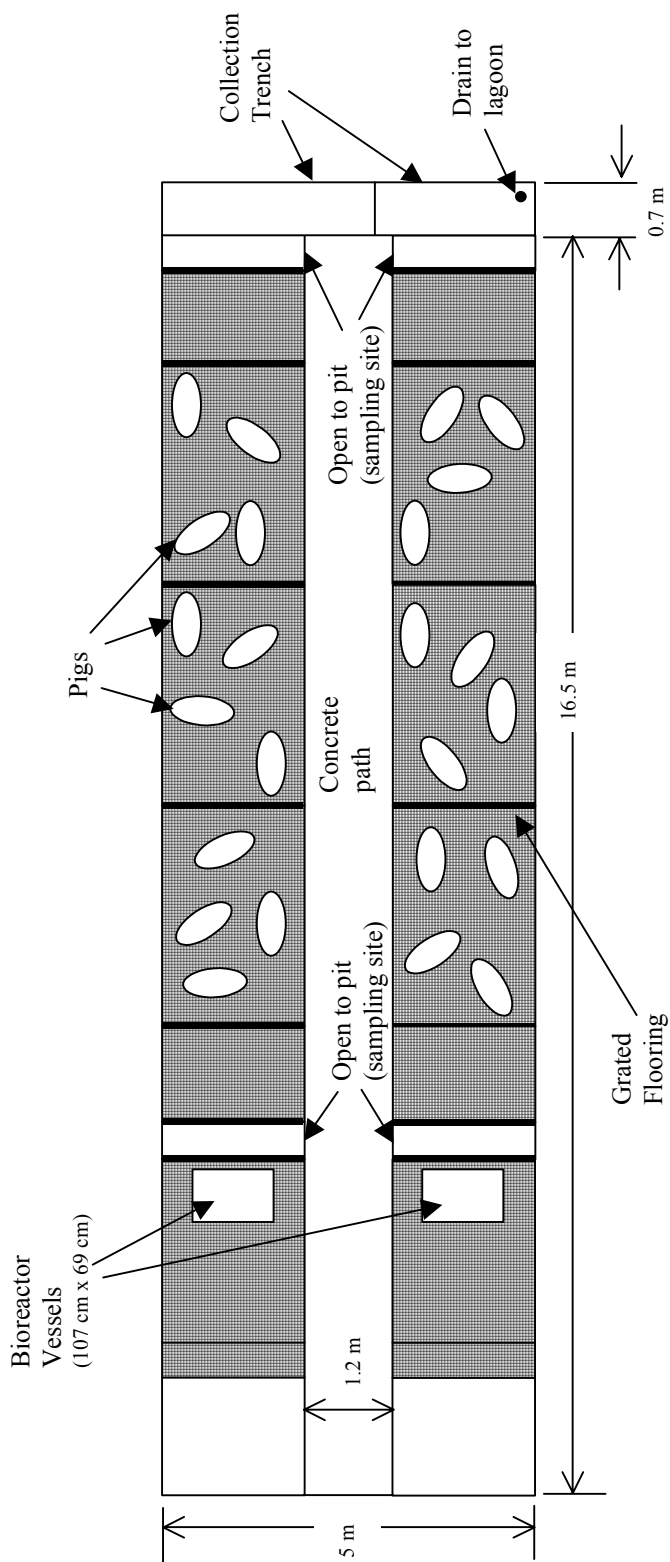
Figure 3.6. Schematic of barn (top view)

Figure 3.7. Bioreactor and distribution system

Aeration System

Anaerobic degradation of manure results in the generation of odorous volatile compounds. However, these odorous compounds can be degraded quite rapidly, or even prevented, under aerobic conditions (Evans et al., 1986). Therefore, an aeration system was installed in the collection pits to determine if the performance of the bioreactor system could be improved by aerating the pit volumes.

The aeration system installed in the collection pits included twenty-eight 18cm (7 in) diameter ceramic diffusers (14 per collection pit) submerged under water in the collection pit and in the collection sump. Figure 3.8 presents a picture of the ceramic diffusers used in this study. A 746-watt (1 hp) regenerative blower, and a 5.1 cm (2 in) ID PVC piping network that included a rotameter and valving, supplied atmospheric air to the diffusers at a rate of 1.4 m^3/min (50 cfm). Figure 3.9, an overhead view of the pits, shows the diffuser placement within the collection pits and sumps.

Figure 3.8. Ceramic diffuser used in the aeration system

An aeration system was also installed within the bioreactor itself. Perhaps adequate treatment could be achieved by aeration of the bioreactor alone, reducing the cost and maintenance that would be associated with pit aeration. Aeration in the bioreactor consisted of the installation of a Flexline fine bubble membrane tube diffuser and a 746-watt (1 hp) regenerative blower. A 61 cm (24 in) tubular fine bubble diffuser was installed in the center of the bioreactor (Figure 3.10). A regenerative blower was used to introduce air at a rate of 0.4 m3/min (15 cfm) to the center of the bioreactor. A 5.1 cm (2 in) ball valve and rotameter controlled the flow rate of air into the bioreactor. The membrane tube diffuser could be easily removed and replaced in the bioreactor as needed.
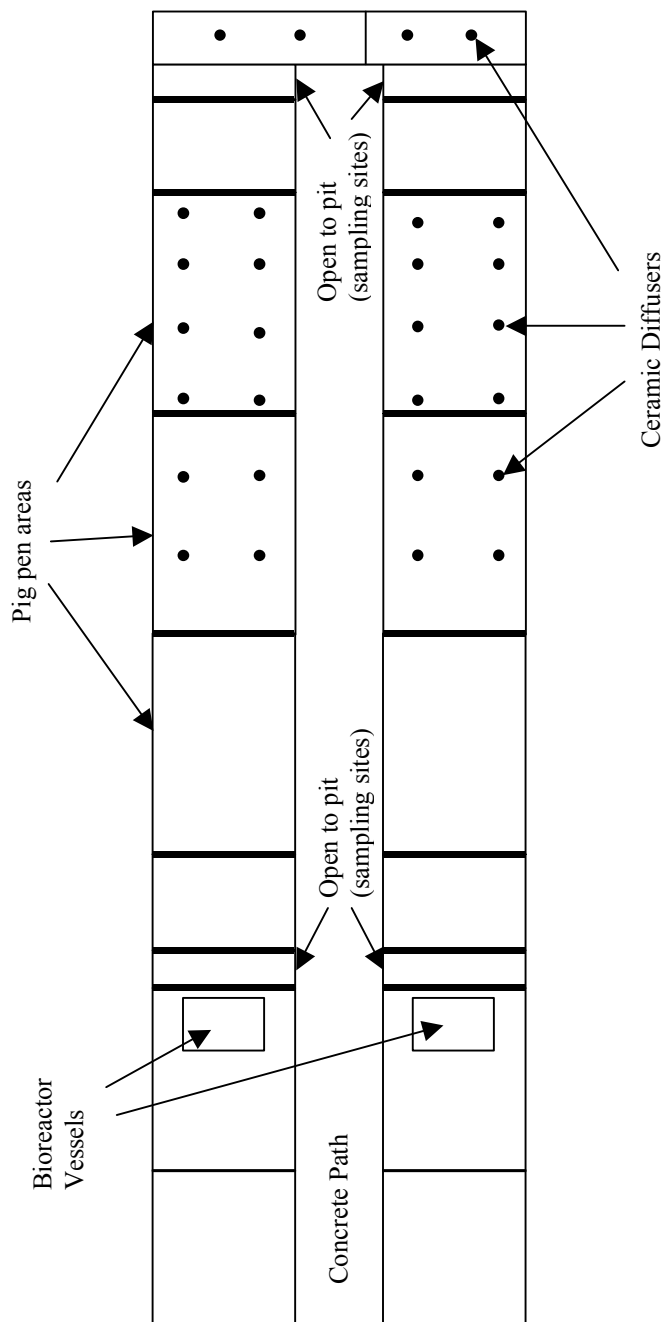
Figure 3.9. Schematic of diffuser placement

Figure 3.10. Membrane diffuser installed in the bioreactor

Treatment Systems Description

Seven different treatment system configurations were evaluated throughout the course of this study. Table 3.1 lists and gives a short description of all the systems. A detailed description of each system is presented later in this section. For all of the systems, the wastewater collection pits were filled with 3,785 L (1,000 gallons) of fresh water at the beginning of each testing period. The testing period lasted 7 days for all tests. At the end of the testing period, the plug in the collection sump was pulled and the wastewater drained to the lagoon. After the removal of any residual solids in the pits or collection sump, the drain plug was replaced and the facility was ready for the next 7-day experiment.

Table 3.1. System List and Description

System	Description
Control	Wastewater remains undisturbed in the pits (mimics current practices)
BIO	Wastewater circulates through the bioreactor at rate of 22.35 L/min•m^3 Kenaf is used as the organic packing media
BIO/AMS	Wastewater circulates through the bioreactor at rate of 22.35 L/min•m^3; Kenaf is used as the organic packing media; Aeration of collection pit; Addition of microbial seed
ABIO	Wastewater circulates through the bioreactor at rate of 22.35 L/min•m^3; Kenaf is used as the organic packing media; bioreactor is aerated by membrane tube diffuser (collection pit not aerated)
ABIO/AMS	Wastewater circulates through the bioreactor at rate of 22.35 L/min•m^3; Kenaf is used as the organic packing media; Aerated bioreactor; Aeration of collection pit; Addition of microbial seed
Hardwood Mulch	Wastewater circulates through the bioreactor at rate of 22.35 L/min•m^3 Hardwood mulch is used as the organic packing media (no aeration)
Corncobs	Wastewater circulates through the bioreactor at rate of 22.35 L/min•m^3 Corncobs are used as the organic packing media (no aeration)

Control System

For the control system, the wastewater in the collection pits remains undisturbed in terms of mixing, aeration, and pumping as in the bioreactor system. As the manure, urine, and wasted feed falls through the openings in the grated floors it is collected in the pits until it is drained to the lagoon at the end of the seven day testing period. This is the typical treatment system used in swine facilities throughout the southeastern U.S.

BIO System

In the BIO system, the wastewater was circulated through the bioreactor at a rate of 22.35 L/min•m^3 for the entire testing period of seven days. Neither the collection pits nor the bioreactor was aerated during the BIO system.

BIO/AMS System

The BIO/AMS system also circulated the wastewater through the bioreactor at a rate of 22.35 L/min•m^3, but the collection pits were aerated and a microbial seed (activated sludge) was added. The microbial seed used in this research was return

activated sludge from the Ernest P. Jones Wastewater Treatment Plant in Starkville, MS.

Thirty-eight liters (10 gallons) of activated sludge was added to the shallow end of the

wastewater collection pit at the beginning of the test period. Atmospheric air was

introduced into the pit wastewaters to reduce or possibly eliminate the anaerobic

reactions that form the malodorous compounds. It was thought that the bacterial

consortium within the activated sludge would be better prepared to rapidly degrade the

waste deposited into the underdrains than the bacterial consortia typically present.

ABIO System

With the ABIO system, the inner portion of the bioreactor was aerated using a

membrane tube diffuser. Atmospheric air at a rate of 0.4 m^3/min (15 cfm) was

introduced into the center of the bioreactor. Like the other tests, the wastewater was

continuously circulated through the bioreactor at a rate of 22.35 L/min·m^3. The

collection pits were not aerated for this system.

ABIO/AMS System

The ABIO/AMS system was a combination of the BIO/AMS and the ABIO

systems. The bioreactor was aerated at a rate of 0.4 m^3/min (15 cfm) and the collection

pits were seeded and aerated at a rate of 1.4 m^3/min (45 cfm).

Hardwood Mulch and Corncob Systems

Kenaf was used as the organic plant media in the above systems (BIO, ABIO,

BIO/AMS, ABIO/AMS). The hardwood mulch and corncob systems were tested to

compare the overall performance of other organic media to the kenaf media. Figures 3.11

and 3.12 present pictures of the corncobs and hardwood mulch used for these systems, respectively.

The BIO system methodology used with the previous tests was also used for the evaluation of the different media. At no time during the media evaluation tests were the collection pits or bioreactor aerated.

Figure 3.11. Corncob Media

Figure 3.12. Hardwood Mulch Media

Swine Care

Only 11 m^2 (120 ft^2) of the surface area of each pen was used for housing the pigs. Therefore, based on a stocking rate of 0.9 m^2 (10 ft^2) per pig, 12 pigs were placed in each pen for a total of 24 pigs in the barn. Mixed sex York Berkshire cross pigs from the Swine Unit at Mississippi State University were used in this study. Four different sets of pigs were used in this study. For three of the four sets, the pigs weighed an average of 64 kg (140 lbs) when they arrived at the barn. They were kept at the Physiology Barn until they reached the market weight of 100 – 110 kg (220 – 240 lbs). This weight range of 64 to 100 kg (140 – 220 lb) is typical of a farrowing to finishing house. However, one set of pigs were brought in at only 11 kg (25 lbs) and stayed until they reached market weight. The smaller set of pigs was brought in to evaluate the performance of both the bioreactor and control systems at a lower waste loading.

Personnel from the Animal and Dairy Science Department at MSU fed the pigs twice a day and washed their pen area daily. Corn was the major grain source used in the feed (Luce et al., 1992). Table A.1 in Appendix A lists the ingredients and calculated analysis of the feed used in this study.

The pigs were weighed periodically throughout the study. This allowed for estimations of the organic waste load (measured as COD) that entered the collection pits to be made. The Agricultural Waste Management Field Handbook states that 2.75 kg (6.06 lb) COD is produced per day per 454 kg (1,000 lb) of pig weight. Tables B.1 – B.4 in Appendix B list the dates and the average pig weight at each weighing.

Sampling Procedures

Wastewater samples were taken at days 1, 2, 5, and 7 of the testing period for all systems. Duplicate grab samples were taken from both the shallow and deep ends of the collection pits. Sampling sites are depicted in Figures 3.6 and 3.9. Samples were collected in labeled 500 mL Nalgene bottles. One set of the samples was brought to the ABE Water Quality Laboratory and the other to the MSU E-Tech Laboratory for analysis (different analytes were run in each lab – details provided below).

Water Quality Analysis

The following tests were performed on the water samples: dissolved oxygen (DO), redox potential (ORP), pH, conductivity, ammonia (NH_3-N), chemical oxygen demand (COD), ortho-phosphate (PO_4^{-3}-P), total solids (TS), phenols, and volatile acids (VA). The DO and ORP measurements were taken directly from both the shallow and deep ends of the collection pits. Phenols and volatile acids analyses were conducted by the MSU E-Tech Laboratory. The ABE Water Quality Laboratory performed the pH,

conductivity, NH3-N, COD, and PO4-3 analyses. Table 3.2 describes the

instrumentation protocol for each analylate.

Table 3.2. Wastewater analysis instrumentation and protocol

Analylate	Instrument	Protocol
Dissolved Oxygen	Hach Sension6 – Dissolved Oxygen Meter w/ probe	Standard Methods, 17th Edition, Procedure 4500-O
Redox Potential	Hach SensIon2 – pH, ISE Meter, Sension Combination ORP Electrode Model #50230	Direct sensing platinum electrode combined with Ag/AgCl reference electrode
pH	Orion SenserLink pH/ISE/ORP	Standard Methods, 17th Edition, Procedure 4500H+
Conductivity	Orion Conductivity/TDS Meter – Model #124	Standard Methods, 17th Edition, Procedure 2510B
Ammonia	Hach DR/4000 Spectrophotometer	Hach Method #10031 Salicylate Method Test N Tube Vials
Ortho-Phosphate	Hach DR/4000 Spectrophotometer	Hach Method # 8048 Ascorbic Acid Method PhosVer 3 Powder Pillows
COD	Hach COD Reactor (Model 45600) and Hach DR/4000 Spectrophotometer	Hach Method #8000 Reactor Digestion Method High Range (0-1500 ppm) Vials
Total Solids	Precision Scientific Model 144 Drying Oven (105 C)	Standard Methods, 17th Edition, Procedure 2540 B
Phenols	Hach DR/4000 Spectrophotometer	Hach Method #8047 4-Aminoantipyrine Method
Volatile Acids	Hach DR/4000 Spectrophotometer	Hach Method # 8196 Esterification Method

Odor Evaluation

Sample Preparation

All odor evaluations were done within 6 hours of retrieving the samples from the barn. Ten mL of wastewater from the pits was placed in individual 250 mL Nalgene Teflon FEP One-Piece Wash Bottles. These bottles are highly resistant to absorption/adsorption of liquids or gases (odorants). The internal drawtube was removed from each bottle to keep the liquid portion of the sample from escaping into the cap (neck). The bottles were then wrapped in aluminum foil and randomly numbered (double blind study). A small piece of glass wool was inserted into the neck of the stem each time the Teflon bottles were used. In order to reduce the effect of olfactory dulling, only 8-10 samples were analyzed during each meeting for both training and testing periods. After each testing period, all bottles were washed with soap and water, thoroughly rinsed, and placed in a 100° C oven overnight to ensure that the bottles were odor free for the next testing period.

Olfactory Panel

A human olfactory panel consisting of 10-15 volunteers was established for the study. Panel members were selected from various departments at MSU. The panel was approved by the Institutional Review Board (IRB # 00-075) at Mississippi State University. The panel was trained for approximately 2 months, meeting 3 times weekly. During these weekly meetings, various swine waste samples were introduced to the panel, from which 9 descriptive terms were chosen to describe the odor. The terms chosen were as follows: overall intensity, acridity, sulfurous, earthy, musty, fecal, cheesy, sweet/grainy, and ammonia. Each term was rated on 0-8 point scale, with 0

being no detectable odor and 8 being a strong odor. A fecal standard was prepared from a mixture of p-cresol (210 mg/L) and skatole (12.8 mg/L) in deionized water. The fecal standard was assigned a rating of 4 for both overall odor intensity and fecal characteristic. All odor samples were rated against this standard. The samples were also given a pleasantness rating between 0 and 8. A rating of 0 was a very pleasant odor, 4 was neither pleasant nor unpleasant, and a rating of 8 was considered to be a very unpleasant odor.

To evaluate a sample, the panelist swirled the bottles to fill the bottle head-space with odorants and gently squeezed the bottle in a series of small pulses to force the odorant laden air out of the bottle to an area beneath the nose and above the lip (being careful not to allow the bottle to touch any portion of the panelist's face). The panelist then recorded their response to the odorant on the score sheet. A sample score sheet is presented as Appendix C.

<div align="center">Gas Analyses</div>

The air directly above of the pit was monitored using an Omni 4000 portable multi-gas detector. The Omni 4000 was fitted with four gas sensors that were used to test oxygen (O_2), ammonia (NH_3), hydrogen sulfide (H_2S), and the lower explosion level (LEL/CH_4). A small peristaltic pump on the Omni 4000 draws air into the gas-sensing chamber. The gas sensors register the air phase concentrations of the four gases and displays the O_2 concentration in percent, the NH_3, H_2S, and CH_4 concentrations in the parts per million (ppm). The Omni 4000 was calibrated at the factory at the time of purchase and in May 2000 when the meter was sent in for repairs and sensor replacement.

Measurements were taken by placing the intake tube of the meter above a 0.5 cm (0.2 in) diameter hole cut in the bottom of plastic trash cans that were placed upside down in both the shallow and deep ends of the pits in order to trap gases released from the pits. To allow for wastewater flow, side panels were cut out of the trash cans.

<u>Temperature Measurement</u>

Temperature is an important parameter because of its effect on biochemical reactions and reaction rates. Therefore, temperature readings of the air inside the barn were recorded on a daily basis throughout the study. These measurements were taken from a HOBO Pro Series Relative Humidity (RH) and Temperature logging device. The device was programmed to take a temperature reading every 30 minutes. The resulting temperature data was imported into an Excel spreadsheet, and an average temperature value was calculated for each day of the study. The average daily temperature data are located in Table D.1 in Appendix D.

CHAPTER IV

COMPARISON OF CONTROL AND BIOREACTOR (BIO) SYSTEMS

This chapter presents a comparison between the BIO and control systems. A

description of these systems is listed in Table 4.1. Comparisons were based upon results

of pit water quality, pit gas analysis, and olfactory evaluations. The BIO system

discussed in this chapter did not involve aeration of the collection pits or aeration of the

bioreactor vessel (these enhancements are discussed in Chapter V).

Table 4.1.   System List and Description

System	Description
Control	Wastewater remains undisturbed in the pits (mimics current practices)
BIO	Wastewater circulates through the bioreactor at rate of 22.35 L/min•m^3 Kenaf is used as the organic packing media

Data Manipulation

Other research was being conducted at the Swine Physiology Barn during the

same time as this study. Therefore, only one wastewater collection pit was available for

use during several of the testing periods. As a result, the BIO systems are seldom directly

compared to the control for the same testing period. Changes in waste load, temperature,

wind direction, and other factors from week to week (testing period to testing period)

made direct comparison between the control and BIO systems difficult. To account for

this, the organic waste load and average temperature for each testing period was

determined. A normalization technique based on COD load was developed to best facilitate comparisons between systems. This technique is presented below.

The Agricultural Waste Management Field Handbook states that 6.06 lb COD is produced per day per 454 kg (1000 lb) of pig weight. Assuming a linear growth rate, the weight of the pigs on any day could be approximated. The weight of the pigs was used to calculate the daily organic waste load (in terms of COD) entering the collection pits. The cumulative total waste load for the entire testing period (7 days) was computed for each individual testing period. It must be noted that wasted feed from the feed troughs entering the collection pits would also contribute to the COD load. However, this was not taken into consideration when calculating the COD load for each testing period.

The COD load for the testing periods varied from approximately 10 kg COD/7 days (d) to 50 kg COD/7d. For comparison purposes, the testing periods for each system were divided into three groups based on COD load. One group consisted of testing periods having a low COD load, ranging between 0 to 15 kg COD/7d. The next group, the mid load-range, consisted of testing periods with loads between 16 and 30 kg COD/7d. The last group, the high load-range, consisted of the testing periods that had over 30 kg COD/7d. The data generated from each testing period that fell into each respective group were averaged to provide a single value for each load-range. This provided an opportunity to directly compare the systems in the three load-ranges.

Tables E.1 and E.2 in Appendix E list the estimated COD load, temperature, and dates for each of the control and BIO system testing periods, respectively. The control system was evaluated a total of 17 times throughout this study. Two control testing periods were conducted at the low load-range, six at the mid load-range, and nine testing

periods at the high load-range. The BIO system was evaluated 14 times during this

study. Two testing periods of the BIO system were conducted at the low load-range,

three at the mid load-range, and nine at the high load-range. Tables 4.2, 4.3, and 4.4 list

the average weekly COD load and temperature for the control and BIO systems at the

low, mid, and high load-ranges, respectively.

Table 4.2.   Average COD load and temperature for the low load-range control and BIO systems

System	Number of Testing Periods	Average COD Load (kg COD/7-d)	Avg Air Temperature	
			(C°)	(F°)
Control	2	9	18	64
BIO	2	11	20	68

Table 4.3.   Average COD load and temperature for the mid load-range control and BIO systems

System	Number of Testing Periods	Average COD Load (kg COD/7-d)	Avg Air Temperature	
			(C°)	(F°)
Control	6	23	23	73
BIO	3	24	19	66

Table 4.4.   Average COD load and temperature for the high load-range control and BIO systems

System	Number of Testing Periods	Average COD Load (kg COD/7-d)	Avg Air Temperature	
			(C°)	(F°)
Control	9	42	27	81
BIO	9	40	21	70

Water Quality Results

Tables F.1- F.31 in Appendix F list all of the raw water quality data for each

testing period of the control and BIO systems. Averaged water quality data for the low,

mid, and high load-ranges of the control and BIO systems are listed in Tables G.1, G.2,

and G.3 of Appendix G. The averaged water quality data are also presented as Figures

4.1 – 4.12 and will be discussed in the following sections of the chapter.

Dissolved Oxygen

Figure 4.1 presents the dissolved oxygen (DO) concentrations measured within

the pits for the control and BIO systems at all three load-ranges. Problems with the DO

meter itself prevented measurements to be taken at days 1 and 2 for the low load-range

BIO system testing periods. Fresh water with a DO concentration of approximately 4

mg/L was used to fill the pits at the beginning of each testing period. Once the DO level

fell below 0.5 mg/L, it was considered to be devoid of oxygen. Although this is not

technically anaerobic, it is indicative of a system with oxygen tensions below those

acceptable for supporting continual aerobic activity.
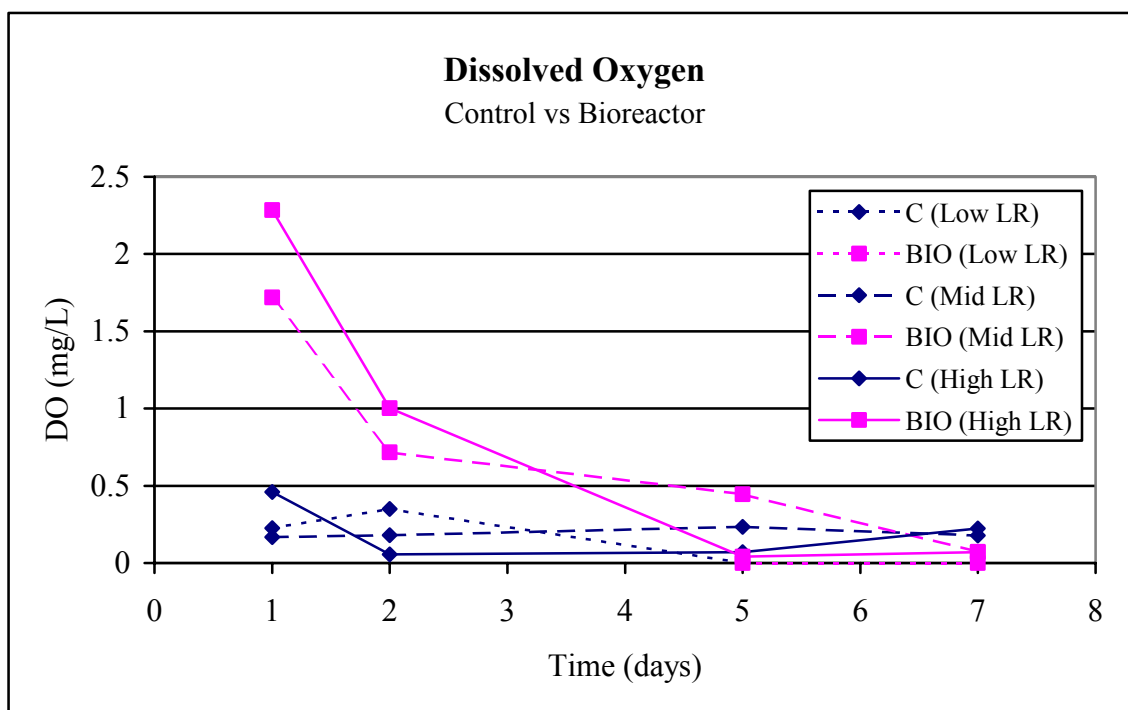
Figure 4.1. **DO concentration versus time for control and BIO systems**
(C = Control; LR = Load-Range)

The control at all three load-ranges did not have any appreciable DO in the wastewater at day 1 and was essentially anaerobic throughout the rest of the 7-day testing period. The BIO systems, however, maintained aerobic conditions within the pit for longer periods (2 days) during the mid and high load-ranges. Although by day 5, the DO of the wastewater was below 0.5 mg/L for all of the BIO systems at all load-ranges and appeared to be anaerobic throughout the remainder of testing.

The higher DO levels of the BIO system at days 1 and 2 can be attributed to the circulation of the wastewater through the BIO system. Also, the wastewater was aerated slightly as it trickled through the media within the bioreactor vessel. However, by day 5 the oxygen demand exceeded input and the pits became anaerobic.

Although, the wastewater of the BIO system was anaerobic by day 5, it is believed that both aerobic and anaerobic activity was occurring within the bioreactor. Since the bioreactor was open to the atmosphere, it is assumed that the outer layer of the media within the bioreactor was supportive of aerobic microbial activity, while the inner layers of media in the bioreactor were operating under anaerobic conditions.

ORP

The ORPs of the BIO systems and control for the low, mid, and high load-ranges are presented as Figure 4.2. In general, the BIO systems had a higher ORP than the control. The low load-range control and BIO systems had similar ORPs that tended to remain above –200 mV throughout the test period. This level was maintained because the lower load was not enough to drive the pits deeply anaerobic. However, the mid and high load-ranges of the control fell to around –300 mV by day 2. The mid load-range BIO systems also ranged between –200 mV to –300 mV for the testing period. The high

load-range BIO system had an ORP that ranged from +100 mV at the beginning of the testing period to around –200 mV by day 7.
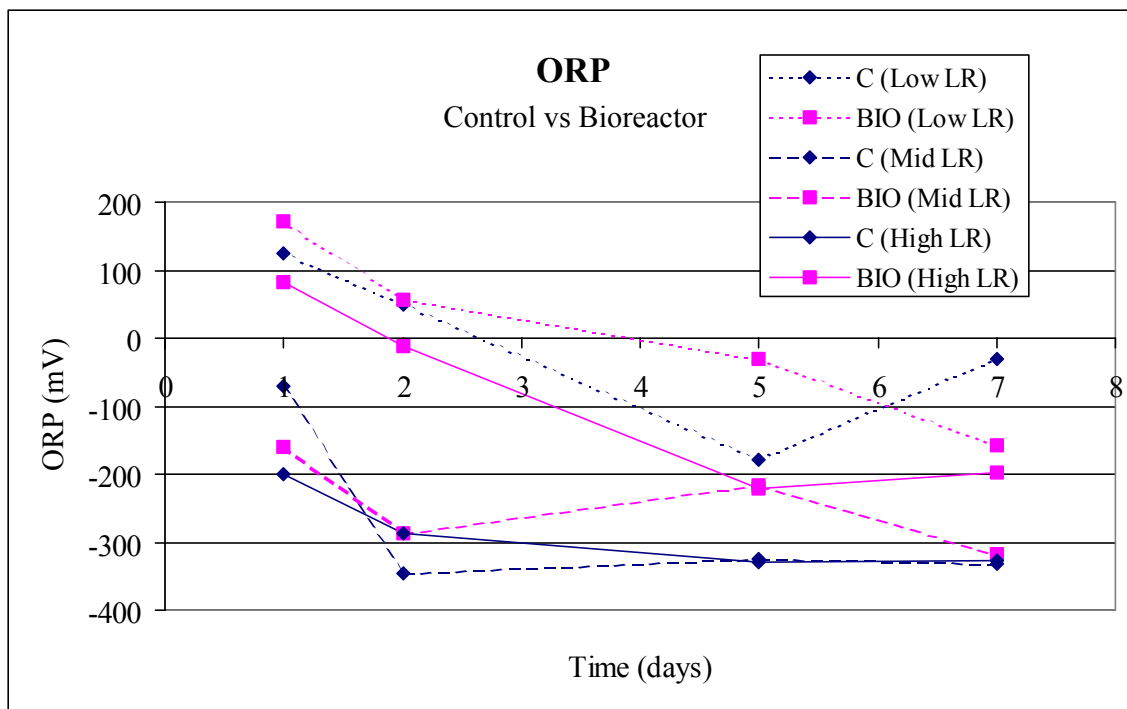
Figure 4.2. ORP measurements versus time for control and BIO system
(C = Control; LR = Load-Range)

The ORP (oxidation/reduction potential) of water is a measurement of its ability to either oxidize or reduce ionic species. Bacterial activity in water is dependent upon the ORP and is related to the redox couples present. Reduction in the ORP is caused by reduction of dissolved oxygen and other redox couples present in the water. The bacterial degradation of high concentrations of organic compounds leads to the depletion of oxygen and an eventual decrease in the ORP (Baker and Herson, 1994). Therefore, it was not surprising to see the ORP of the systems drop with time and with increased load. As more organic matter entered the pits, more oxygen was being consumed leading to a decrease in the ORP of the wastewater.

Most aerobic and facultative anaerobic microorganisms require a redox potential of +50 mV or higher. However, the optimal ORP for obligate anaerobic microorganisms is around −200 mV (Baker and Herson, 1994). Evans et al. (1986) claimed that ORP during aerobic treatment must be higher than −200 mV if the rapid regeneration of odorants after treatment is to be avoided. Therefore the low ORPs (~ -300 mV) of the mid and high load-range control system and the mid load-range BIO system indicate predominantly anaerobic activity within the collection pits. This is significant because anaerobic microbes are responsible for the malodor generated from swine manure. The key culprit odorous compounds (volatile fatty acids, ammonia and volatile amines, indoles and phenols, and volatile sulfur containing compounds) are the normal end or intermediates products during the degradation of fecal substances by anaerobic bacteria (Mackie et al., 1998). The higher ORPs of the high load-range BIO systems were above the optimum range for anaerobic activity.

It is unclear why the mid load-range would have lower ORP levels than the high load-range BOD system, especially since the DO concentrations of the mid load-range were higher than those of the high load-range BIO system. However, the lower ORP levels correspond with the higher ammonia and volatile acids concentrations of the mid load-range BIO system compared to the other bioreactor systems. These results will be more fully discussed later in this chapter.

Total Solids

The total solids data for the BIO systems and controls are presented in Figure 4.3. The total solids concentration generally increased as the load increased, both in terms of time and rate. There was little difference in concentrations for the control and BIO

systems at any of the load-ranges. The total solids concentration increased linearly

throughout each experiment as seen in Figure 4.3. The data does not indicate that the

BIO system provides any benefit over the control in terms of total solids removal.
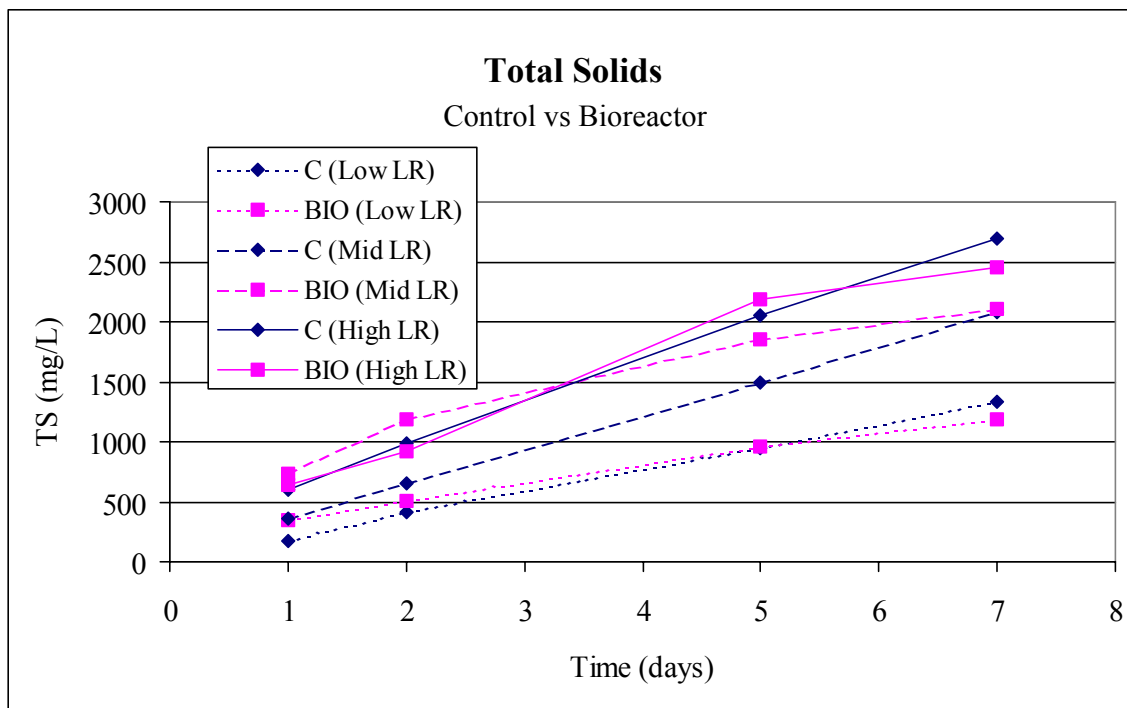
Figure 4.3.   **Total solids concentration versus time for control and BIO systems**
               (C = Control; LR = Load-Range)

Ammonia

Figure 4.4 shows the liquid phase ammonia concentrations versus time for the

control and BIO systems. The low and high load-ranges for the control and BIO systems

had similar ammonia concentrations, with the BIO systems being slightly higher. The

mid load-range BIO system had the highest ammonia concentration of all control and

BIO systems.
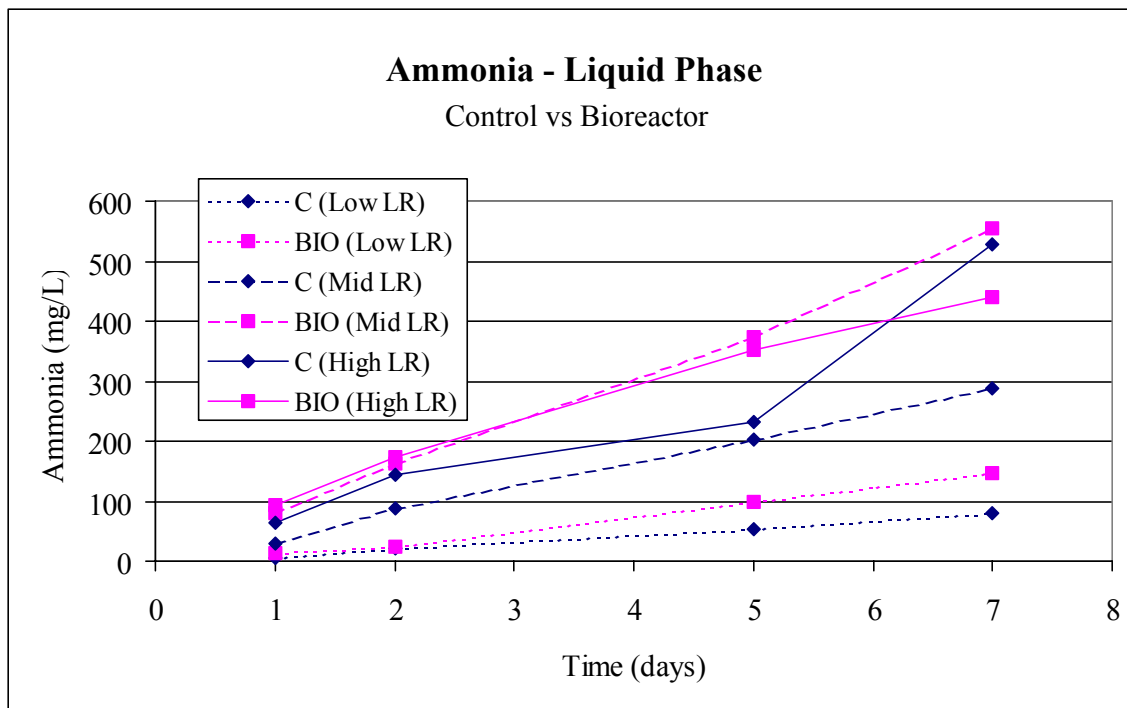
Figure 4.4. **Ammonia concentrations versus time for control and BIO systems (C = Control; LR = Load-Range)**

Ammonia is generated from the microbial decomposition of urea in the urine and nitrogenous compounds in the feces (Zhang and Day, 1996; Mackie et al., 1998). However, ammonia can be removed from wastewaters biologically through assimilation and nitrification (Metcalf and Eddy, 1991). With assimilation, a portion of the ammonia is removed by heterotrophic microbes (both anaerobic and aerobic) and incorporated into cell mass as a nitrogen source. With nitrification, the ammonia is converted to nitrate by nitrifying bacteria (autotrophic aerobic bacteria). Nitrifying bacteria (*Nitrosomonas* and *Nitrobacter*) are sensitive and DO concentrations above 1 mg/L are essential for nitrification to occur. If DO levels drop below this value, oxygen becomes the limiting chemical and nitrification is inhibited or eliminated (Metcalf and Eddy, 1991). The DO concentrations were 0.5 mg/L or below after day 2 for all systems at any load-range,

therefore, it is doubtful that significant nitrification occurred in either the control or BIO system to any extent.

Ammonia can also be removed from wastewater by volatilization (Metcalf and Eddy, 1991). Ammonia moves through by molecular diffusion to the top surface where it is constantly released to the atmosphere (Zhang and Day, 1996). This fact might help explain the higher ammonia levels associated with the mid load-range BIO system. Two of three BIO system tests at the mid load-range were conducted without barn ventilation. The vents in the top of the barn were closed and the ventilation fans were not on during the testing periods. The lower temperatures of the two mid load-range BIO systems would also decrease the ammonia volatilization, since volatilization increases as temperatures increase (Metcalf and Eddy, 1991).

The extent of ammonia volatilization would be reduced without proper ventilation. When a volatile compound (such as ammonia) is dissolved in water, a small amount in gaseous form exists in the air immediately above the surface of the water. Henry's law is used to describe this phenomenon. Henry's Law implies that under equilibrium conditions, the partial pressure of a gas above a liquid is proportional to the concentration of the chemical in the liquid (LaGrega et al., 1994). Without proper ventilation, an equilibrium is reached between the gas and liquid phases therefore preventing further volatilization. By replenishing the air above pits this equilibrium is destabilized allowing for constant volatilization as long as the liquid concentration remains sufficiently high. The control systems at the mid load-range and both the control and BIO systems at the high load-range were conducted with the ventilation system

functioning. Therefore, it is believed that ammonia volatilization may have been

hindered during the mid load-range BIO system due to poor ventilation.

The ammonia concentrations in the air above the pits were also monitored during

the study. Measurements were taken from a semi-confined headspace approximately 20

cm above the liquid surface, to minimize the affects of air movement within the barn.

Therefore, it can be assumed that the concentrations within the barn were less than those

measured by the gas detection meter. The air phase ammonia generally tracked with the

liquid phase ammonia concentrations (see Figures 4.4 and 4.5). At the low load-range,

the BIO system performed similar to the control. The mid load-range BIO system had

the highest concentration of all systems. However, at the high load-range, the BIO

system had reduced levels of ammonia compared to the control.

Ammonia (Air Phase)
Control vs Bioreactor
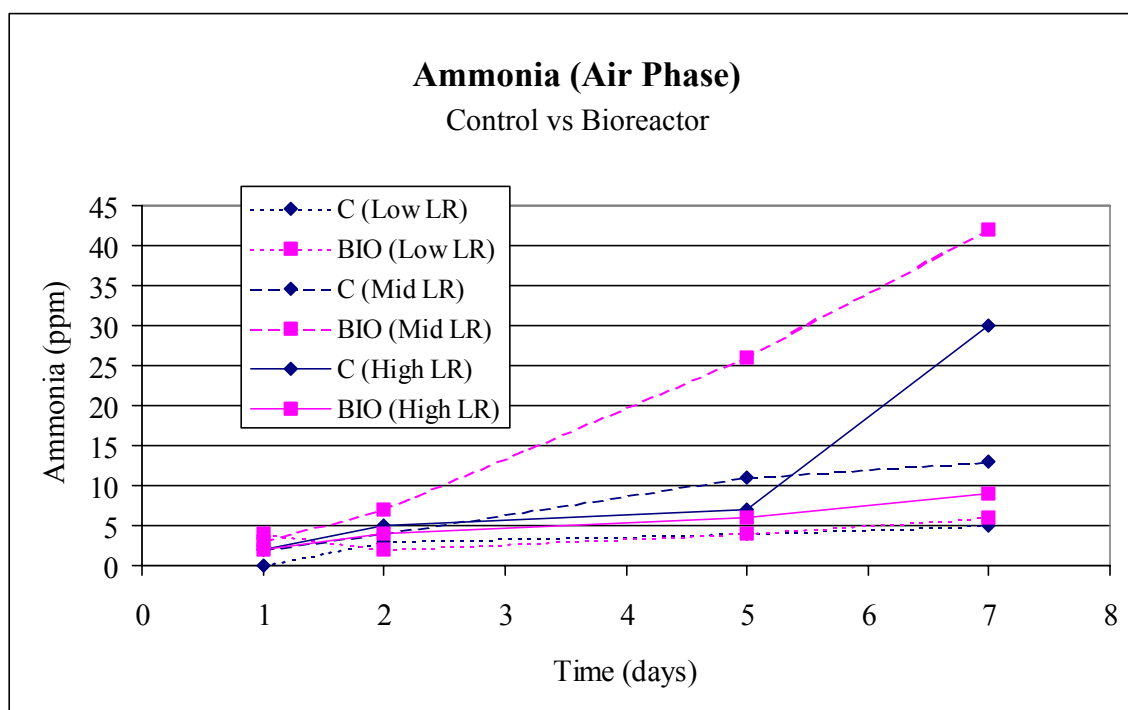
Figure 4.5.   **Ammonia air phase concentrations versus time for control and BIO systems**
         (C = Control; LR = Load-Range)

The low concentrations of ammonia in the air for the low load-range can be attributed to the lower concentrations of ammonia in the collection pits since the gas phase concentrations are directly related to liquid concentrations. The higher concentration of gas phase ammonia for the mid load-range BIO system as compared to the high load-range is probably due to the poor ventilation of the barn during testing. At the high load-range, the BIO system did have lower ammonia concentrations in the air above the pits compared to the control. The BIO system had average endpoint concentration of 9 ppm, while the average endpoint concentration for the control was 30 ppm. Again, it should be noted that the ammonia concentration within the air space occupied by the pigs should be less than the values measured.

It is evident from the data that the BIO system was not effective in reducing the ammonia in the wastewater. Ammonia is a concern for the swine industry because not only is it a contributor to the odor associated with swine facilities, but at high levels can also be a health concern for workers and animals because of its irritant and toxic nature. High ammonia releases from swine facilities have raised concerns about enhancing acid rain deposition and increasing the nitrogen load on natural ecosystems (Zhang and Day, 1996). Therefore, one possible method to control ammonia concentration would be through forced aeration of the bioreactor or collection pits, and seeding with a nitrifying bacteria. It should be noted that the establishment of a functional population of nitrifying bacteria can take months; therefore, it is possible that the timeframe of these experiments did not allow nitrifying bacteria to populate the bioreactor.

Conductivity

The conductivity measurements of the BIO system and control for all load-ranges are presented as Figure 4.6. Overall, the conductivity increased as load increased. There were not any dramatic differences between the control and BIO systems at the low and high load-range. The mid load-range BIO system did have a higher conductivity as compared to the control. Since conductivity is dependent upon on the presence of ions, their total concentration, mobility, valence, and relative concentrations, perhaps the higher conductivity of the mid load-range BIO system was due to the high ammonia (ammonium ion) concentration of the wastewater.
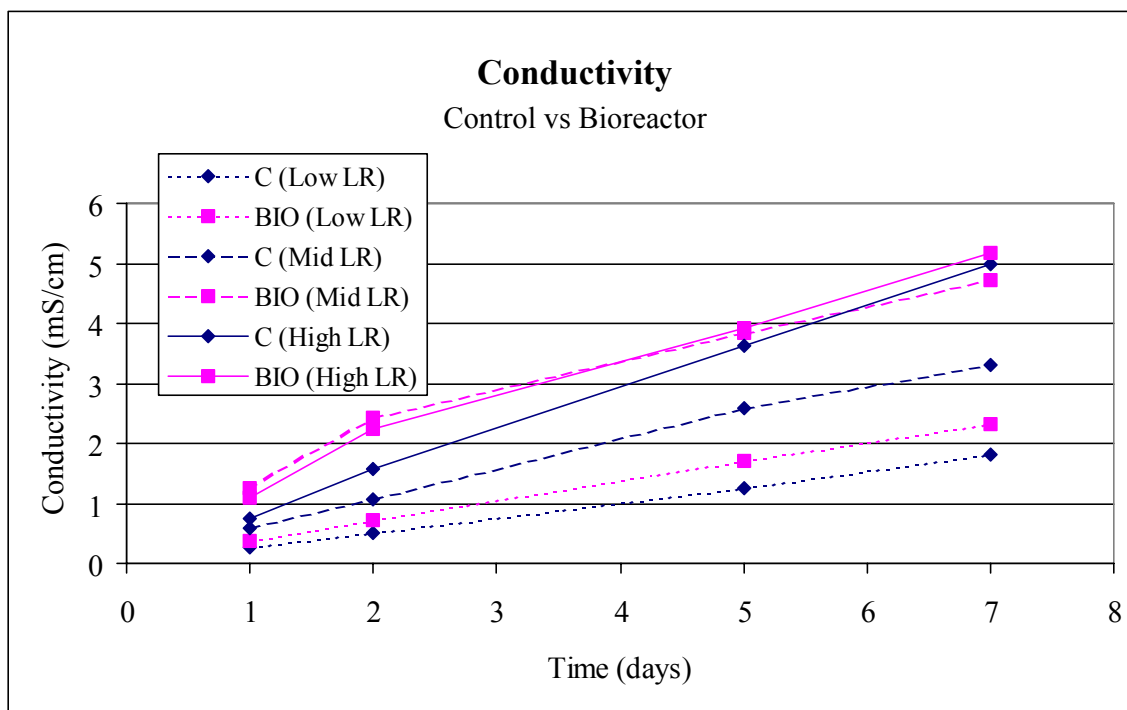
Figure 4.6. Conductivity versus time for BIO and control systems
(C = Control; LR = Load-Range)

COD

The COD concentrations detected within the pits for the control and BIO systems at all load-ranges versus time are presented as Figure 4.7. The concentrations generally increased with time and with load-range. However, the BIO systems had lower concentrations as compared to the control at all the load-ranges.
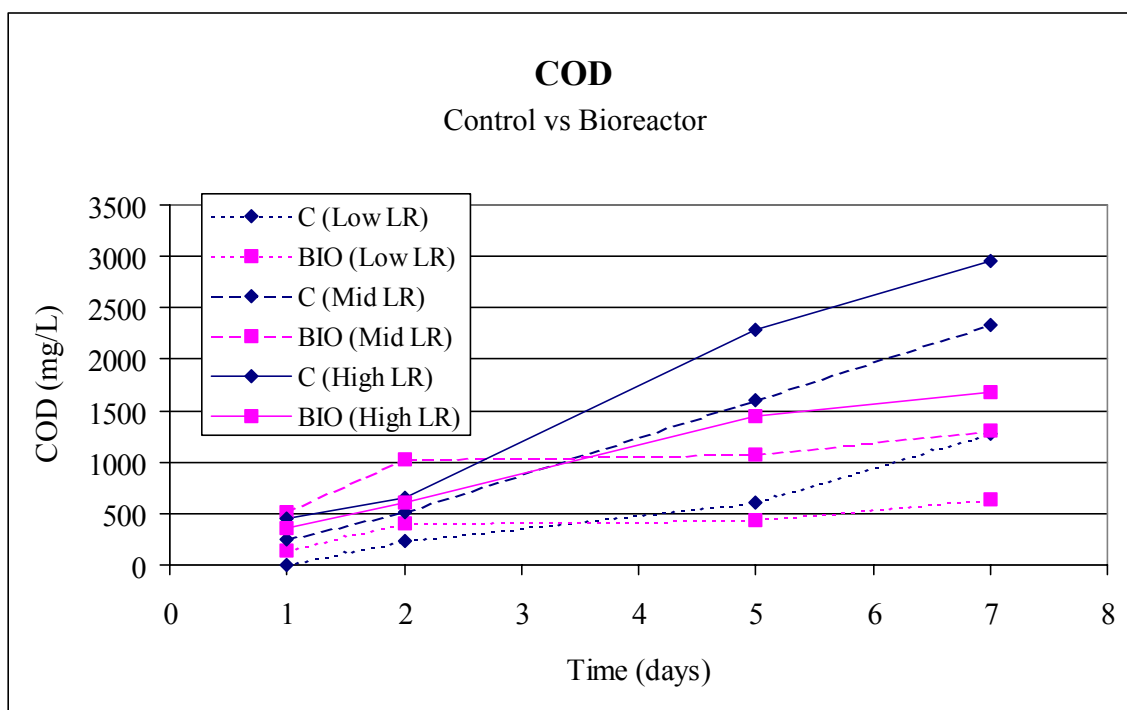
Figure 4.7. **COD concentration versus time for control and BIO systems**
 (C = Control; LR = Load-Range)

COD can be used to determine the amount of oxidizable, organic material present in a liquid sample and as an indirect method for tracking biotreatment progress. Microorganisms convert colloidal and dissolved organic matter into gases and cell mass (Baker and Herson, 1994). Therefore, the lower COD concentrations of the BIO system, as compared to the control, may be attributed to the increased microbial populations within the bioreactor. Visual observations of the microbial slimes observed within the

bioreactor also supports this. Figure 4.8 is a picture of microbial slimes buildup in the bioreactor.
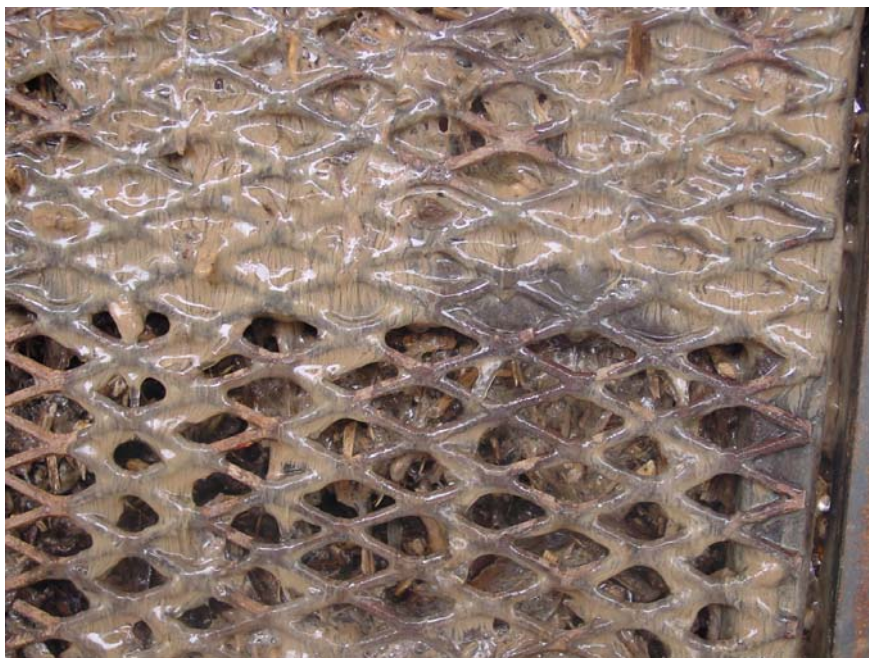
Figure 4.8.   Picture of biological slimes within the bioreactor

It is clear that the BIO system enhanced the removal of organic matter within the pits as compared to the control. The BIO system reduced the endpoint COD concentration by 50%, 44%, and 43% for the low, mid, and high load-rates, respectively as compared to the control. The removal of COD or organic matter is significant because, by removing COD, odorous compounds and precursors to the odorous compounds are also removed.

Orthophosphate

The orthophosphate results for the control and BIO systems are presented in Figure 4.9. For the low load-range, there was little difference between the orthophosphate concentrations found in the control and BIO systems. However, at the

mid and high load-ranges the BIO systems had less orthophosphate than the control.

These results tended to track along with the COD data. The BIO system experienced

more microbial growth than the control as evident from the microbial slimes present in

the bioreactor and COD removal (see Figure 4.8 and 4.9). Phosphorus is utilized by

microbes (anaerobic and aerobic) for cell synthesis and energy transport. Therefore, it is

believed that reduced orthophosphate concentrations of the BIO systems are the result of

increased cell synthesis.
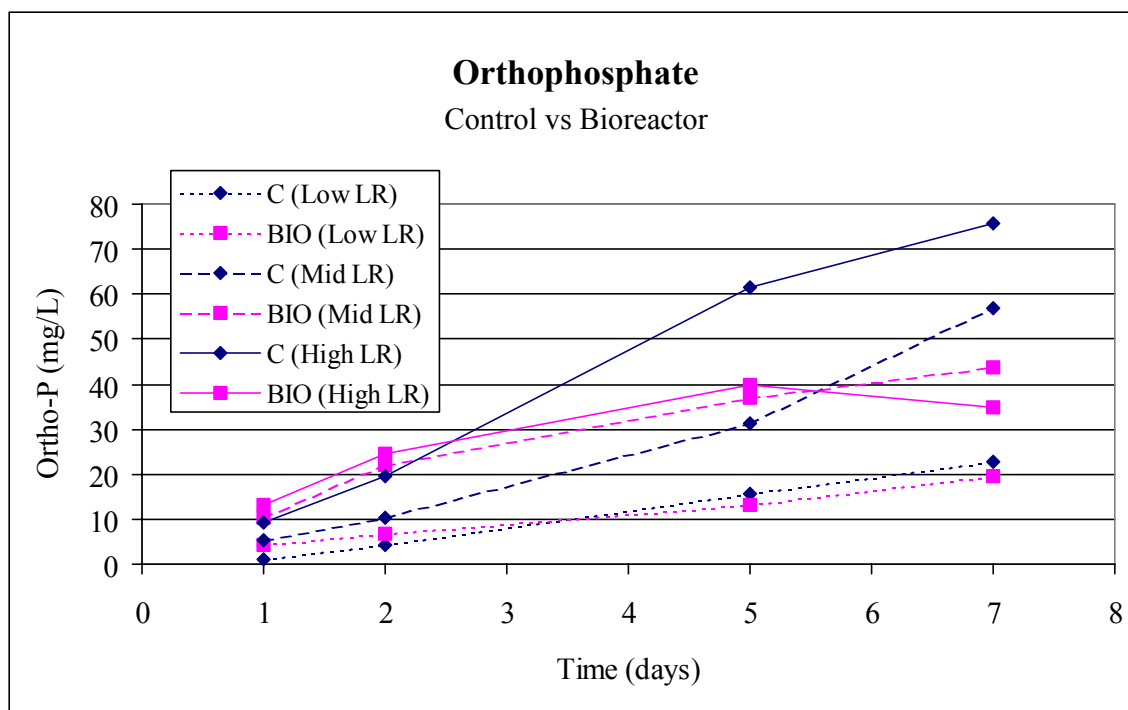
Figure 4.9. **Orthophosphate concentrations for control and BIO systems**
(C = Control; LR = Load-Range)

One other possible explanation for the higher orthophosphate concentrations of

the control systems as compared to the BIO systems would be through the release of

stored phosphorus by certain microbes. Under anaerobic conditions, some microbes will

release stored phosphorus when high concentrations of volatile acids are present (Metcalf and Eddy, 1991). The control did have high concentrations of volatile acids while the BIO system did not.

Phenols

The concentrations of phenols versus time for the control and BIO systems are presented as Figure 4.10. The phenol concentrations for the BIO system were less than those detected in the control runs at all load-ranges. The BIO system reduced endpoint phenol concentrations by 65%, 58%, and 67% for the low, mid, and high load-ranges, respectively, as compared to the control.

Phenols
Control vs Bioreactor

Legend:
- C (Low LR)
- BIO (Low LR)
- C (Mid LR)
- BIO (Mid LR)
- C (High LR)
- BIO (High LR)

Y-axis: Phenols (mg/L)
X-axis: Time (days)
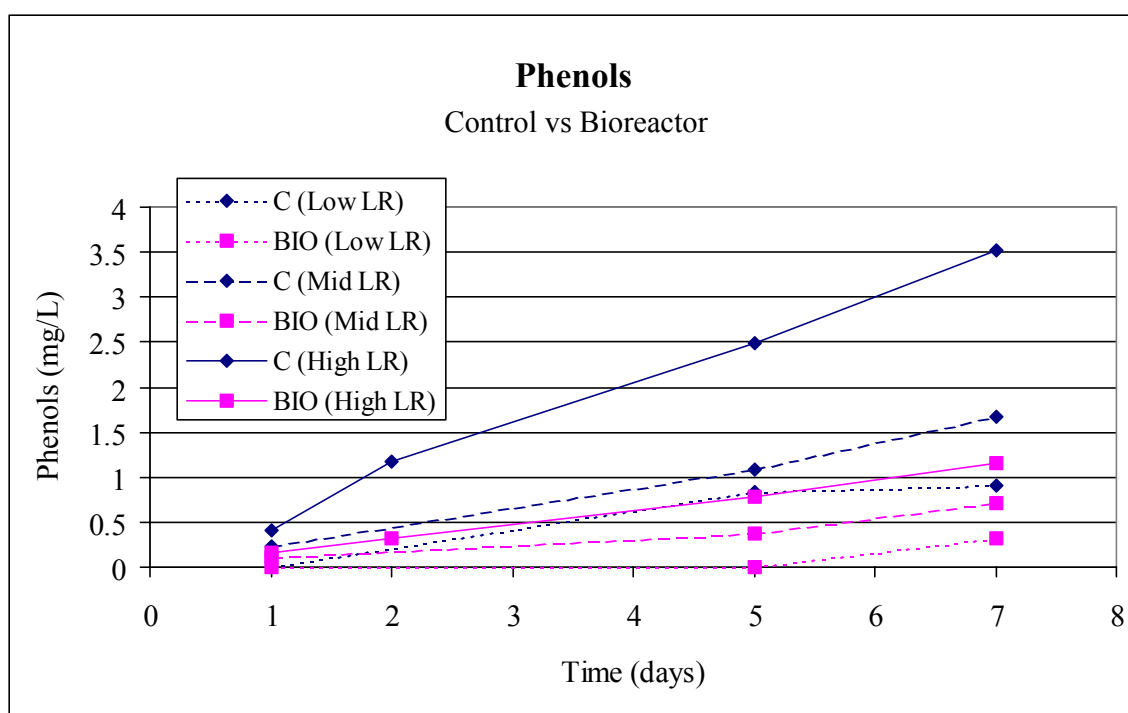
Figure 4.10. Phenols concentration versus time for control and BIO systems
(C = Control; LR = Load-Range)

Phenolic compounds are present in freshly excreted feces and in urine and continue to form from the anaerobic degradation of protein in the feces during storage (Spoelstra, 1977). They also contribute to the odor in confinement swine buildings and in stored wastes. A study by Ishaque et al. (1985) determined that phenol and p-cresol were readily oxidized under aerobic conditions by mixed microbial cells; however, no degradation occurred under anaerobic conditions. Therefore, the higher phenol concentrations in the control were expected. The continual anaerobic conditions found with the control allowed for further degradation of protein within the pit resulting in the accumulation of phenols. Since phenols are formed and not degraded under anaerobic conditions, the decreased concentrations of the BIO system indicate the presence of some aerobic activity within the system. Aerobic activity could decrease the phenol concentration by two methods: by preventing the formation of phenols and degrading the phenols present.

The low phenol concentrations of the BIO systems were encouraging, especially since phenols are known to contribute to the odors associated with swine waste. If the phenol concentrations can be reduced by the BIO system, perhaps the odor associated with swine waste will also be reduced.

Volatile Acids

Figure 4.11 presents a plot of the volatile acid concentrations versus time for the control and BIO systems. The volatile acid concentrations detected in the pits for the BIO system was generally less than that of the control. The volatile acid concentration of the control tended to increase with time and with load. The endpoint concentrations of the control were approximately 300, 600, and 1000 mg/L for the low, mid, and high load-

ranges, respectively. With the exception of the low load-range, the BIO system

maintained volatile acid concentrations of about 250 mg/L or less. Compared to the

control, the BIO system reduced the volatile acid concentration by 69% and 75% for the

mid and high load-ranges, respectively.

Figure 4.11. Volatile acids concentration versus time for control and BIO systems
(C = Control; LR = Load-Range)

The anaerobic biodegradation of swine waste enhances the production of odorous

compounds, which are dominated by the volatile fatty acids (Jolicoeur and Morin, 1987).

At temperatures between 35 and 55 °C (thermophilic) volatile acids are further broken

down to methane and carbon dioxide by methanogens. Volatile acids will persist in

anaerobic conditions at lower temperatures because the methanogenic bacteria are less

active. However, volatile acids are readily degradable by aerobic bacteria (Stevens and

Cornforth, 1974; Cooper and Cornforth, 1978; Evans et al., 1986; Williams et al., 1989;

ranges, respectively. With the exception of the low load-range, the BIO system

maintained volatile acid concentrations of about 250 mg/L or less. Compared to the

control, the BIO system reduced the volatile acid concentration by 69% and 75% for the

mid and high load-ranges, respectively.

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(C = Control; LR = Load-Range)

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active. However, volatile acids are readily degradable by aerobic bacteria (Stevens and

Cornforth, 1974; Cooper and Cornforth, 1978; Evans et al., 1986; Williams et al., 1989;

Chen et al., 1994;). Therefore, the relatively high volatile acid concentrations of the control were expected. The anaerobic conditions found within the control pits encouraged volatile fatty acid production. However, due to the low temperature of the control testing periods, the volatile acids degradation via methanogenesis was likely inhibited. The average temperature of the control testing periods ranged between 17 °C and 31 °C, with an overall average of 24 °C. This is well below the optimum range (35° to 55 °C) for methanogens (Metcalf and Eddy, 1991).

The lower volatile acid concentration of the BIO systems can be attributed to aerobic activity within the BIO system. Aerobic conditions not only prevent the formation of volatile acids, but also provide an environment under which bacteria can rapidly degrade them.

The high endpoint concentration of the low load-range of the BIO system was probably due to a laboratory error. The two low load-range BIO systems were conducted during the same testing period. Therefore, it is possible that a laboratory error occurred while performing the volatile acids test on the day 7 samples. It is doubtful that the volatile acid concentration of the low load-range would be three times higher than the endpoint concentration of either the mid or high load-range on day 7. Also, if the volatile acid concentration increased that much from day 5 to day 7, a drop in the pH of the wastewater would be expected. The wastewater of the BIO system at the low load-range did not experience a significant drop in pH from day 5 to day 7 (see Figure 4.12). Since all other volatile acids versus time data are basically linear, we can conclude that the day 7 volatile acid point for the low load-range BIO system was a laboratory error.

The ability of the BIO system to reduce the volatile acid concentration is encouraging, especially since volatile acids are a major contributor to the odor associated with swine waste. If the BIO system can reduce the volatile acid concentration, it is probable that the odor will also be reduced.

pH

Figure 4.12 is a plot of pH versus time for the control and BIO systems. The pH of all systems was essentially neutral, ranging from 6.8 to 8. In general, the pH of the control decreased with time, while the pH of the BIO systems remained stable throughout the testing period.
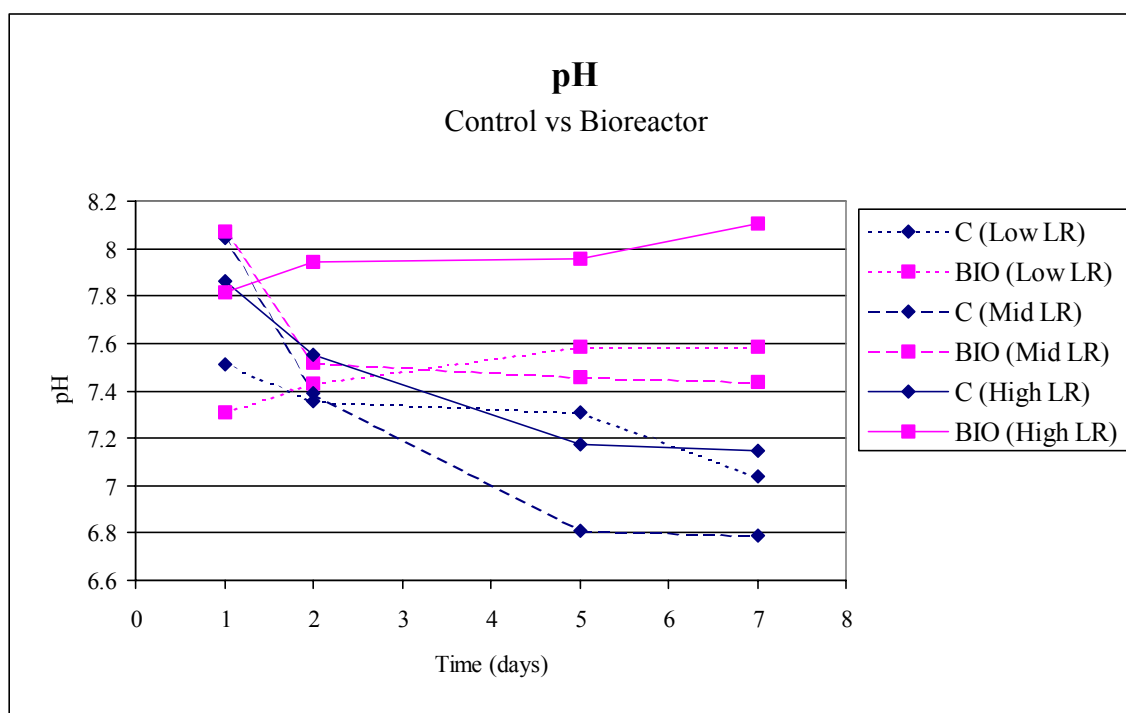
Figure 4.12. pH measurements versus time for control and BIO systems (C = Control; LR = Load-Range)

The pH of manure slurries is largely determined by the strength and equilibrium of carbonic acid-bicarbonate buffers and the amount of volatile fatty acids and ammonia produced. However, as the VFA concentrations increase, pH is controlled primarily by VFA and ammonia concentrations (Georgacakis et al., 1982). Therefore, the drop in pH of the control can be attributed to the rise in volatile acid concentrations. The BIO systems did not have high concentrations of volatile acids; therefore, the pH remained more stable throughout the testing periods. Note that there was not a significant drop in pH for the low load-range BIO system, which supports the theory that the higher volatile acid concentration of day 7 was due to laboratory errors.

Hydrogen Sulfide Air Measurements

The air directly above the collection pits was also monitored for hydrogen sulfide on days 1, 2, 5, and 7 of each testing period for the control and BIO systems. No hydrogen sulfide was detected during the low load-range BIO systems or control. During the mid load-range control, hydrogen sulfide was detected on two different occasions. During one of the testing periods, 2 ppm and 1 ppm of hydrogen sulfide was detected on day 5 and 7, respectively. No hydrogen sulfide was detected for the mid load-range BIO system.

At the high load-range control, hydrogen sulfide was detected on nine different occasions. The concentrations ranged from 1 to 20 ppm. The BIO system also had measurable hydrogen sulfide concentrations on six occasions during the high load-range, but the concentrations were never above 1 ppm.

Hydrogen sulfide, a malodorous gas, is formed from the anaerobic decomposition of organic matter containing sulfur and from the reduction of sulfates (Metcalf and Eddy,

1991). Sulfate reducing bacteria are strict anaerobes with an optimum ORP of –200 mV (Baker and Herson, 1994). Therefore, it was not surprising that no hydrogen sulfide was detected during the low load-range as the ORP for these testing periods never fell below –200mV.

The detection of hydrogen sulfide for the control systems at the mid and high load-range further indicates that anaerobic conditions were dominant in the wastewater collection pits. The detections of hydrogen sulfide for the BIO system were much lower than those of the control. However, it should be noted again, that measurements were taken from a semi-enclosed headspace which allowed concentrations to accumulate. Therefore, it is doubtful that any hydrogen sulfide would be detected in the air space occupied by pigs or humans.

Temperature Effects

Temperature has a major influence on growth rate of microbes. Cellular activity, particularly enzyme systems, responds to heat so that the rate of cell growth increases sharply with increasing temperature until the optimum is reached. Cellular activity below the optimum temperature can more than double with a rise of about 10°C (Viessman and Hammer, 1998).

Optimum temperature for mesophilic bacterial activity is in the range from a bout 25° to 35°C. Aerobic digestion and nitrification stop when the temperature is above 50°C. When the temperature drops to about 15°C, methane-producing bacteria become practically inactive, and at 5°C the autotrophic-nitrifying bacteria virtually cease functioning. At 2°C, even the chemoheterotrophic bacteria acting on carbonaceous material become basically dormant.

The endpoint results from testing periods in the high load-range with the lowest and highest average temperature where graphed to determine the temperature effect of the control and BIO systems. Figure 4.13 is a graphical representation of the endpoint concentrations for the high and low temperature testing periods of the control and BIO systems. The two control testing periods had high and low temperatures of 31° C and 24° C, respectively. The load for the control was approximately 40 kg COD/testing period. The high temperature of the BIO system was 28° C and the low temperature was 9° C. The load for the BIO systems was approximately 48 kg COD.
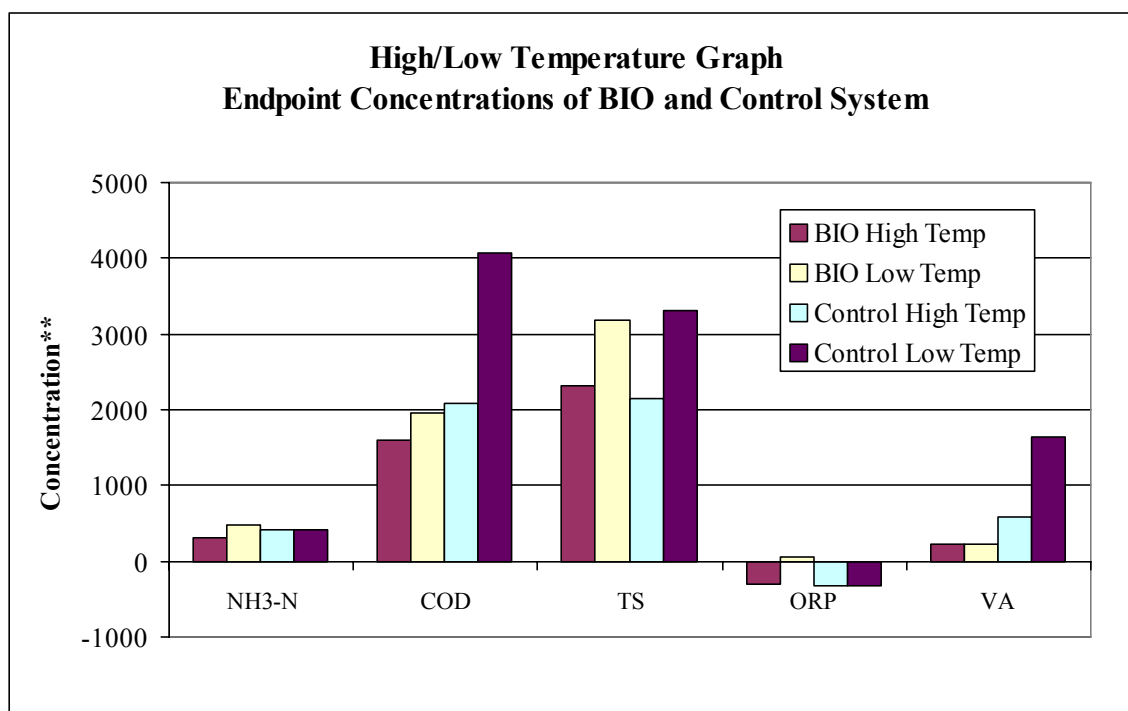
Figure 4.13. Control and BIO system temperature variance graph
(NH3-N, COD, TS, VA = mg/L; ORP = mV)**

The BIO system testing period with the higher temperature had lower concentrations of ammonia, COD, and total solids than the low temperature BIO testing

period. This indicates the microbial degradation was likely enhanced with higher temperatures. The ORP of the high temperature was much lower than that of the low temperature. This might be attributed to the fact that oxygen is more soluble in water at lower temperatures than at higher temperatures.

Temperature also impacted the performance of the control.   The control experienced decreases in concentrations of COD, total solids, and volatile acids at the higher temperature. The improved performance was attributed to the increased anaerobic microbial activity at the higher temperatures.

Both the BIO systems and the control performed better at the higher temperatures. The better performance was attributed to greater microbial activity both aerobic and anaerobic. It is possible that the lower COD and volatile acids concentration at the higher temperature of the control was associated with methanogenic activity. This implies that performance by both systems (control and BIO) is temperature dependent, and thus, will vary during warm and cool seasons.

<center>Olfactory Evaluation</center>

No odor data for the control at the low and mid load-ranges were taken. Therefore, the comparison of the control and BIO system odor abatement capabilities will be based on the high load-range data only. Wastewater samples at days 2, 5, and 7 were evaluated by the sensory panel. The samples were rated on a scale from 0 to 8 with 0 being no detectable odor and 8 being a strong odor. For the pleasantness rating (hedonic tone), a 0 was a very pleasant odor, a 4 was neither pleasant nor unpleasant, and a rating of 8 was considered to be a very unpleasant odor.

Mean odor responses and statistical inferences for days 2, 5, and 7 are in Tables 4.5, 4.6, and 4.7, respectively. These data were analyzed using SAS Version 6.12 (SAS Institute Inc.) and means were separated by Duncan's Multiple Range test. All statistical comparisons were at the $\alpha = 0.05$ level.

Table 4.5. Day 2 mean odor response and statistical inferences for control and BIO systems

System	Pleasantness	Intensity	Acrid	Sulfur	Earthy	Musty	Fecal	Cheesy	Sweet	NH3
Control	5.5	3.7	0.5	1.1	0.1	0.5	1.7	0.4	0.1	0.7
BIO	4.2	2.6	0.1	0.2	1.1	0.9	0.9	0.3	0.3	0.2
Control	a	a	a	a	b	a	a	a	a	a
BIO	b	a	b	b	a	a	b	a	a	b

Note: Means with the same letter are not significantly different.

Table 4.6. Day 5 mean odor responses and statistical inferences for control and BIO systems

System	Pleasantness	Intensity	Acrid	Sulfur	Earthy	Musty	Fecal	Cheesy	Sweet	NH3
Control	6.0	4.4	0.9	1.7	0.3	0.7	2.0	1.0	0.3	0.8
BIO	4.6	2.6	0.2	0.1	1.0	0.9	0.6	0.2	0.2	0.3
Control	a	a	a	a	b	a	a	a	a	a
BIO	b	b	b	b	a	a	b	b	a	b

Note: Means with the same letter are not significantly different.

Table 4.7. Day 7 mean odor responses and statistical inferences for control and BIO systems

System	Pleasantness	Intensity	Acrid	Sulfur	Earthy	Musty	Fecal	Cheesy	Sweet	NH3
Control	5.5	4.8	0.8	2.0	0.2	0.7	2.4	1.1	0.3	0.8
BIO	4.9	3.3	0.3	0.3	1.2	0.9	0.8	0.2	0.3	0.5
Control	a	a	a	a	b	a	a	a	a	a
BIO	b	b	b	b	a	a	b	b	a	b

Note: Means with the same letter are not significantly different.

At day 2, the wastewater from the BIO system was found to be significantly different from the control with regard to pleasantness and the acridity, sulfurous, earthy, fecal, and ammonia characteristics. It was rated as more pleasant and less intense, acrid, sulfurous, fecal, cheesy and ammoniacal. The BIO system also had a higher earthy rating at day 2.

By day 5, the BIO system was significantly different from the control with regard to all characteristics except for musty. The control had higher ratings of all characteristics except for earthy and musty. This same trend was seen in the day 7 data.

The BIO system received lower ratings on all odor characteristics as compared to the control, except for the earthy and musty characteristics. It is assumed that the earthy and musty odors of the BIO system samples are caused by actinomycetes, a type of fungi-like bacteria found in soil and compost. Most actinomycetes species are chemo-organotrophic, aerobic, mesophilic, and grow optimally at a pH near neutrality. They are capable of decomposing and transforming a wide variety of complex organic residues (Csuros and Csuros, 1999).

The earthy and musty odors can be attributed to volatile metabolites formed during normal Actinomycete development. Two such compounds, geosmin and 2-

methylisoborneol, have been isolated and identified as the agents responsible for the earthy-musty odors (Csuros and Csuros, 1999).

Additionally, the Mississippi Forest Products Laboratory conducted a biological analysis of kenaf that revealed that actinomycetes were present in both fresh kenaf and spent kenaf (kenaf removed from the bioreactor). The results from the biological analysis are located in Appendix H.

Overall, the BIO system was found to be significantly different from the control with regard to pleasantness, overall odor intensity, acridity, sulfurous, earthy, fecal, cheesy, and ammonia characteristics. According to the ratings, the control exhibited an unpleasant odor with medium intensity dominated by sulfurous, fecal, and cheesy characteristics. In comparison, the wastewater of the BIO system was more pleasant, less intense, and was dominated by earthy and musty characteristics.

Summary

The BIO system was capable of reducing the organic content of the wastewater as compared to the control. COD, volatile acids, and phenols concentrations were reduced by 43%, 75%, and 67%, respectively at the high load-range. Orthophosphate concentrations were reduced by as much 50% with the BIO system. There was little difference between the control and the BIO systems with regard to conductivity, ammonia, or total solids. It is doubtful that ammonia removal can be achieved with the BIO system in its present form. Another treatment device that is optimized for nitrification could be added to the system. Forced aeration and seeding with nitrifying bacteria might lead to improved ammonia removal within the system.

The BIO system was also able to significantly reduce the odor of the wastewater as compared to the control. The wastewater from the control exhibited an unpleasant odor with medium intensity that was predominantly sulfurous, cheesy, and fecal in character. The BIO system wastewater on the other hand was more pleasant, less intense, and was dominated by earthy and musty characteristics.

The amounts of ammonia and hydrogen sulfide in the air above the pits was also decreased with the BIO system as compared to the control when the barn was ventilated properly. This data indicates that an attached growth BIO system reduced odor and may be a viable component of a comprehensive odor management system.

CHAPTER V

EVALUATION OF AERATION ENHANCEMENT TO

BIOREACTOR PERFORMANCE

This chapter compares the three modified bioreactor systems (BIO/AMS, ABIO, and ABIO/AMS) to the BIO system. The modified systems were evaluated to determine if aeration and the addition of a microbial seed would enhance the performance of the attached growth bioreactor system. Table 5.1 lists the systems and gives a short description of each. The BIO/AMS system involved aeration of the collection pits and the addition of a microbial seed (activated sludge). In the ABIO system, only the bioreactor vessel was aerated (no seed was added). The ABIO/AMS system is a combination of the two previous systems is in which the collection pits were aerated, a microbial seed was added to the pits, and the bioreactor vessel was aerated. The same sampling and analysis procedures described previously were followed for these tests.

Table 5.1.   System list and description

System	Description
Control	Wastewater remains undisturbed in the pits (mimics current industry practices in the southeastern US)
BIO	Wastewater circulates through the BV at rate of 22 L/min•m^3 Kenaf is used as the organic packing media
BIO/AMS	Wastewater circulates through the BV at rate of 22 L/min•m^3; Kenaf is used as the organic packing media; Aeration of collection pit; Addition of microbial seed
ABIO	Wastewater circulates through the BV at rate of 22 L/min•m^3; Kenaf is used as the organic packing media; BV is aerated by membrane tube diffuser (collection pit not aerated)
ABIO/AMS	Wastewater circulates through the BV at rate of 22 L/min•m^3; Kenaf is used as the organic packing media; Aerated BV; Aeration of collection pit; Addition of microbial seed

The BIO/AMS system was evaluated five times throughout this study. Three of the BIO/AMS systems were conducted at the mid load-range and two at the high load-range. The ABIO and ABIO/AMS systems were evaluated only once and at the high load-range. The average weekly COD loads, testing frequencies, and temperatures are listed in Tables 5.2 and 5.3 for the mid and high load-ranges, respectively.

Table 5.2.   Average COD loads and temperatures for the mid load-range systems

System	Number of Testing Periods	Average COD Load (kg COD/7-d)	Avg Air Temperature	
			(C°)	(F°)
Control	6	23	23	73
BIO	3	24	19	66
BIO/AMS	3	20	22	72

Table 5.3.   Average COD loads and temperatures for the high load-range systems

System	Number of Testing Periods	Average COD Load (kg COD/7-d)	Avg Air Temperature	
			(C°)	(F°)
Control	9	42	27	81
BIO	9	40	21	70
BIO/AMS	2	34	20	68
ABIO	1	45	31	88
ABIO/AMS	1	54	23	73

Mid Load-Range Systems

Water Quality Results

Tables F.25 – F.27 in Appendix F lists all the raw water quality data from the BIO

mid load-range systems. Tables F.32, F.33, and F.36 in Appendix F list the raw water

quality data from the BIO/AMS mid load-range systems. The averaged water quality

data for the systems are listed in Table G.4 in Appendix G and presented graphically in

Figures 5.1 – 5.11. A discussion of the data for the mid load-range systems is presented

in the sections below.

Dissolved Oxygen

The DO concentrations of the wastewater in the pit for the BIO, BIO/AMS, and

control systems at the mid load-range are shown in Figure 5.1. Dissolved oxygen

concentrations above 0.5 mg/L are considered functionally aerobic. The BIO/AMS

system maintained higher dissolved oxygen concentrations than the control or BIO

systems at the mid load-range through day 5. The BIO was only able to sustain aerobic

conditions until day 2, while the BIO/AMS system remained aerobic through day 5. The

control did not have any appreciable DO at any time during the testing period. However,

all systems were anaerobic by day 7.

During the BIO/AMS treatment, the collection pits were aerated at a rate of 0.37 m^3/min•m^3 (0.05 cfm/gal). This aeration rate was capable of keeping the wastewater in the collection pits aerobic until day 5. However, it is apparent that by day 7, the oxygen demand of the wastewater exceeded the input capacity of the aeration system and the pits became anaerobic.
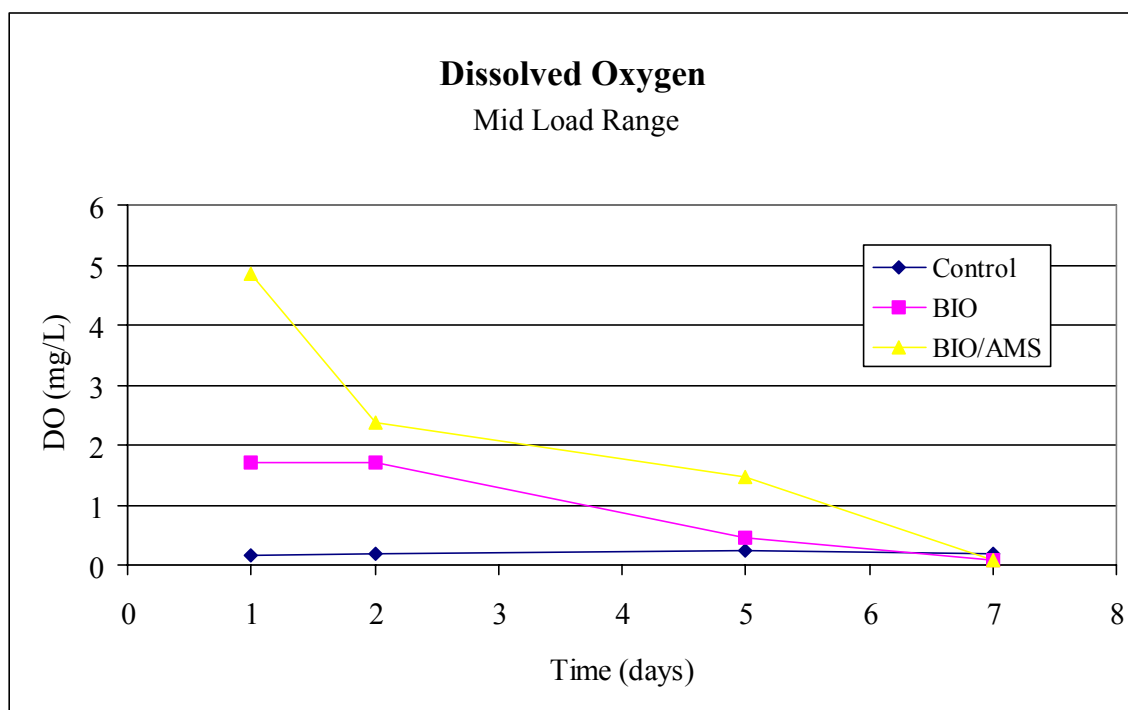
Figure 5.1.   DO of the BIO and BIO/AMS systems at the mid load-range

ORP

The ORP data for the mid load-range systems are presented in Figure 5.2. The BIO/AMS system maintained a higher ORP than either the control or BIO systems at the mid load-range. The ORP of the BIO/AMS system remained above +70 mV through day 5. However, by day 7, the ORP fell below –200 mV. The BIO and control systems, on the other hand, performed similarly with an ORP around –300 mV by day 2.
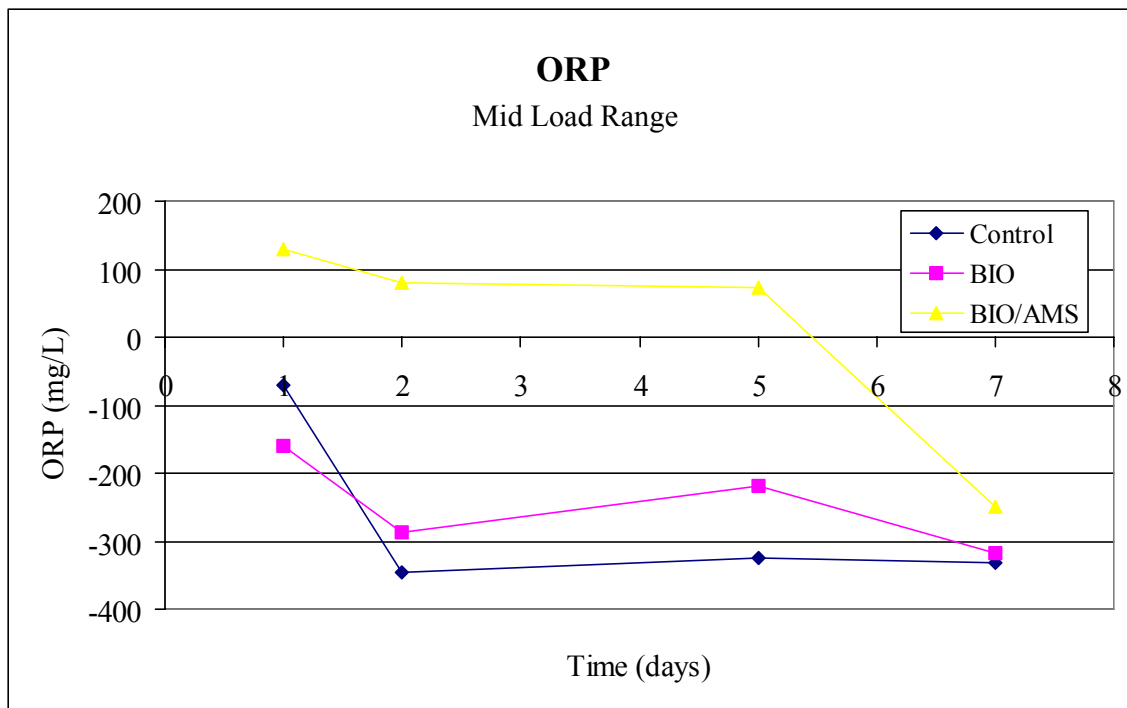
Figure 5.2. ORP of the BIO and BIO/AMS systems at the mid load-range

As stated previously, aerobes and facultative anaerobes require an ORP of at least 50 mV, while the optimum ORP of strict anaerobes is -200 mV (Baker and Herson, 1994). Therefore, the ORP data indicates that aerobic activity could exist in the BIO/AMS system until day 5, while the BIO and control systems were essentially anaerobic by day 2. The fact that the BIO/AMS system could sustain aerobic conditions for most of the testing period suggests that it might provide better odor reduction capabilities than the BIO system. The rate of aerobic degradation is usually higher than anaerobic degradation (Baker and Herson, 1994). Therefore, greater organic removal efficiency would be expected under aerobic conditions. Also, the formation of odorous compounds such as organic acids and phenols are hindered and actually removed under aerobic conditions (Chen et al., 1994). Therefore, sustaining aerobic conditions for

longer periods of time, the BIO/AMS system at the mid load-range does show higher potential as an odor control method for swine waste over the other systems.

<div align="center">Ammonia</div>

Ammonia concentrations versus time for the mid load-range BIO, BIO/AMS, and control systems are shown in Figure 5.3. The BIO system had the highest ammonia concentration of the various mid load-range systems throughout the testing period. There was little difference between the liquid phase ammonia concentrations for the BIO/AMS and control systems.

Ammonia - Liquid Phase
Mid Load Range
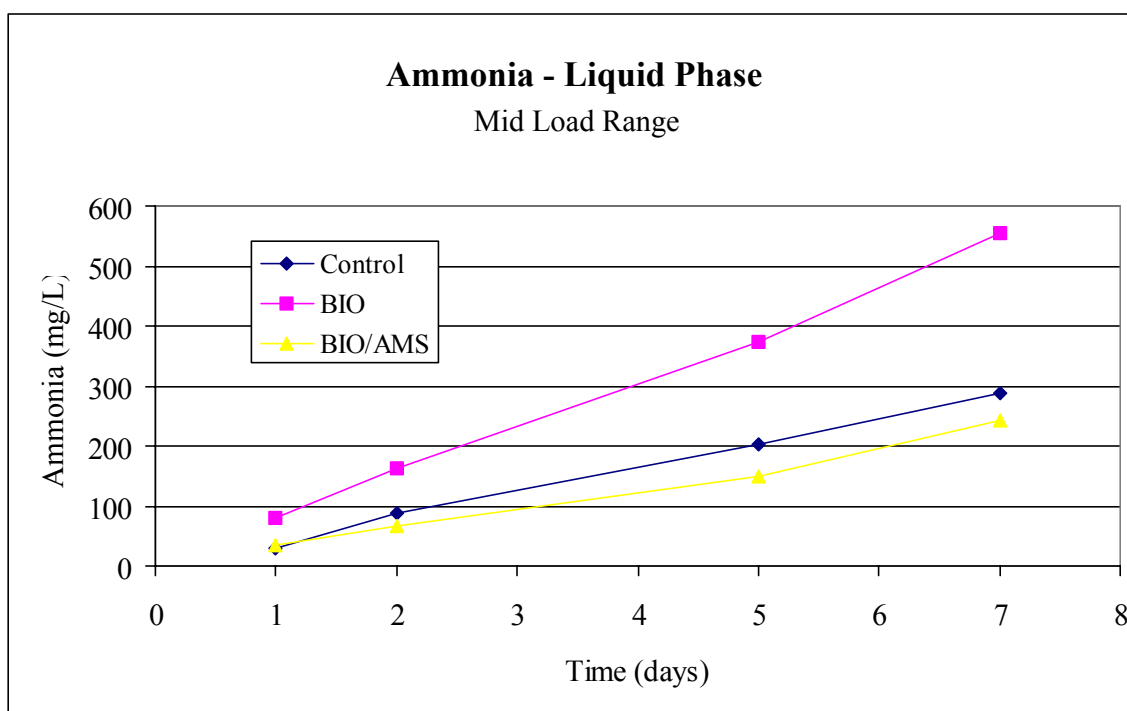
Figure 5.3.   Ammonia concentrations for the BIO and BIO/AMS systems at the mid load-range

Not only did the BIO/AMS system exhibit lower concentrations of ammonia in the liquid phase when compared to the BIO system, but also in the gas phase. Figure 5.4 depicts the ammonia levels in the air space above the collection pits for the mid load-

range systems. The gas phase ammonia concentrations generally tracked with the liquid phase concentrations. The BIO system had much higher concentrations, as compared to the BIO/AMS and control systems. There was little difference between the gas phase ammonia concentrations of the control and BIO/AMS systems. It must be noted that with most of the testing periods of the BIO system, the BIO/AMS systems were evaluated without proper ventilation of the barn. Therefore, as discussed previously, it is possible that lower concentrations of ammonia in the gas and liquid phase could be achieved with proper ventilation of the barn.

Ammonia - Gas Phase
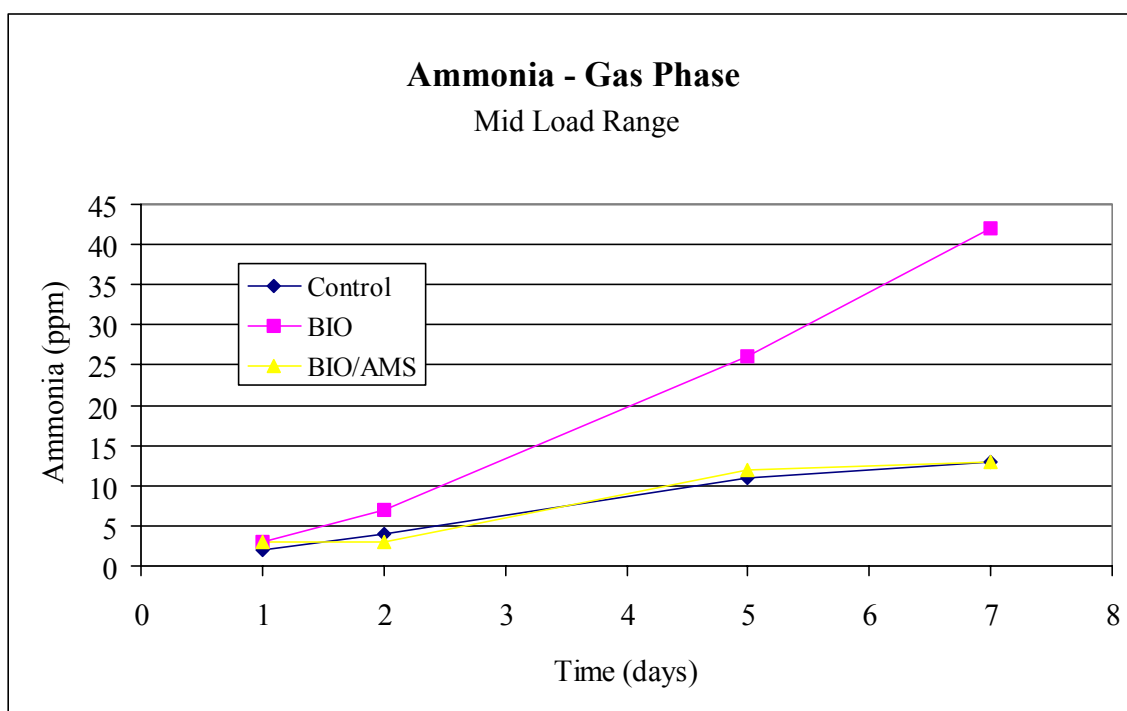
Mid Load Range

Figure 5.4. **Ammonia concentrations in the air above the pits for the BIO and BIO/AMS systems at the mid load-range**

The exact cause for the decreased ammonia concentrations of the BIO/AMS when compared to the BIO system is not known. However, several possible causes have been hypothesized. The DO levels were high enough (DO > 1 mg/L) to facilitate nitrification

if nitrifying bacteria were present within the system (Metcalf and Eddy, 1991). The addition of the microbial seed might also have increased the amount of ammonia utilized for microbial growth and maintenance. Since ammonia is also removed through volatilization, the air diffusing through the wastewater in the BIO/AMS system might increase volatilization as compared to the BIO system. Perhaps some or all of these hypotheses contributed to the lower ammonia concentrations of the BIO/AMS system compared to the BIO system.

Although the exact cause is unclear, the BIO/AMS system lowered both the gas and liquid phase ammonia concentrations as compared to the BIO system at the mid load-range. These results are promising as ammonia is not only responsible for unpleasant odors, but can also affect the comfort, health, and production efficiency of animals and caretakers (Muehling, 1970; Zhang and Day, 1996).

<div align="center">Orthophosphate</div>

Figure 5.5 presents the orthophosphate concentrations for the mid load-range BIO, BIO/AMS, and control systems. The BIO/AMS system had lower endpoint concentrations of orthophosphate as compared to the BIO and control systems. There was little difference between the orthophosphate concentrations for any of the treatments on days 1, 2, and 5. Perhaps the sharp increase of the control system from day 5 to 7 may be attributed to the relatively high concentrations of volatile acids (Figure 5.5). Certain microbes release stored phosphorus in the presence of high concentrations of volatile acids (Metcalf and Eddy, 1991). The lower concentrations of the BIO/AMS system compared to the BIO system might be attributed to increased microbial activity. Microbes require phosphorus for cell synthesis and energy transport (Metcalf and Eddy,

1991). Therefore, some orthophosphate would be removed as microbial populations

increase. It is assumed that the microbial activity was increased within the BIO/AMS

system as compared to the BIO and control systems by both the addition of the microbial

seed and by the higher concentration of DO in the wastewater (through day 5). Increased

microbial activity of the bioreactor systems was evident through the visual observations

of the microbial slime buildup within the bioreactor.
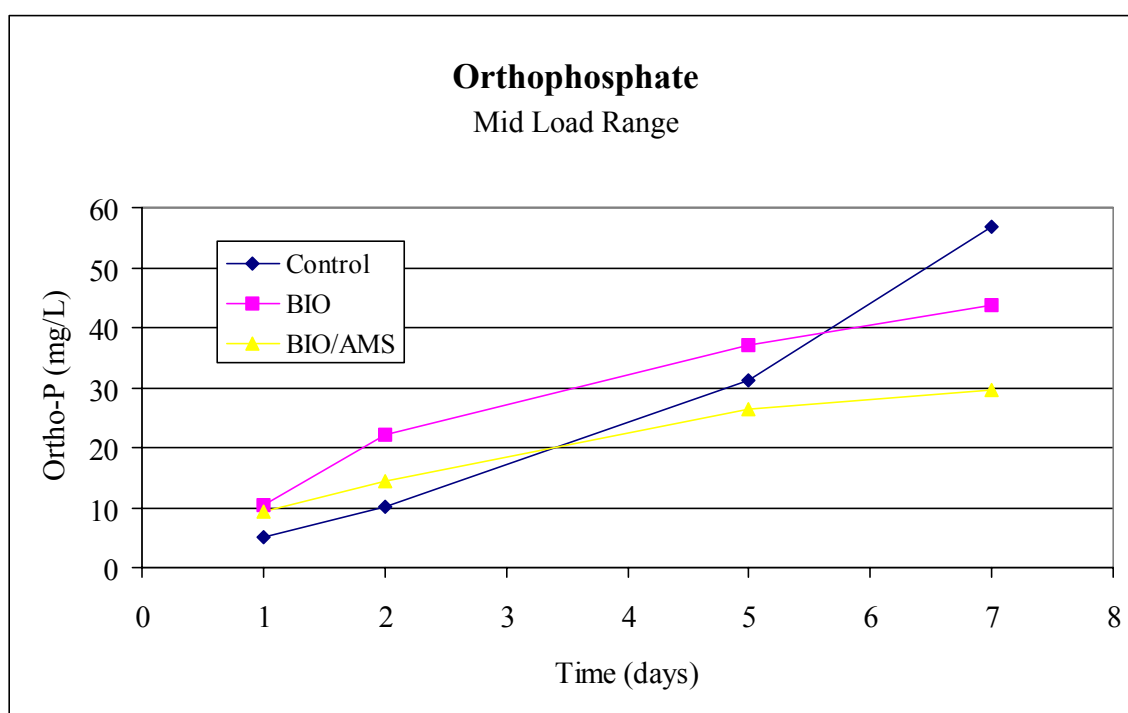
Figure 5.5.   Orthophosphate concentrations of the BIO and BIO/AMS systems at the mid load-range

COD

COD concentrations for the mid load-range BIO, BIO/AMS, and control systems

are presented in Figure 5.6. The BIO and BIO/AMS systems had lower COD

concentrations than the control system at the mid load-range. In fact, the endpoint

concentrations of the BIO and BIO/AMS systems were about 45% lower than the control system. There was little difference between the concentrations of the BIO and BIO/AMS systems, especially on days 5 and 7. Since microbes convert colloidal and dissolved organic matter into gases and cell mass, it is believed that the lower COD concentrations of the BIO and BIO/AMS systems may be attributed to increased microbial activity as discussed previously. The slightly lower concentrations of the BIO/AMS system compared to the BIO system may be attributed to the addition of the microbial seed and/or the increased DO concentrations at day 1 through 5 of testing.
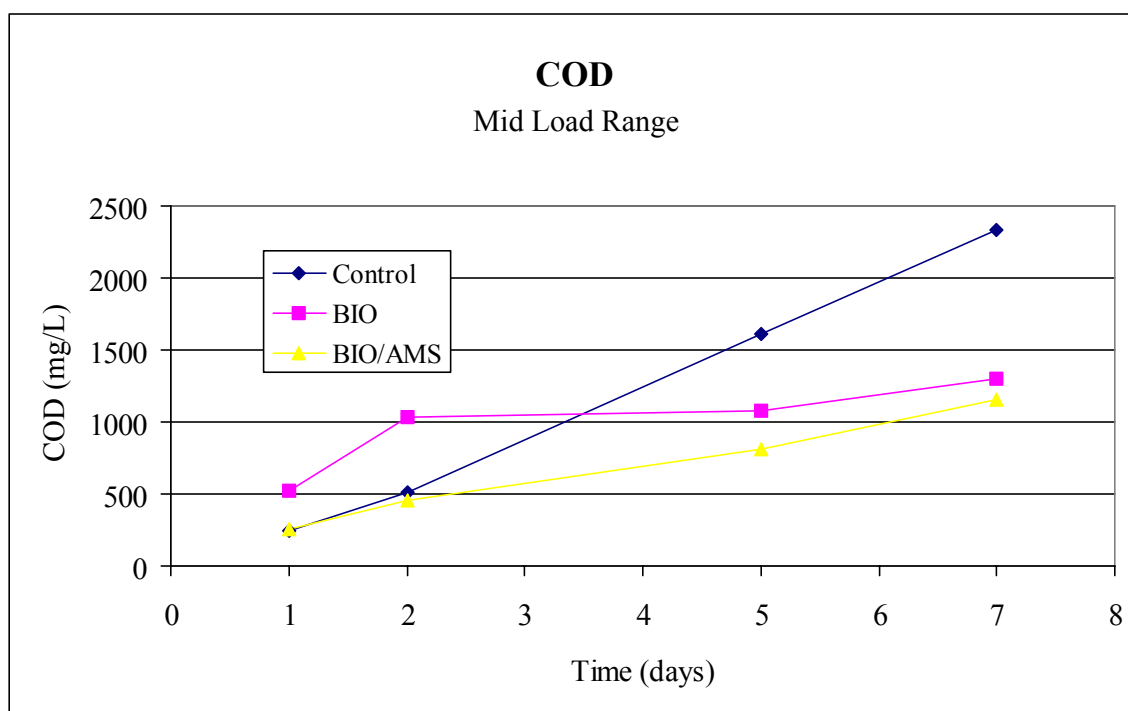
Figure 5.6. **COD concentrations of the BIO and BIO/AMS systems at the mid load-range**

Total Solids

The total solids concentrations versus time for the mid load-range BIO/AMS and BIO systems are shown in Figure 5.7. There was little difference between the total solids concentrations of any system at the mid load-range. The total solids concentrations

increased as the loads increased during the testing periods. The total solids data does not indicate that the BIO/AMS system provides any improvement in total solids reduction as compared to the BIO system or control.
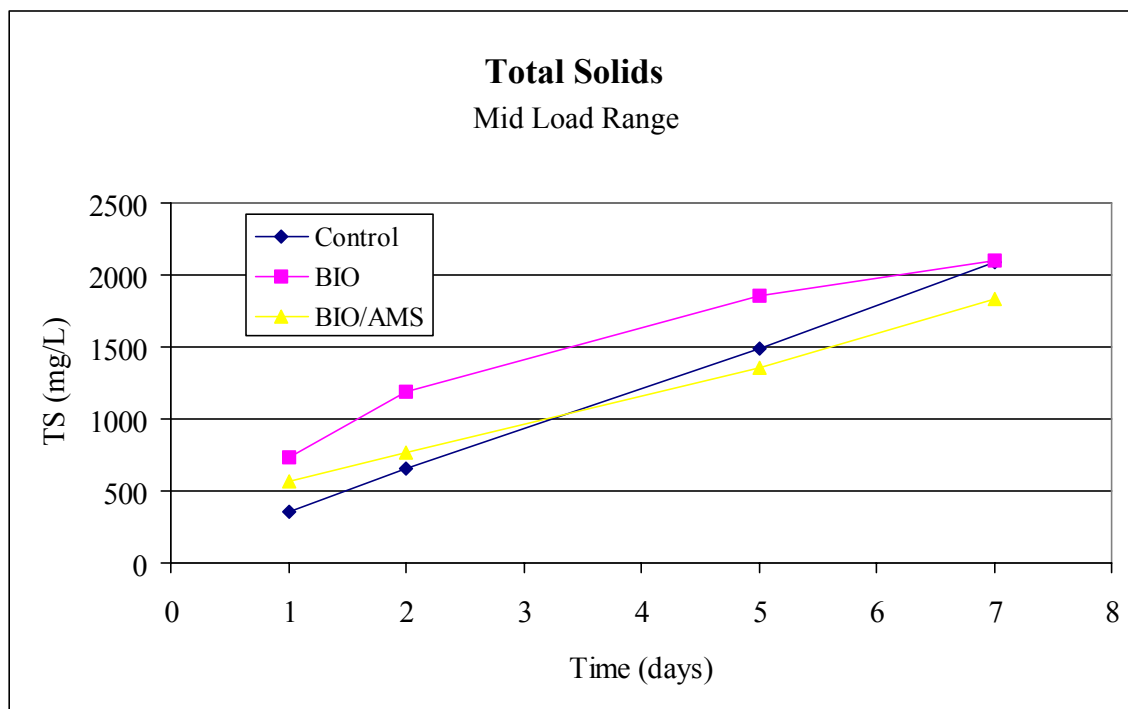
Figure 5.7. **Total solids concentration of the BIO and BIO/AMS systems at the mid load-range**

Volatile Acids and Phenols

Figures 5.8 and 5.9 present the volatile acids and phenols concentrations for the mid load-range systems, respectively. Both bioreactor systems (BIO and BIO/AMS) had lower volatile acids and phenols concentrations compared to the control system. However, the BIO/AMS system lowered the phenol and volatile acid concentration by 61% and 95%, respectively, compared to the BIO system. The greater removal efficiency of the BIO/AMS system is likely attributed to the higher DO concentrations and ORP of the wastewater through day 5. Aerobic conditions hinder the formation of both phenols

and volatile acids, as well as allow for the aerobic degradation of such compounds present in the wastewater. This is significant because both phenols and volatile acids have been linked with odor production in swine waste (Ishaque et al., 1985; Evans et al., 1986). By lowering the volatile acids and phenols concentration by 98% and 84%, respectively, as compared to the control system, the BIO/AMS may have the potential to reduce the odor associated with swine waste.
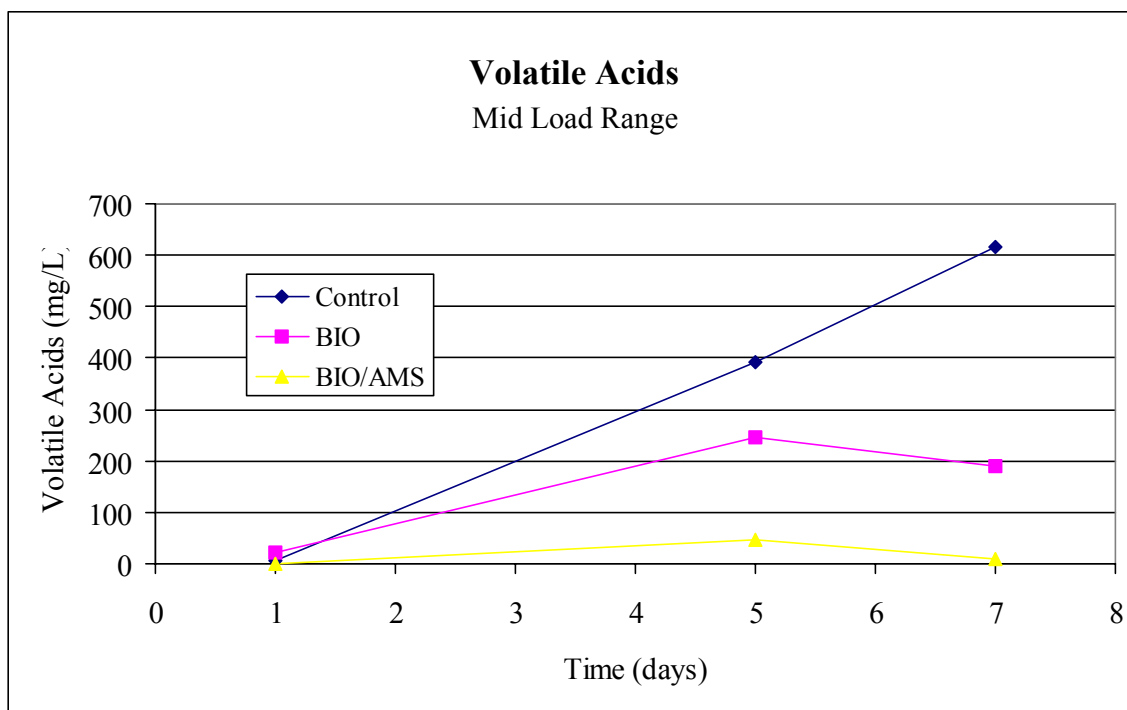
Figure 5.8.   Volatile acids concentration of the BIO and BIO/AMS systems at the mid load-range
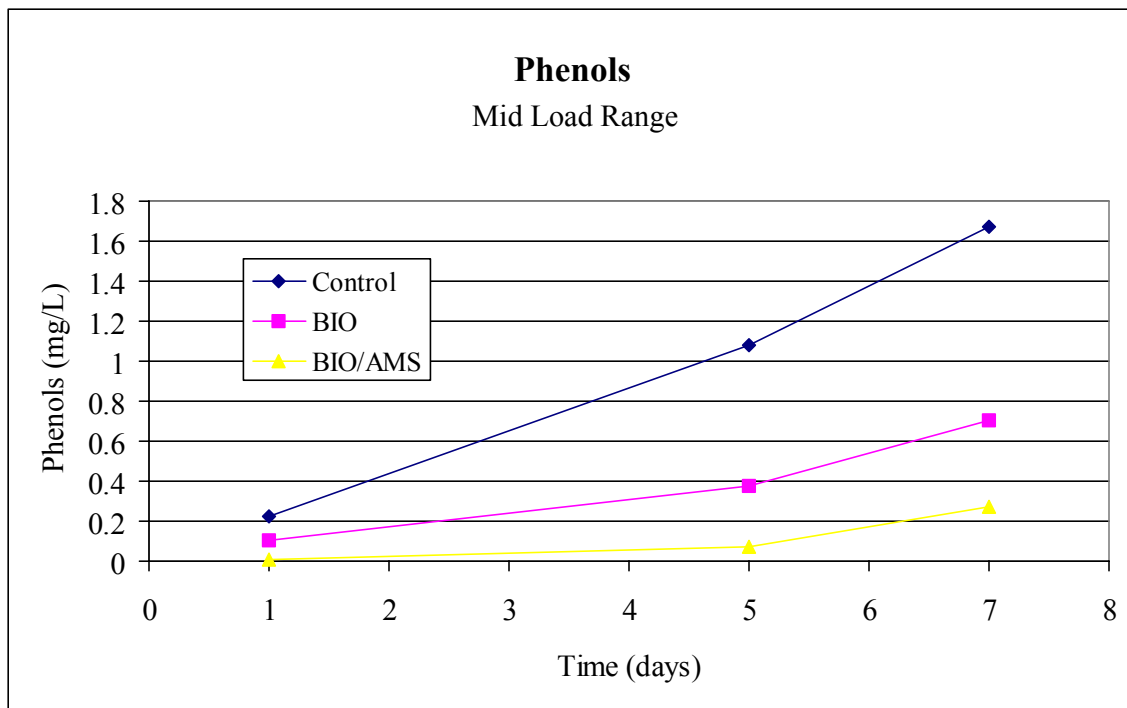
Figure 5.9. **Phenols concentration of the BIO and BIO/AMS systems at the mid load-range**

pH and Conductivity

The pH and conductivity data for the BIO, BIO/AMS, and control systems at the mid load-range are shown in Figures 5.10 and 5.11, respectively. The bioreactor systems (BIO and BIO/AMS) had higher and more stable pH during the testing periods as compared to the control system. The pH of the control system decreased with time from 8 at day 1 to 6.8 at day 7. The decrease in the control system is most likely attributed to the relatively high concentrations of volatile acids as compared to the bioreactor systems (see Figure 5.8).
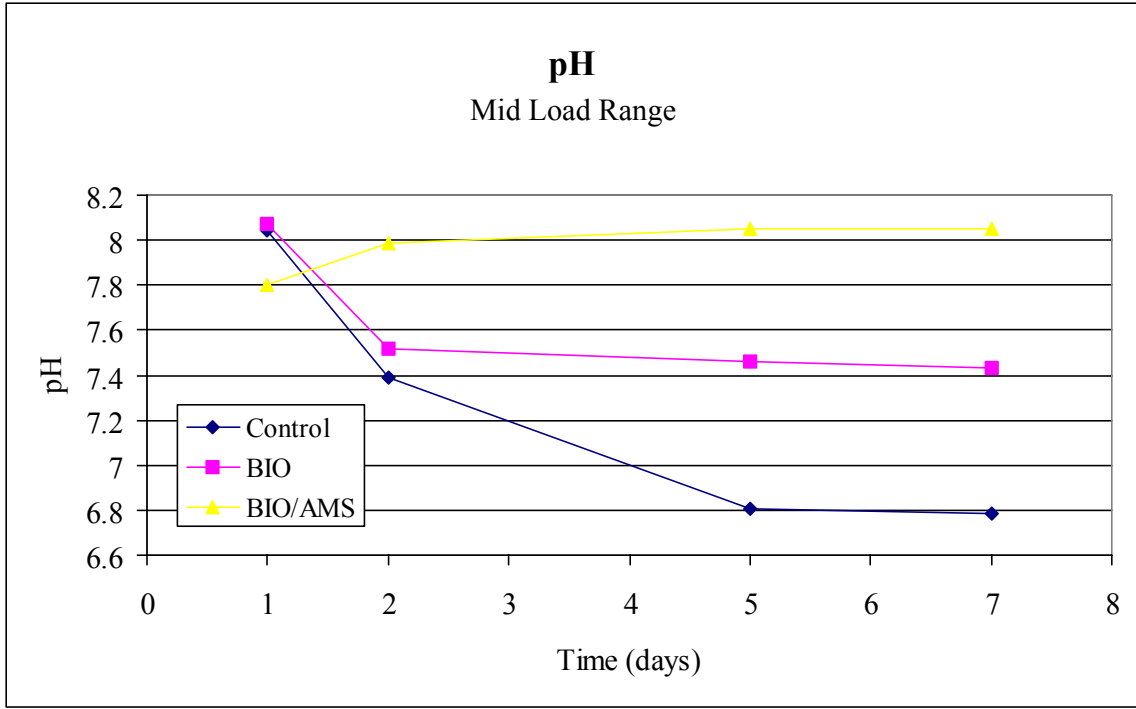
Figure 5.10. pH of the BIO and BIO/AMS systems at the mid load-range
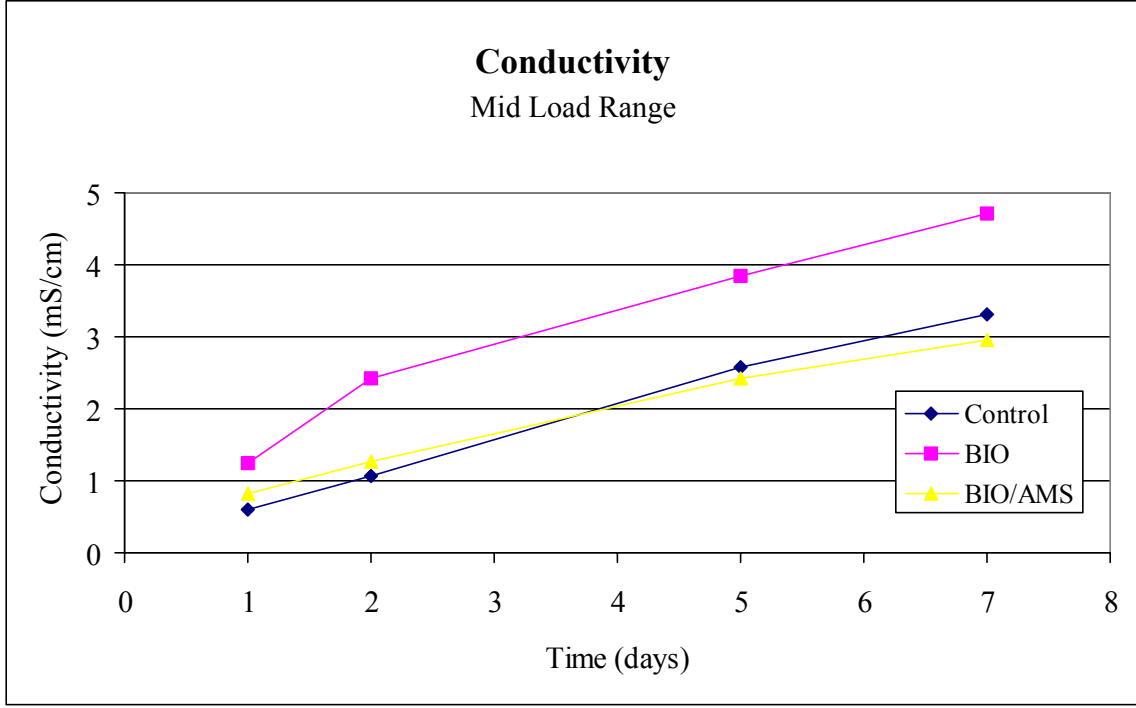
Figure 5.11. Conductivity of the BIO and BIO/AMS systems at the mid load-range

The BIO system had the highest conductivity of the mid load-range systems. The control and BIO/AMS system had very similar conductivities. This data tracks with the ammonia concentration of the wastewater (see Figure 5.3). These results further support that conductivity is related to the ammonia concentration as discussed previously in Chapter IV.

Hydrogen Sulfide Measurements

Hydrogen sulfide concentrations in the air above the pits were also monitored. At no time during the evaluations of the mid load-range BIO and BIO/AMS systems was hydrogen sulfide detected. Hydrogen sulfide was detected on two occasions during the mid load-range control system. However, it should be noted that the hydrogen sulfide concentrations were relatively low (1 and 2 ppm) and it is doubtful that it would be detectable in the air space occupied by pigs or humans.

Odor Evaluation

Odor evaluations were completed for the BIO and BIO/AMS mid load-range systems. Mean odor responses and statistical inferences for the mid load-range BIO and BIO/AMS systems on day 5 and day 7 are listed in Tables 5.4 and 5.5, respectively. The odor panel was not available to evaluate the mid load-range control systems.

Table 5.4. Day 5 Mean Odor Responses and Statistical Inferences (Mid Load-Range)

System	Pleasantness	Intensity	Acrid	Sulfur	Earthy	Musty	Fecal	Cheesy	Sweet	NH3
BIO	5.5	3.1	0.5	0.5	0.4	0.6	1.2	0.9	0.2	0.2
BIO/AMS	4.8	2.8	0.3	0.4	1.0	0.7	0.5	0.4	0.3	0.1
BIO	a	a	a	a	b	a	a	a	a	a
BIO/AMS	b	a	a	a	a	a	b	a	a	a

Table 5.5. Day 7 Mean Odor Responses and Statistical Inferences (Mid Load-Range)

System	Pleasantness	Intensity	Acrid	Sulfur	Earthy	Musty	Fecal	Cheesy	Sweet	NH3
BIO	5.3	2.8	0.2	0.2	0.7	0.4	1.0	0.4	0.0	0.3
BIO/AMS	5.0	2.2	0.2	0.2	0.5	0.6	1.0	0.5	0.1	0.1
BIO	a	a	a	a	a	a	a	a	a	a
BIO/AMS	a	b	a	a	a	a	a	a	a	b

Overall, there was little difference between the BIO and the BIO/AMS system for the mid load-range regarding odor control. At day 5, the BIO/AMS was rated lower and found to be significantly different from the BIO system with regard to pleasantness and the fecal characteristic of the wastewater odor. It was also rated higher and significantly different on the earthy characteristic. No other significant differences were found between the samples. By day 7, both systems received the same fecal rating, but the BIO/AMS was rated lower and found to be significantly different from the BIO with regard to overall intensity and the ammonia characteristic. It should be noted that there was only a 0.2 difference on the ammonia rating and they were both very low on the

rating scale (0-8). There were no other significant differences found between the two systems.

While, the BIO/AMS system did increase the pleasantness of the wastewater and reduce the overall odor intensity, there were not any significant differences in the acridity, sulfurous, fecal, or cheesy characteristics. Therefore, the added cost of aerating pits at the mid load-range may not be warranted for achieving an acceptable level of odor control.

<center>High Load-Range</center>

Water Quality Results

Tables F.18 – F.22 and F.28 – F.31 in Appendix F lists all the raw water quality data from the BIO high load-range systems. Tables F.34 and F.35 in Appendix F lists the raw water quality data from the BIO/AMS high load-range systems. The raw data for the ABIO and ABIO/AMS high load-range systems are listed in Tables F.37 and F.38, respectively. The averaged water quality data for the systems are listed in Tables G.5 and G.6 in Appendix G and presented graphically in Figures 5.12 – 5.22. A discussion of the high load-range systems is presented below.

<center>Dissolved Oxygen</center>

Figure 5.12 presents the dissolved oxygen concentration versus time for the enhanced bioreactor systems at the high load-range. Problems with the dissolved oxygen meter itself prevented measurements to be taken during the evaluation of the ABIO system. The ABIO/AMS system had the highest DO concentration (3.3 mg/L) at day 1, but was devoid of oxygen (DO < 0.5 mg/L) by day 2. The BIO system was aerobic

through day 2. The BIO/AMS and control systems had the lowest dissolved oxygen

concentration of all the systems and were assumed to be anaerobic throughout the entire

testing period.
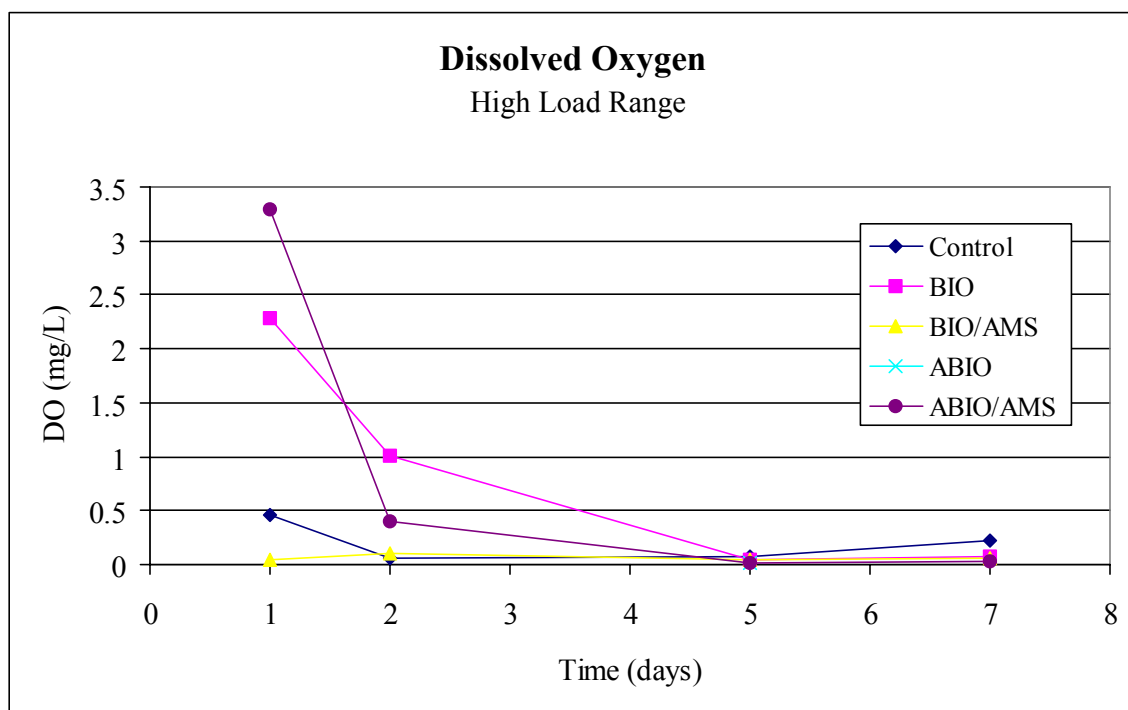
Figure 5.12. DO of the high load-range systems

The low DO concentration of the BIO/AMS system at day 1 was surprising, since

oxygen was being supplied to the collection pit through diffused aeration. Also, higher

DO concentrations were achieved by the BIO/AMS system during the mid load-range

experiments. Clearly, the oxygen demand at the high load-range exceeded the oxygen

input capacity of the aeration system.

The ABIO/AMS system had the highest DO concentration at day 1, which was

expected as both the collection pits and bioreactor vessel were aerated. However, by day

2, the ABIO/AMS system could be considered anaerobic. The BIO system was able to maintain aerobic conditions longer than the BIO/AMS or ABIO/AMS systems. Therefore, unless the efficiency and/or oxygen capacity of the aeration system is increased, it is doubtful that aerating the collection pits will enhance the performance of the attached growth bioreactor system at the high load-range.

<div align="center">ORP</div>

Figure 5.13 represents the ORP data for the high load-range systems. As expected, the control system had the lowest ORP throughout most of the testing period. All the bioreactor systems were able to maintain an ORP of above –200mV through day 2. However, by day 5, all the bioreactor systems had ORPs less than –200 mV. There was not much difference between the ORP of the BIO/AMS and control systems from day 5 to 7. The ORP data suggests that from day 1 to day 2, the wastewater in the pits could sustain some aerobic activity; however, by day 5, the wastewater was highly anaerobic, especially that of the BIO/AMS system.
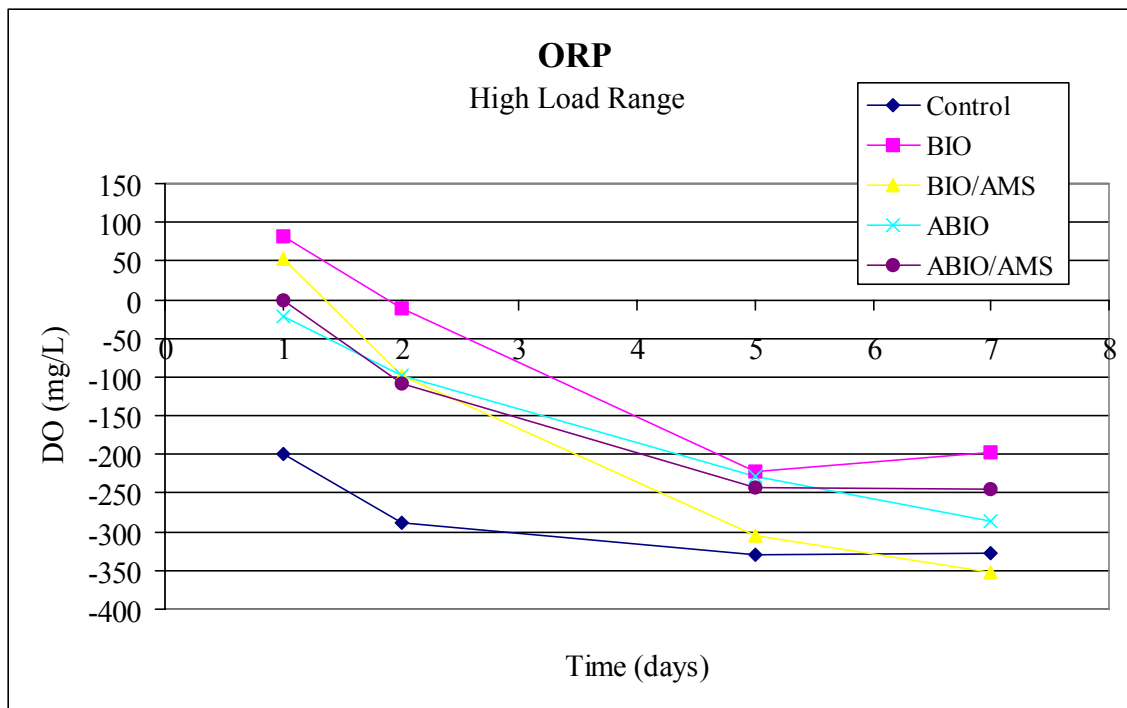
Figure 5.13. ORP of the high load-range systems

Ammonia

Ammonia concentrations versus time for the high load-range systems are shown in Figure 5.14. The BIO, ABIO, and ABIO/AMS systems all had concentrations similar to the control system. The BIO/AMS system, however, had the highest ammonia concentrations of all the systems. It should be noted that the during the two testing periods of the high load-range BIO/AMS systems, the ventilation fans were not on and the vents were closed within the barn. Therefore, poor ventilation, as discussed previously in Chapter IV, may be one reason for the higher ammonia concentration. All other systems at the high load-range were evaluated with the barn ventilated.

Ammonia
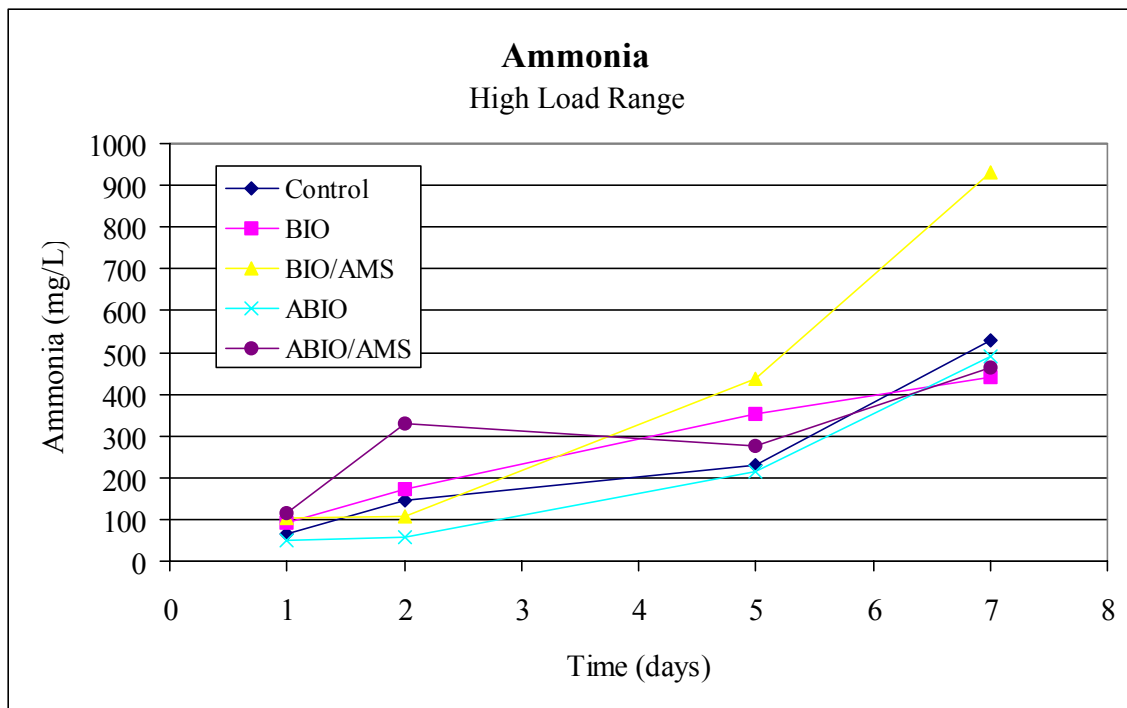
High Load Range

Figure 5.14. Ammonia concentrations of the high load-range systems

The data does not indicate that pit or bioreactor aeration enhances ammonia removal over the BIO system or the control. Biological ammonia removal is achieved through nitrification, which requires a DO concentration of at least 1 mg/L (Metcalf and Eddy, 1991). Therefore, unless an aeration system is able to maintain DO levels above 1 mg/L, it is doubtful that the ammonia levels can be reduced with the attached growth bioreactor system as it is configured in the pilot-scale implementation.

Gas phase ammonia concentrations in the headspace above the pits were also monitored during the evaluation of the high load-range systems. The data is shown in Figure 5.15. The BIO and ABIO system exhibited relatively low endpoint concentrations of ammonia (gas phase) compared to the control, BIO/AMS, and ABIO/AMS systems.

The two systems with pit aeration (BIO/AMS and ABIO/AMS) had the highest pit headspace ammonia concentrations.

The higher concentrations of gas phase ammonia for the BIO/AMS and ABIO/AMS systems are most likely due to increased ammonia volatilization caused by the aeration of the pits. The 50 and 40 ppm for the BIO/AMS and ABIO/AMS systems, respectively, are above the threshold limit values for both humans (30 ppm) and animals (10 ppm) (Mackie et al., 1998).

The higher concentrations of gas phase ammonia for the BIO/AMS and the ABIO/AMS systems are most likely due to increased ammonia volatilization caused by the aeration of the pits. A laboratory study by Zhang and Day (1996) found that continuous low rate aeration rates resulted in high ammonia emission rates. Therefore, it was concluded that continuous aeration was not recommended for use in underfloor pits due to the concern of decreased air quality, unless proper ventilation is provided to remove the gases from the headspaces of the pit.
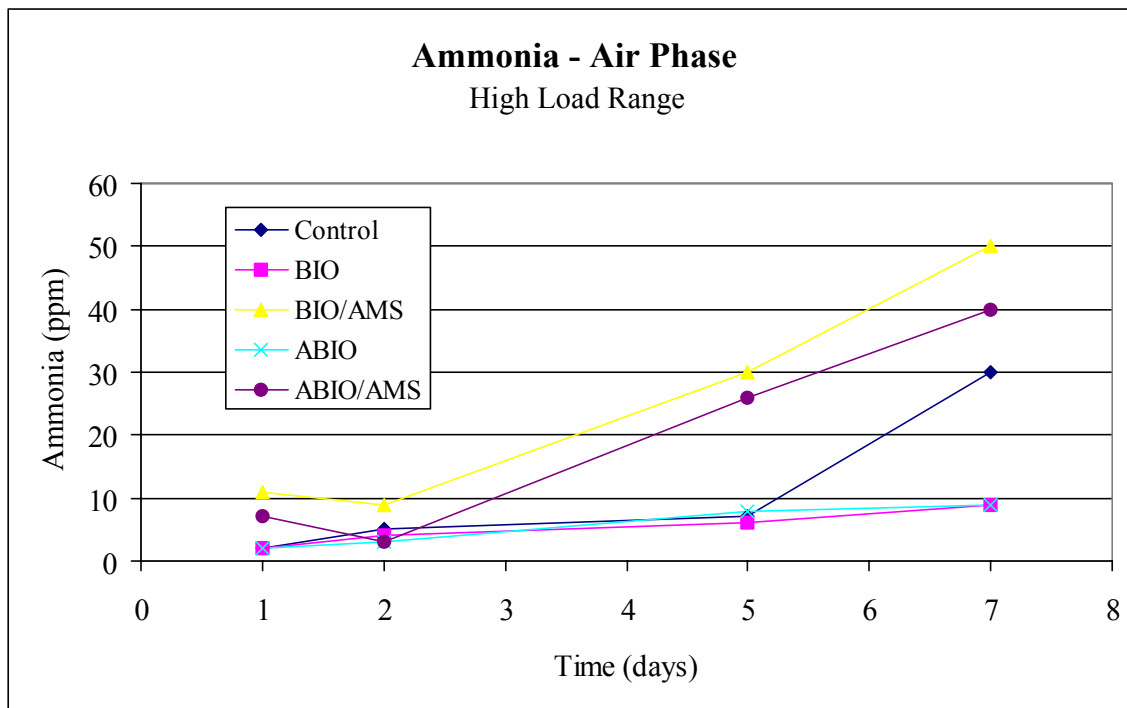
Figure 5.15. **Ammonia (gas phase) concentrations for the high load-range systems**

Total Solids

The total solids concentrations versus time for the high load-range systems are shown in Figure 5.16. There was little difference in the concentrations for the high load-range systems. Once again, none of the bioreactor systems showed any improvements over the control for solids removal. The slightly higher total solids concentration of the BIO/AMS and ABIO/AMS, while not significant, may be a result from the mixing of the wastewater generated by the pit aeration.
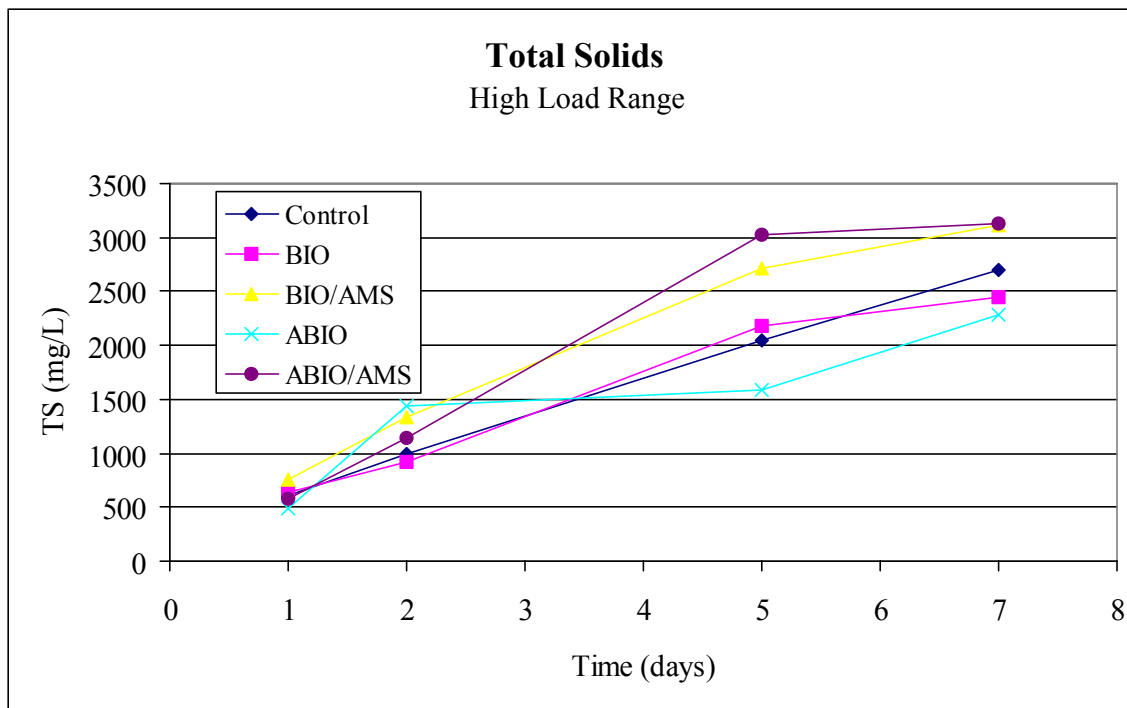
Figure 5.16. **Total solids concentrations of the high load-range systems**

Volatile Acids

The volatile acids concentrations versus time for the high load-range systems are in Figure 5.17. The BIO, ABIO, and ABIO/AMS systems were effective in lowering the volatile acids concentrations as compared to both the BIO/AMS and control systems. However, the two systems with an aerated bioreactor had the lowest volatile acid concentrations. There was little difference between the concentrations of the BIO/AMS and control systems at days 5 and 7.

The relatively high volatile acids concentration of the BIO/AMS system suggests that the bioreactor vessel was operating under anaerobic conditions within portions of the bioreactor volume. This is further supported by the ORP data, as the ORP of the

BIO/AMS system at days 5 and 7 was below –300 mV. However, the low volatile acids concentrations of the ABIO and ABIO/AMS systems suggest that the bioreactor was capable of supporting more aerobic microbial activity and less anaerobic activity. As discussed previously, volatile acids are not readily degraded under anaerobic conditions, but can be under aerobic conditions (Jolicoeur and Morin, 1987). Therefore, the aeration of the bioreactor does show some promise in enhancing the performance of the BIO system.
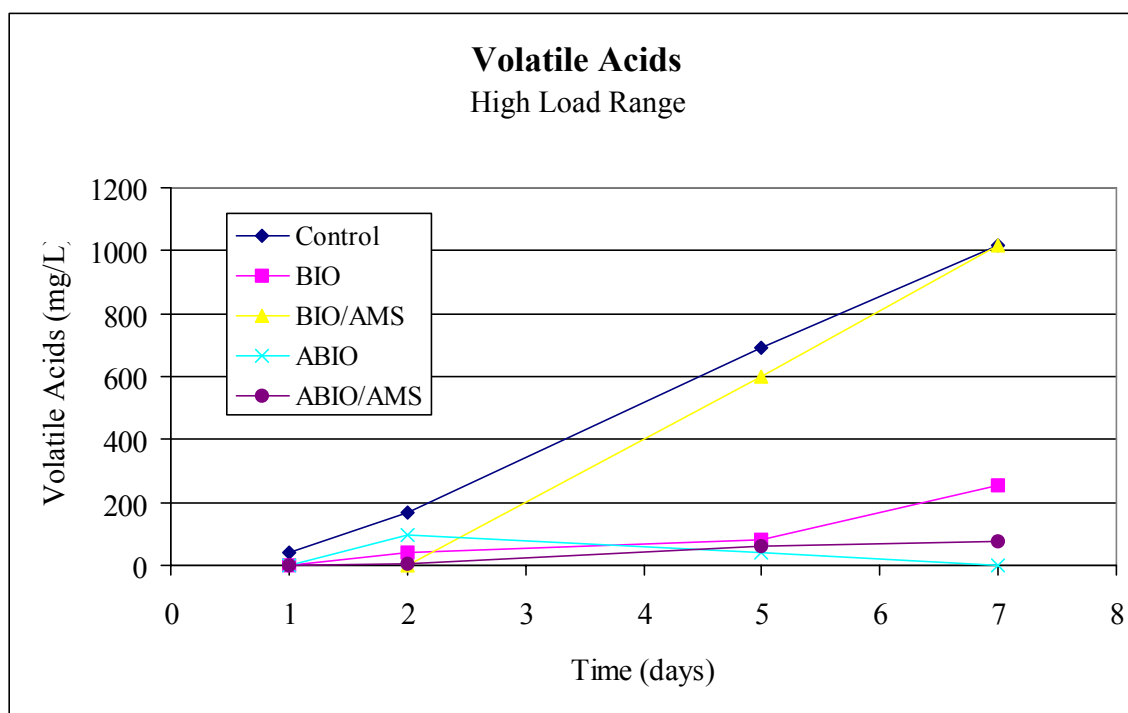
Figure 5.17. Volatile acids concentration of the high load-range systems

COD

Figure 5.18 represents the COD concentrations for the high load-range systems. The BIO and ABIO/AMS maintained lower COD concentrations (< 2,000 mg/L) throughout the week compared to the other systems. The BIO/AMS system had

relatively high COD concentrations, similar to the control. The ABIO system had lower

concentrations (< 1,000 mg/L) through day 5, but by day 7 the COD concentration was

over 2,500 mg/L.
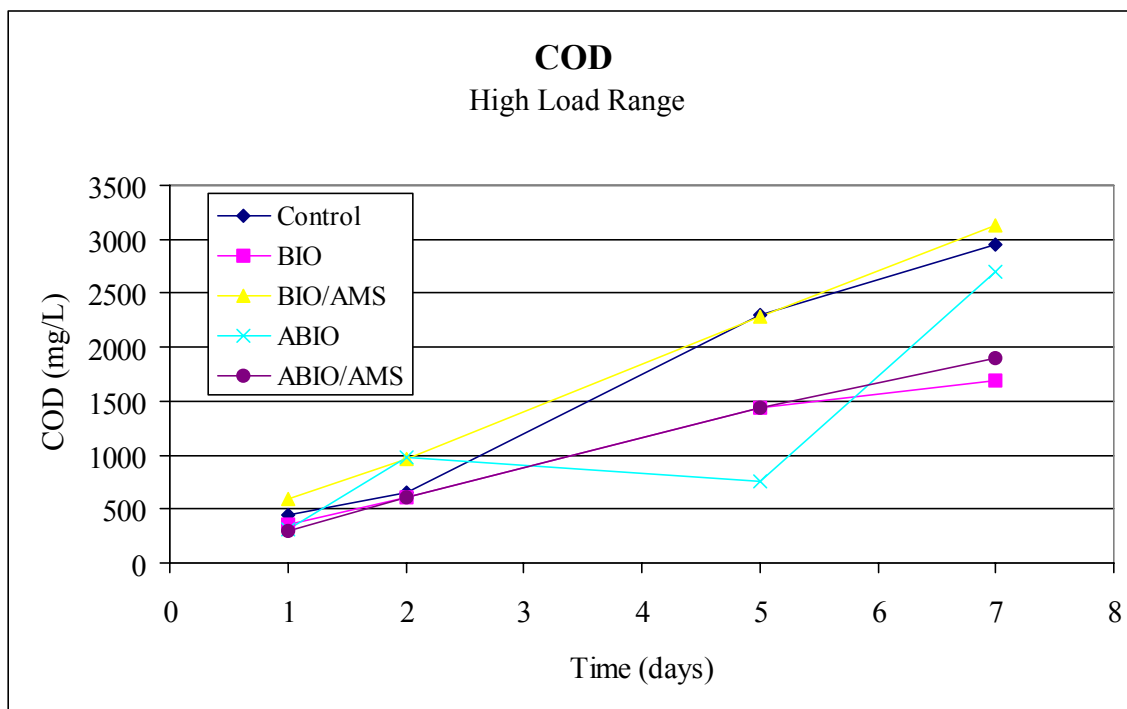
Figure 5.18.   COD concentrations of the high load-range systems

With the exception of the ABIO system, the COD concentrations generally

tracked with the volatile acids concentrations (see Figure 5.17). This was not surprising

since past research has found that organic acids are principal components of and correlate

highly with COD (Williams, 1983). Therefore, the high COD concentrations associated

with the BIO/AMS system are possibly attributed to the high volatile acid concentration.

The low volatile acids concentration of the ABIO system at day 7 would also suggest a

lower COD concentration. Since the ABIO system was only evaluated during one testing

period, laboratory error could be suspect. More testing is necessary before any

conclusion about the ABIO system can be made with regard to COD.

Phenols

Figure 5.19 represents the phenol concentrations versus time for the systems at

the high load-range. The phenol concentrations of all the bioreactor systems were much

lower than that of the control. Even so, the systems involving aeration (BIO/AMS,

ABIO, and ABIO/AMS) had lower concentrations than the BIO system.
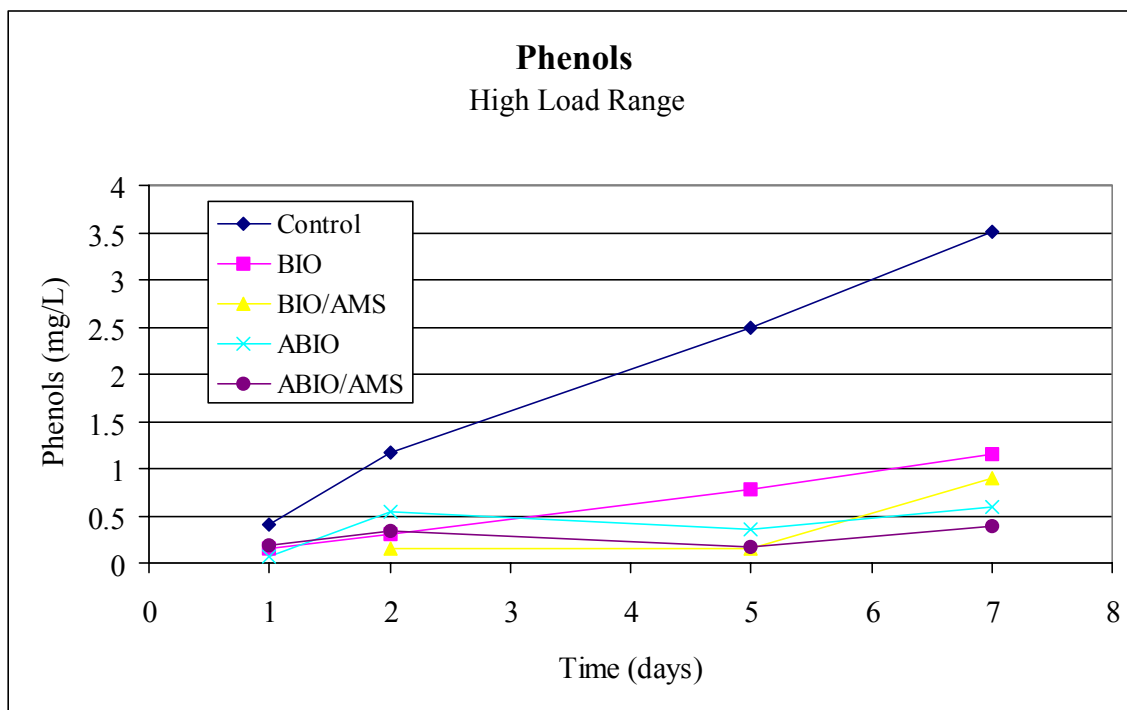
Figure 5.19.   Phenols concentrations of the high load-range systems

The low phenol concentration of the BIO/AMS system was not expected at days 5

and 7. The low DO concentration and ORP of the wastewater, along with the high

volatile acids and COD concentrations on days 5 and 7, would indicate anaerobic activity

within the system. This would suggest higher levels of phenols would be expected for the BIO/AMS system since phenols are not degraded but formed under anaerobic conditions. Perhaps the formation of phenols was hindered until day 5, which would explain the sharp rise in phenols from day 5 to 7.

<div align="center">Orthophosphate</div>

The orthophosphate data are shown in Figure 5.20 for the high load-range systems. The BIO and ABIO systems performed similar, as did the BIO/AMS and the ABIO/AMS systems. The lower concentrations of the BIO/AMS and ABIO/AMS system may be attributed to the addition of the microbial seed (activated sludge) in the collection pit. By introducing another microbial population, it is possible that more phosphorus was being utilized for cell synthesis in the BIO/AMS and the ABIO/AMS systems as compared to the other systems. However, it is clear that the bioreactor systems lower the orthophosphate concentrations as compared to the control.
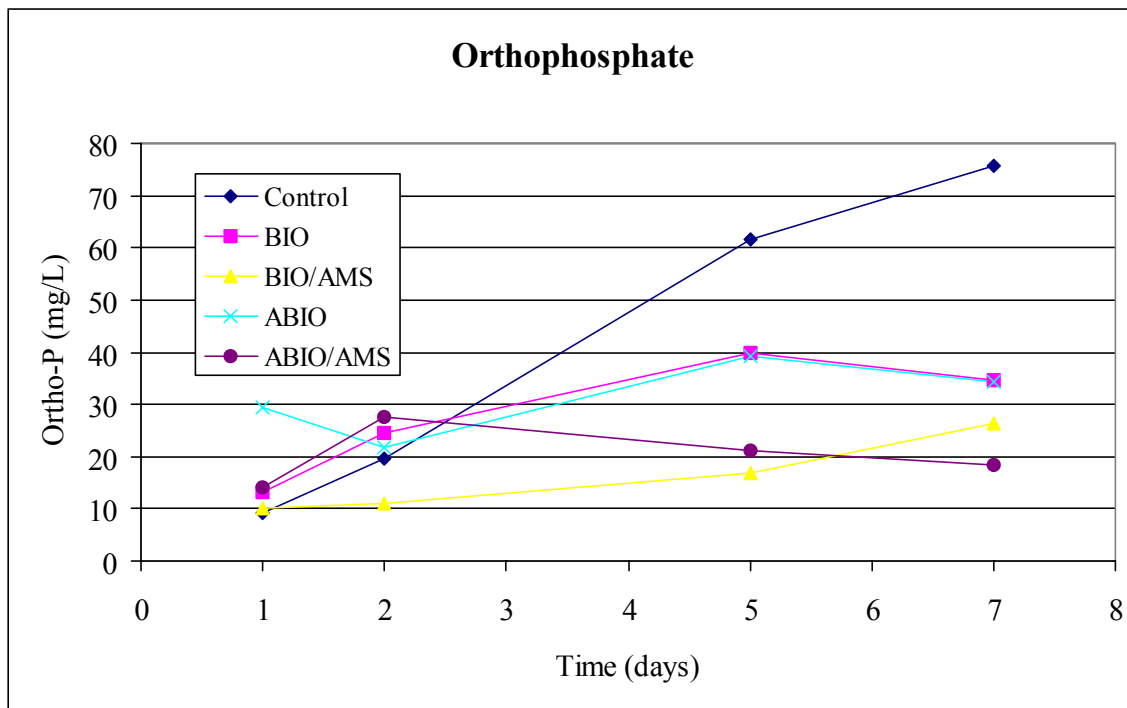
Figure 5.20. Orthophosphate concentrations of the high load-range systems

pH and Conductivity

The pH and conductivity of the high load-range systems are shown in Figure 5.21 and 5.22, respectively. The BIO, ABIO, and ABIO/AMS systems maintained pH levels around 8 throughout the testing period. However, the BIO/AMS system had a slightly lower pH, which decreased from day 5 to 7. This decrease may be attributed to the increase in the volatile acids concentration (see Figure 5.17). The pH of the control system also decreased over the testing period. This trend may be attributed to the increasing volatile acid concentrations of the control systems. The conductivity of all the systems increased with the increase in load as the testing period progressed. The data does not indicate that any system had a significant effect on the conductivity of the pit wastewater.
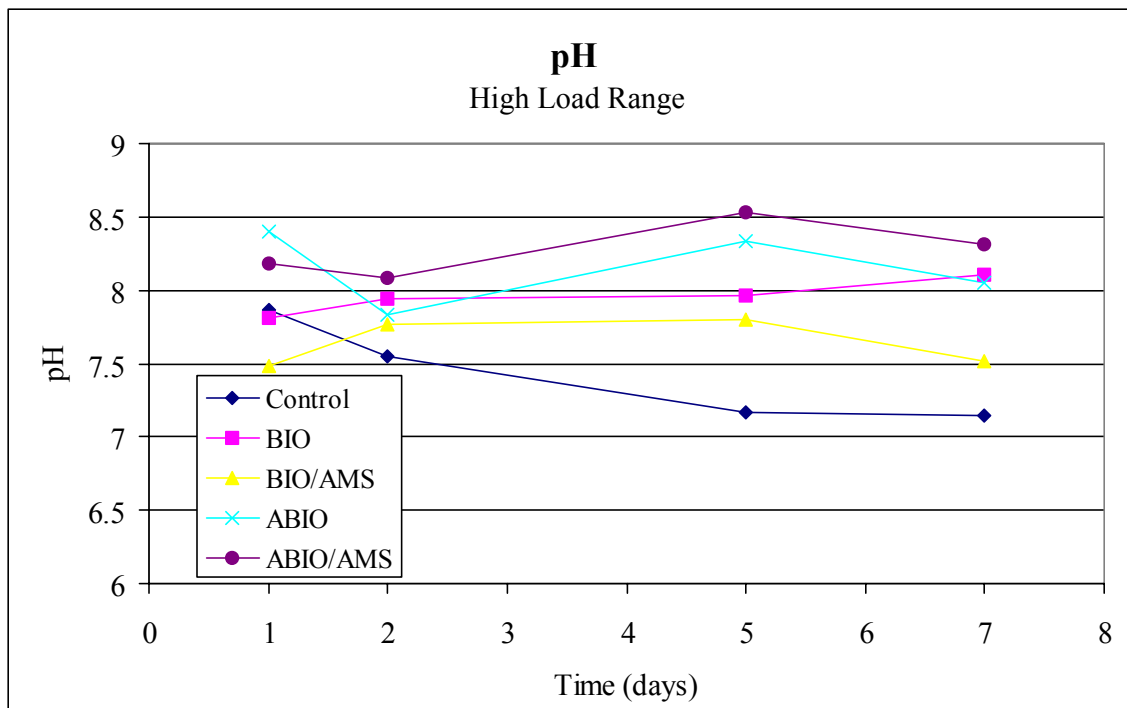
Figure 5.21. pH of the high load-range systems
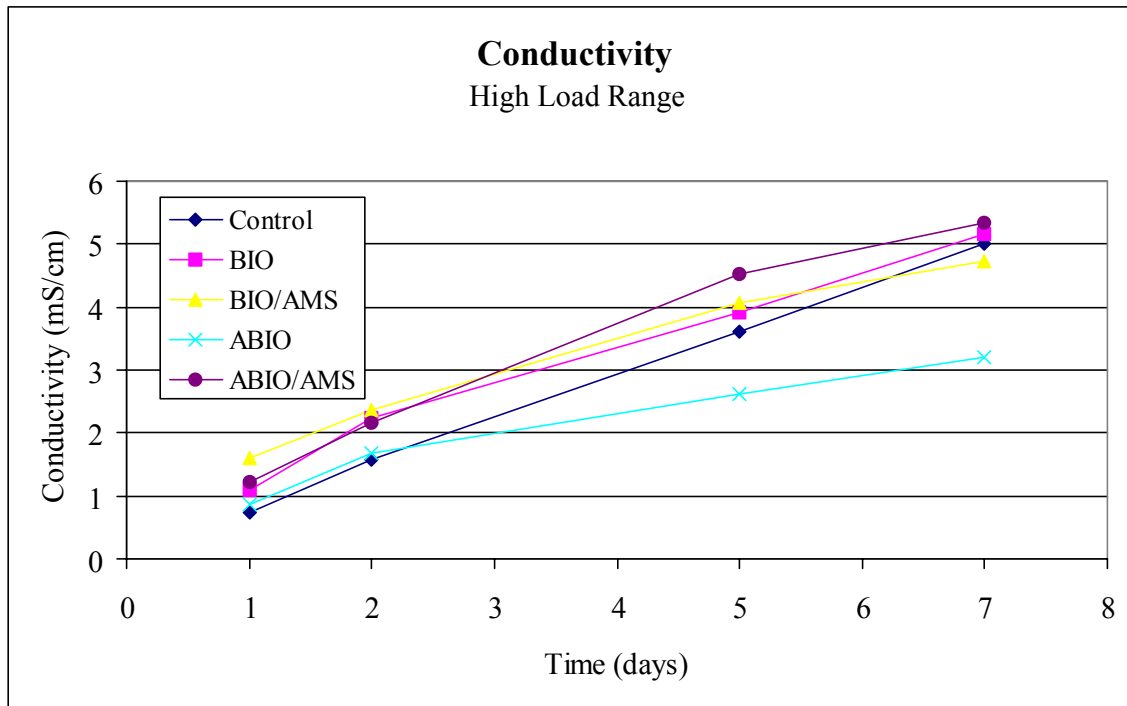
Figure 5.22. Conductivity of the high load-range systems

Hydrogen Sulfide Measurements

The ABIO, ABIO/AMS systems did not have any detectable hydrogen sulfide concentrations at any time during the testing period. Hydrogen sulfide was detected in several instances during evaluations of the BIO systems. However, the concentrations were never above 1 mg/L. The BIO/AMS system, on the other hand, did have a relatively high detection (21 ppm) of hydrogen sulfide on day 7. However, it is doubtful that the hydrogen sulfide concentrations would have been that high with proper ventilation during the high load-range BIO/AMS system.

Odor Evaluation

The odor panel was not available to analyze the BIO/AMS samples for the high load-range. Only the BIO, ABIO, and ABIO/AMS systems were evaluated at the high load-range. The results from day 5 and day 7 are listed in Tables 5.6 and 5.7.

Table 5.6. Day 5 Mean Odor Responses and Statistical Inferences (High Load-Range)

System	Pleasantness	Intensity	Acrid	Sulfur	Earthy	Musty	Fecal	Cheesy	Sweet	NH3
Control*	6.0	4.4	0.9	1.7	0.3	0.7	2.0	1.0	0.3	0.8
BIO	4.6	2.6	0.2	0.1	1.0	0.9	0.6	0.2	0.2	0.3
ABIO	4.4	1.3	0.1	0.2	0.3	0.4	0.7	0.1	0.2	0.2
ABIO/AMS	5.1	2.1	0.3	0.7	0.3	0.2	0.9	0.2	0.2	0.5
BIO	b	a	a	b	a	a	a	a	a	a
ABIO	b	b	a	b	a	ab	a	a	a	a
ABIO/AMS	a	ab	a	a	a	b	a	a	a	a

Note: Means with the same letter are not significantly different.
*Control was not considered in the statistical analysis

Table 5.7. Day 7 Mean Odor Responses and Statistical Inferences (High Load-Range)

System	Pleasantness	Intensity	Acrid	Sulfur	Earthy	Musty	Fecal	Cheesy	Sweet	NH$_3$
Control*	5.5	4.8	0.8	2.0	0.2	0.7	2.4	1.1	0.3	0.8
BIO	4.9	3.3	0.3	0.3	1.2	0.9	0.8	0.2	0.3	0.5
ABIO	4.7	1.2	0.1	0.2	0.2	0.4	0.5	0.1	0.1	0.2
ABIO/AMS	4.7	1.5	0.1	0.1	0.5	0.4	0.6	0.0	0.1	0.4
BIO	a	a	a	a	a	a	a	a	a	a
ABIO	a	b	a	a	b	a	a	a	a	a
ABIO/AMS	a	b	a	a	ab	a	a	a	a	a

Note: Means with the same letter are not significantly different.

*Control was not considered in the statistical analysis

At day 5, the ABIO/AMS system was rated less pleasant, more sulfurous and found to be significantly different from the BIO and the ABIO systems. The BIO system was significantly different from the ABIO system and was rated higher on overall intensity than both the ABIO and ABIO/AMS systems at day 5. A significant difference was not found for the acridity, earthy, fecal, cheesy, sweet, and ammonia characteristics. All systems were rated much less than the control for the following characteristics on day 5: overall intensity, acridity, sulfurous, fecal, cheesy, and ammonia.

At day 7, the BIO had a higher overall odor intensity and was found to be significantly different than the ABIO and ABIO/AMS system. The BIO system also had a higher earthy rating than either the ABIO and ABIO/AMS systems, and was found to be significantly different than the ABIO system. No other statistical differences were found between the systems.

The ABIO and ABIO/AMS systems did significantly reduce the overall odor intensity of the wastewater as compared to the BIO system. However, there were no significant differences with regard to acridity, sulfurous, fecal, cheesy, or ammonia characteristics. Also since the ABIO and ABIO/AMS system was only evaluated one time during the study, more testing is necessary to determine if the aeration of the bioreactor consistently reduces the swine odor as compared to the BIO system.

Summary

Both bioreactor systems (BIO and BIO/AMS) at the mid load-range lowered the orthophosphate, COD, volatile acids, and phenols concentrations as compared to the control system. However, the performance of the bioreactor system at the mid load-range was clearly enhanced by the aeration of the collection pits during the BIO/AMS system evaluations. Ammonia, orthophosphate, COD, volatile acids, and phenol concentrations were all reduced with the BIO/AMS system when compared to the BIO system at the mid load-range. The BIO/AMS system was able to maintain aerobic conditions through day 5, therefore the improved system performance at the mid load-range is likely attributed to increased aerobic microbial activity.

Unlike with the mid load-range, the aeration of the attached growth bioreactor system at the high load-range did not significantly increase performance. In fact, both the

BIO/AMS and the ABIO/AMS system decreased performance with regard to total solids, dissolved oxygen concentrations, and the gas phase ammonia concentrations. Unless the aeration system can achieve and maintain aerobic conditions within the system at the high load-range, it is unlikely that performance will be increased. The aeration of the bioreactor vessel did show some promise for enhanced performance. The phenols and volatile acids were reduced with the ABIO and ABIO/AMS systems along with a decrease in overall odor intensity of the wastewater.

CHAPTER VI

COMPARISON OF ORGANIC MEDIA

This chapter discusses the evaluation of three types of organic media for use

within the attached growth bioreactor. The three types of media evaluated were kenaf,

hardwood mulch, and corncobs. The kenaf was evaluated for three testing periods, the

hardwood mulch for two testing periods, and the corncobs for one testing period. No

aeration was used during any of these tests. All testing was done at the high load-range.

The average weekly COD load and temperature are listed in Table 6.1 for the media

treatments at the high load-range.

Table 6.1.   Average COD load and temperature for the media systems

System	Number of Testing Periods	Average COD Load (kg COD/7d)	Average Temperature	
			C°	F°
Control	9	42	26	79
Kenaf	3	39	17	63
Corncobs	1	32	23	73
Mulch	2	42	14	57

Water Quality Results

Tables F.29 – F.31 in Appendix F lists all the raw water quality data from the

kenaf media systems. Table F.39 lists the raw data for the corncob media systems. The

raw data for the hardwood mulch media systems are listed in Tables F.40 and F.41 in

Appendix F. The averaged water quality data for the systems are listed in Table G.7 in

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Appendix G and presented graphically in Figures 6.1 – 6.11. A discussion of the different media systems is presented below.

Dissolved Oxygen

The DO concentrations versus time for the media and control systems are shown in Figure 6.1. All the media maintained DO levels above 1 mg/L through day 2. The higher DO concentrations of the mulch and corncobs at day 1 may be due to enhanced oxygen diffusion within the filter. The physical characteristics of the hardwood mulch and corncob media (the bioreactor vessel was not as densely packed as with the kenaf media system) allowed more air (especially with the corncob media) to flow into the bioreactor vessel. The corncob media maintained higher DO concentrations than either the kenaf or the mulch media. However, it can not be determined if the higher DO concentrations indicates better performance by the corncob media or simply due to the lower load of the system compared to the other media systems. The corncob media was evaluated at a COD load of 32 kg COD/7d compared to 39 and 42 kg COD/7d for the kenaf and mulch systems, respectively. More testing is necessary to determine if the corncob media can consistently maintain higher DO concentrations. However, by day 5, the wastewater for all media treatments was considered anaerobic. At no time during testing of the control system was there any appreciable DO.

Dissolved Oxygen

Media Treatments
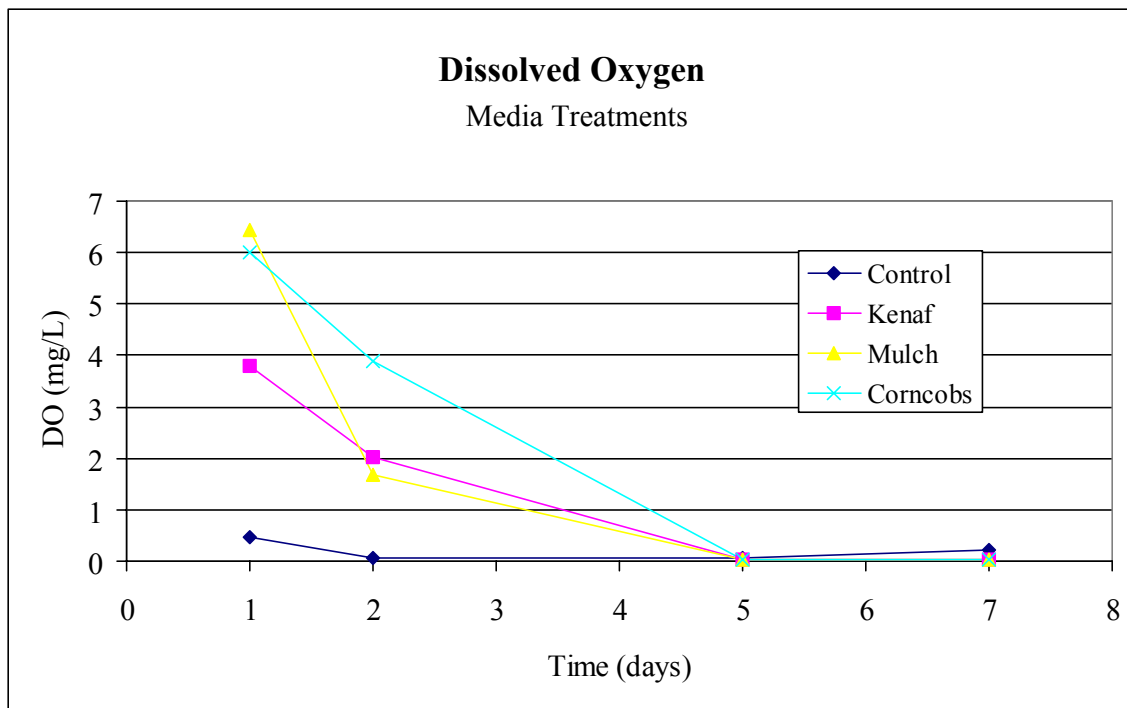
Figure 6.1.   DO of the media systems

ORP

Figure 6.2 presents the ORP data versus time for the media and control systems.

The ORP of the media systems were similar. All media systems maintained a higher

ORP than the control systems. The corncob and kenaf media systems maintained a

positive ORP until day 5. The hardwood mulch media system kept the ORP positive for

the entire testing period. The ORP of the media systems never fell below –200 mV. An

ORP below –200 mV would indicate the presence of strict anaerobes and provide

conditions favorable for malodor generation.
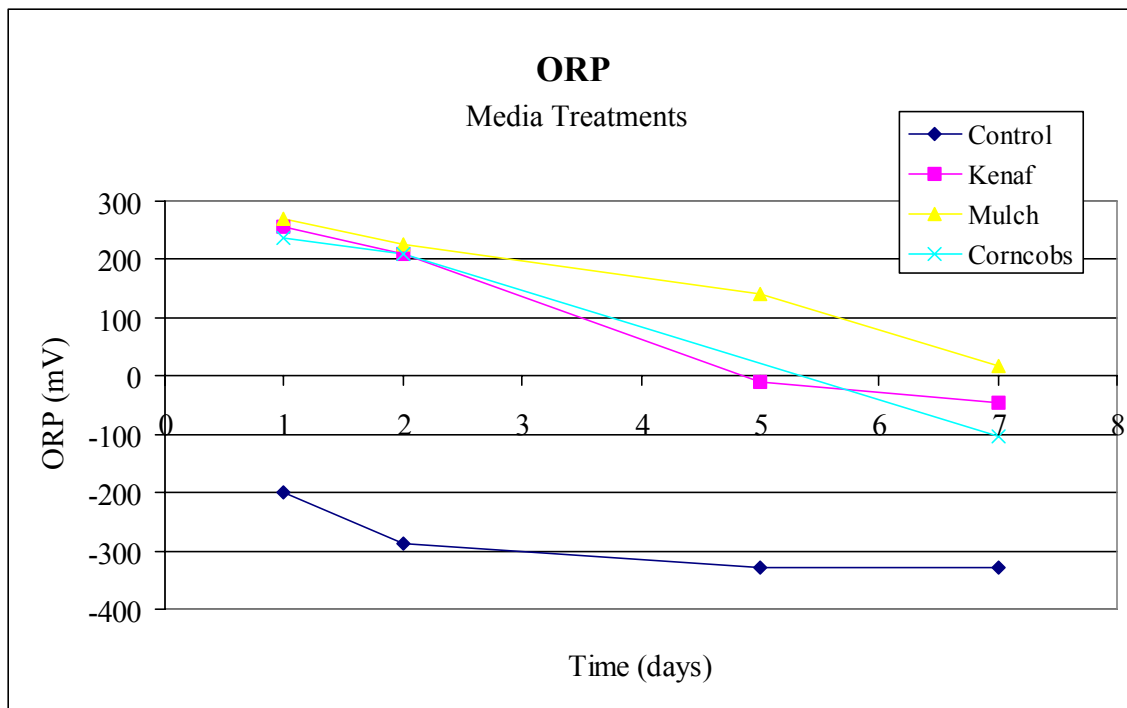
Figure 6.2.   ORP of the media systems

Ammonia

The ammonia concentrations versus time for the media systems are presented in Figure 6.3. The kenaf and hardwood mulch media systems had similar ammonia concentrations to the control system. The corncob media had 40% less ammonia than the other media systems. Again, since the corncob media was only evaluated once, it is unclear whether the lower ammonia concentrations were a result of better performance by the corncob media or due to the lower COD load of the corncob system (refer to Table 6.1 for the average COD loads of the media systems).
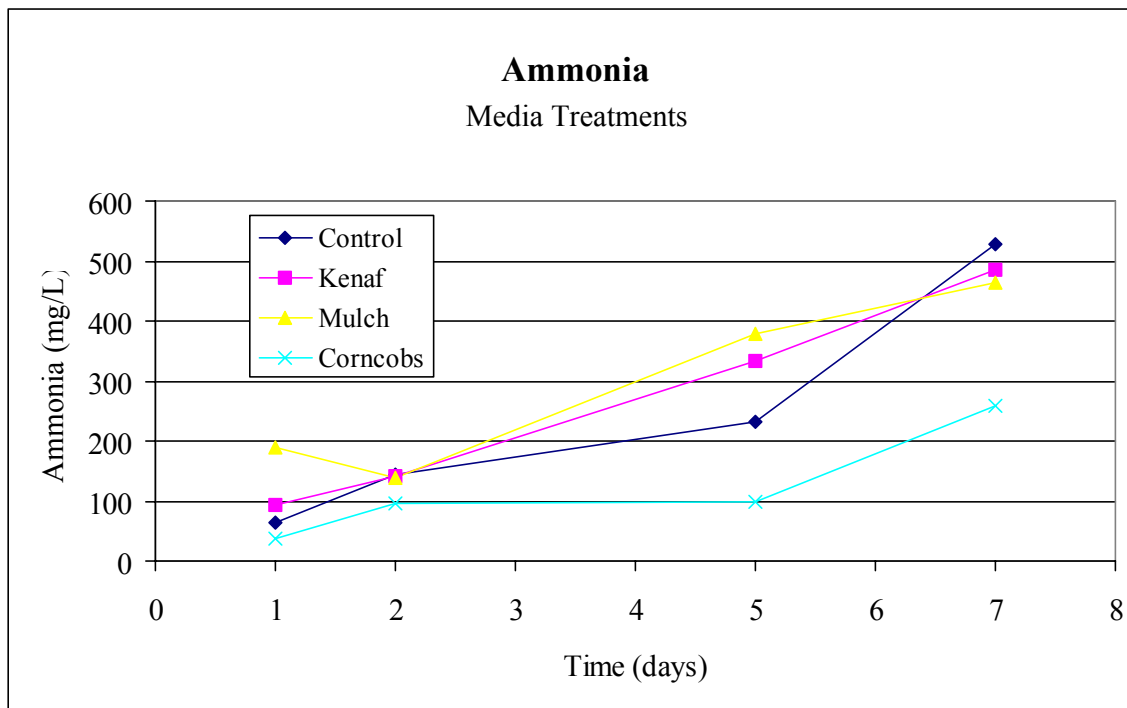
Figure 6.3. **Ammonia concentrations of the media systems**

Figure 6.4 shows the air phase ammonia concentrations of the media and control systems. There was little difference between the gas phase ammonia concentrations of the media systems. All the media systems had lower endpoint concentrations when compared to the control system. Hydrogen sulfide concentrations in the air above the pits were also monitored and at no time during the testing of the media systems was hydrogen sulfide detected.

120
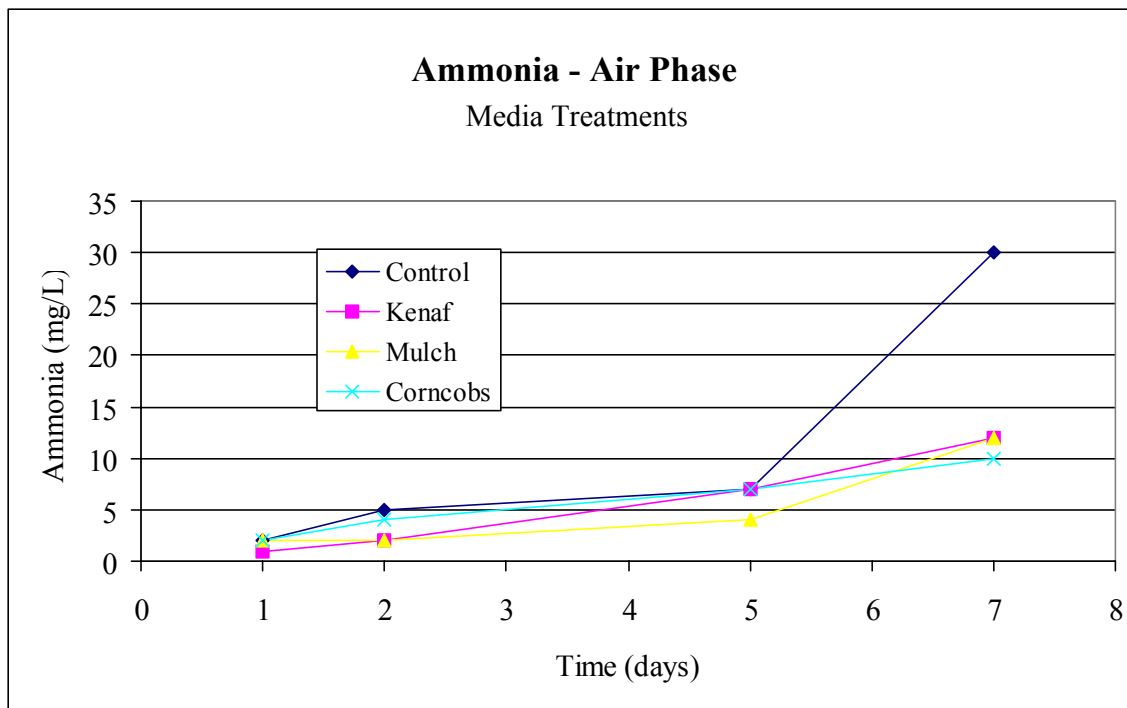
Figure 6.4.   Air phase ammonia concentrations of the media systems

Orthophosphate

The orthophosphate concentrations for the media and control systems are presented in Figure 6.5. All media systems lowered the orthophosphate concentrations of the wastewater compared to the control system. As stated in the previous two chapters, it is believed that the decrease in the orthophosphate concentrations of the media systems can be attributed to the increased microbial uptake of phosphorus for cell synthesis compared to the control system. It is probably not due to gravitational settling, as the treatments are somewhat agitated by the wastewater being re-circulated by the pump.
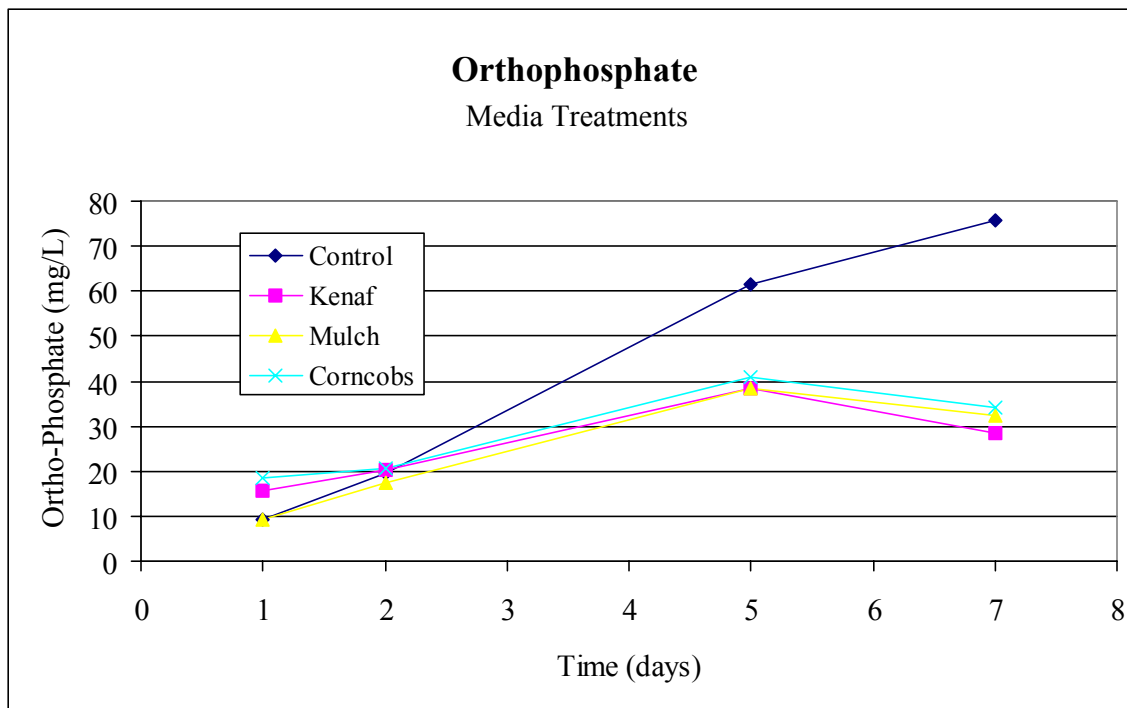
Figure 6.5. **Orthophosphate concentrations of the media systems**

COD

COD concentrations for the media and control systems are presented in Figure

6.6. The kenaf media system exhibited the lowest COD concentration on day 7.

However, all systems reduced the COD concentration by at least 29% when compared to

the control system. The higher COD concentrations of the hardwood mulch at days 1 and

2 can be attributed to the hardwood mulch media itself. A study by McCarty (2000)

indicated that hardwood mulch does exhibit an oxygen demand. In the McCarty study,

500 mL of hardwood mulch was mixed with 1000 mL of water. Water samples were

taken periodically for 74 days and tested for COD. The COD concentrations ranged from

around 650 mg/L to above 1600 mg/L. Therefore, it can be assumed that the higher COD

concentrations at days 1 and 2 can be attributed to the combined chemical oxygen

demand of the mulch media and the organic matter in the wastewater. However, by the

end of the testing period the mulch media system removed 29% of the COD as compared to the control system. It must also be noted that the load of the mulch media systems was higher than that of the corncob or kenaf media systems (Table 6.1).
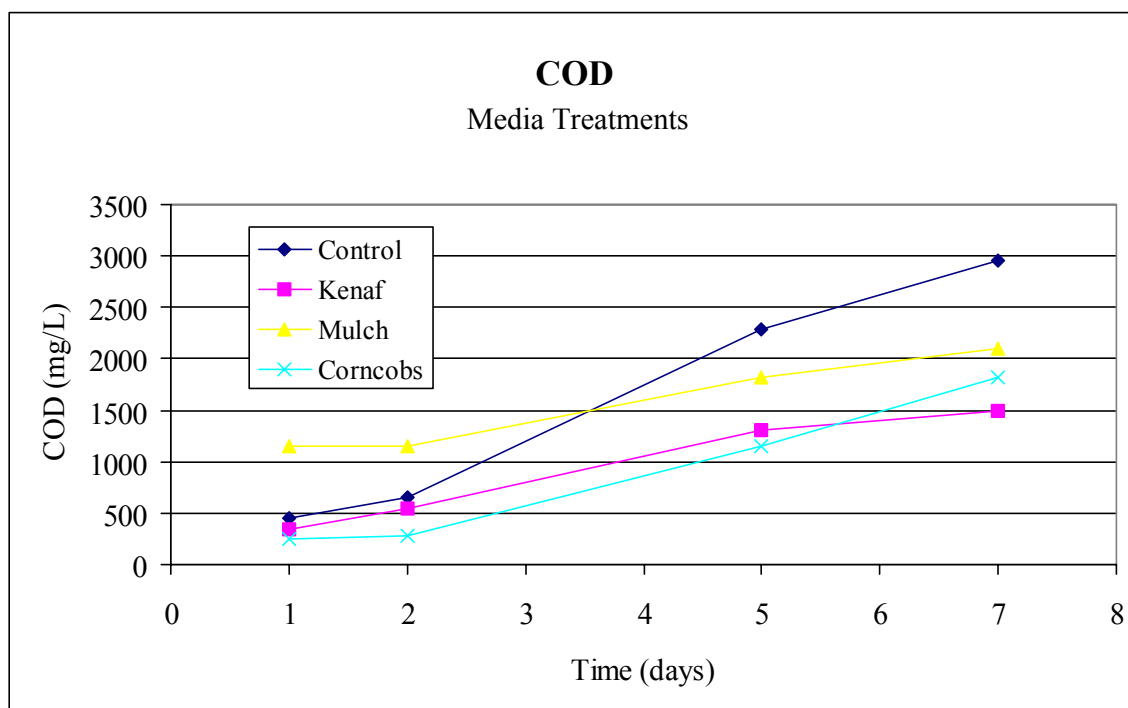
Figure 6.6.   COD concentrations of the media systems

Total Solids

Figure 6.7 presents the total solids concentrations versus time for the control and media systems. There was not much difference between any of the media systems or with the control. This further supports the conclusion that the attached growth bioreactor system was not effective in total solids removal.
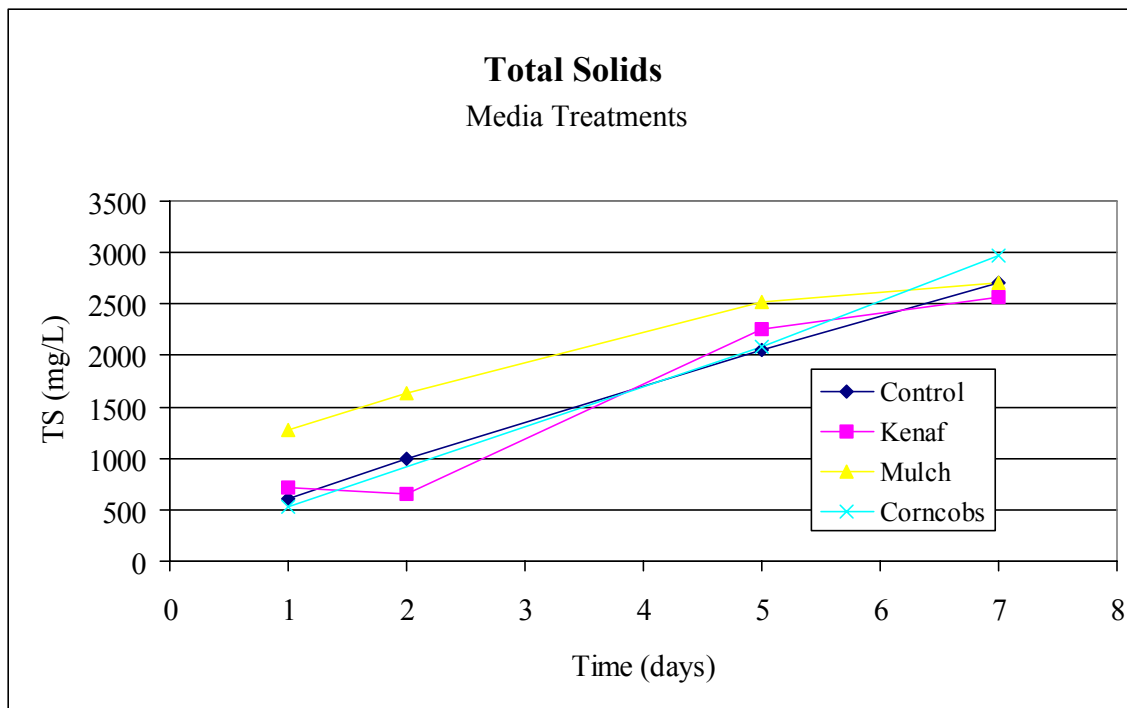
Figure 6.7.   Total solids concentrations of the media systems

Phenols and Volatile Acids

The phenols and volatile acids concentration for the control and media systems are presented in Figures 6.8 and 6.9, respectively. All media systems were effective in reducing the phenols and volatile acids concentration of the wastewater when compared to the control. The kenaf, mulch, and corncob media reduced endpoint phenols concentrations by 78%, 79%, and 68 %, respectively, as compared to the control, while the volatile acid endpoint concentrations were reduced by 88%, 81%, and 86 %, respectively, as compared to the control. The hardwood mulch media did have slightly higher concentrations at day 1 and 2. The mulch media, itself, may have contributed to the concentrations as with COD or it could be due to the increased load that the hardwood mulch media received during testing (refer to Figure 6.1 for the average COD loads of the

media systems.) However, by day 7 all the media systems had very similar volatile acids and phenols concentrations.
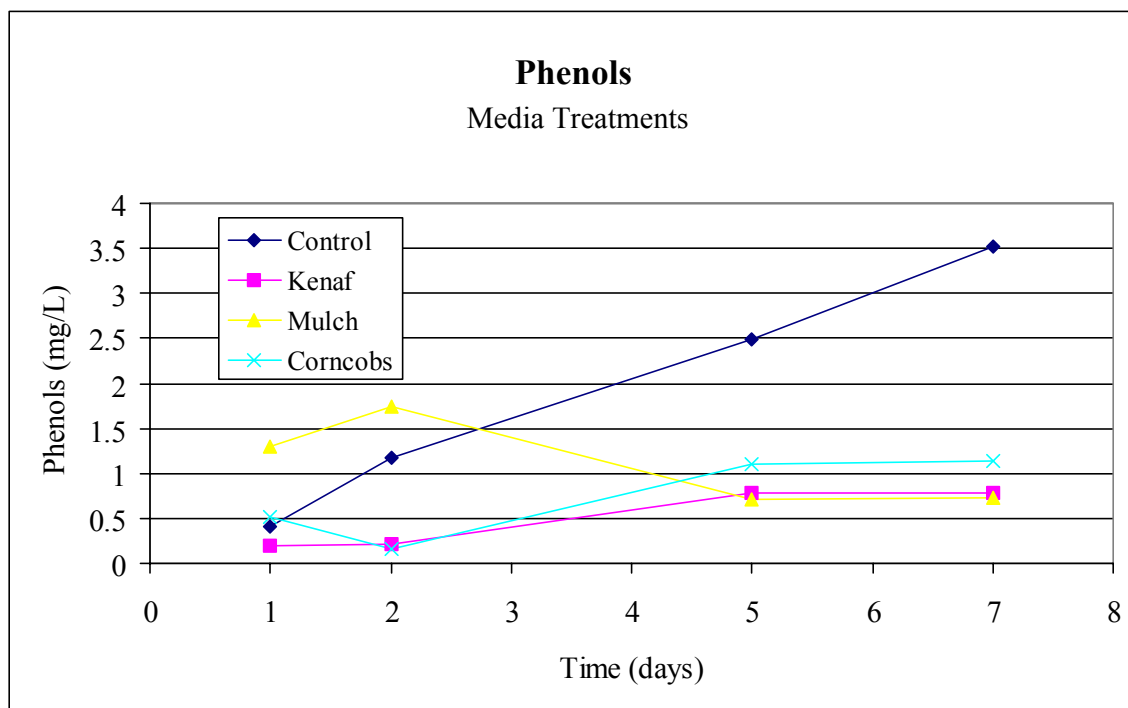
Figure 6.8.   **Phenols concentration of the media systems**
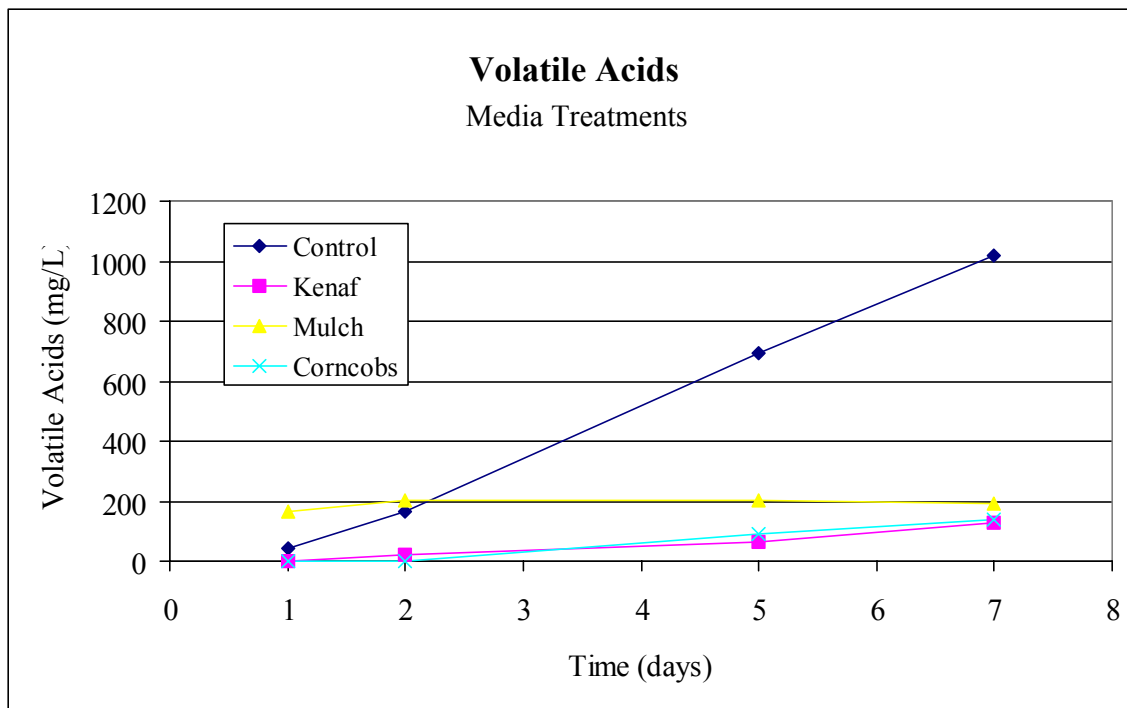
Figure 6.9. **Volatile acids concentrations of the media systems**

pH and Conductivity

Figures 6.10 and 6.11 present the pH and conductivity of the control and media systems, respectively. There was little difference between the media systems with regard to pH or conductivity. The higher pH of the media systems can be attributed to the relatively low volatile acids concentrations as compared to the control (see Figure 6.12).
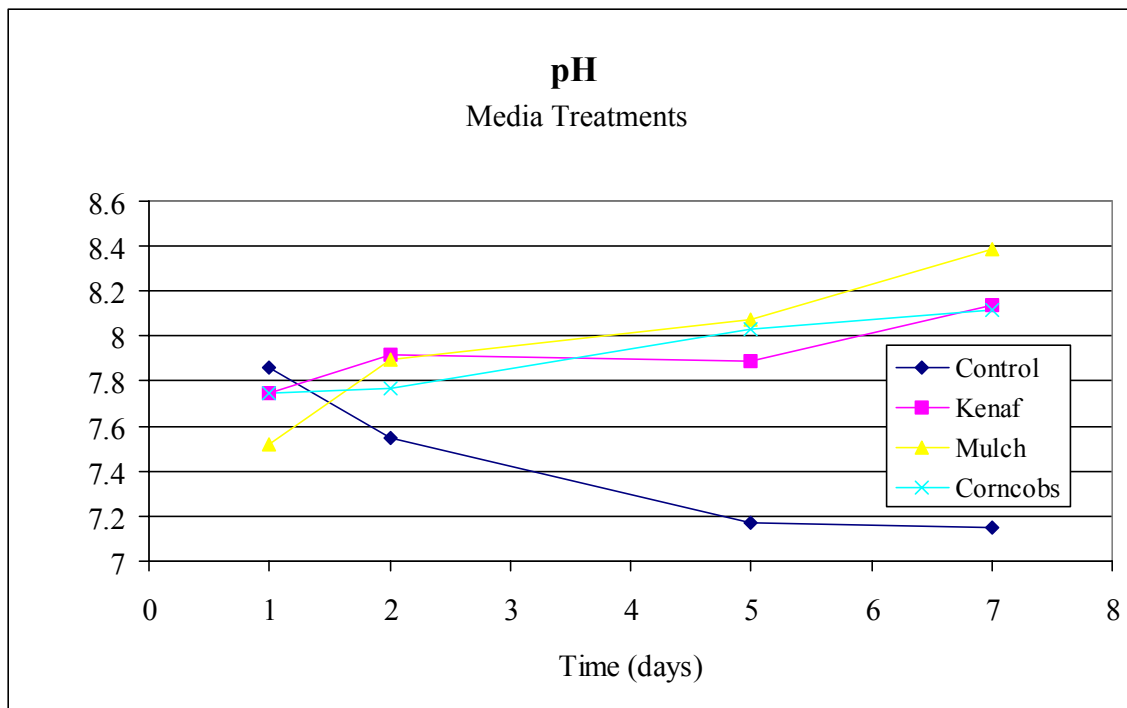
Figure 6.10. pH of the media systems
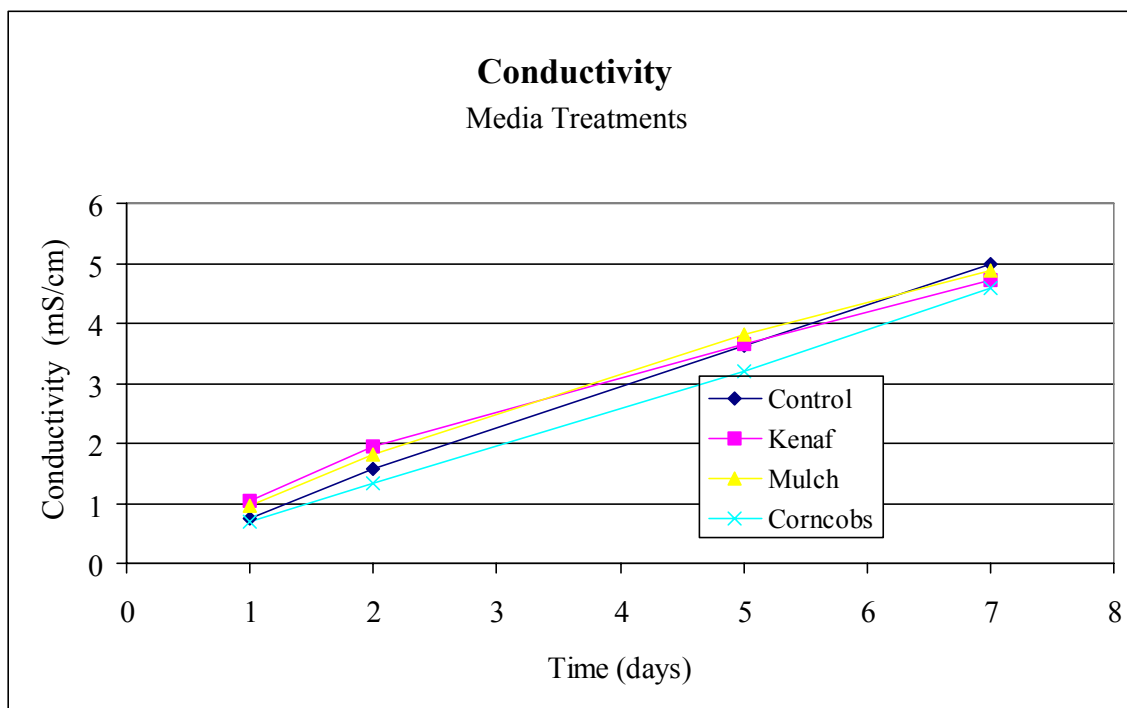
Figure 6.11. Conductivity of the media systems

<u>Odor Evaluation</u>

The sensory panel evaluated the wastewater samples from the different media on days 5 and 7. Mean odor response and statistical inferences can be seen in Tables 6.2 and 6.3. The average control odor data was included to see how the media compared to the control system. They were just included to give a point of reference and not included in the statistical analysis of the three types of media.

Table 6.2.   Day 5 Mean Odor Responses and Statistical Inferences (High Load-Range)

System	Pleasantness	Intensity	Acrid	Sulfur	Earthy	Musty	Fecal	Cheesy	Sweet	NH3
Control	5.5	4.8	0.8	2.0	0.2	0.7	2.4	1.1	0.3	0.8
Kenaf	4.6	2.1	0.1	0.0	0.5	0.6	0.6	0.1	0.2	0.3
Mulch	4.6	1.9	0.1	0.0	0.4	0.4	0.8	0.1	0.1	0.3
Corncobs	5.3	3.5	0.3	1.1	0.5	0.3	2.25	0.30	0.0	0.9
Kenaf	b	b	b	b	a	a	b	a	a	b
Mulch	b	b	b	b	a	a	b	a	a	b
Corncobs	a	a	a	a	a	a	a	a	a	a

Note: Means with the same letter are not significantly different.

Table 6.3.   Day 7 Mean Odor Responses and Statistical Inferences (High Load-Range)

System	Pleasantness	Intensity	Acrid	Sulfur	Earthy	Musty	Fecal	Cheesy	Sweet	NH3
Control	5.5	4.8	0.8	2.0	0.2	0.7	2.4	1.1	0.3	0.8
Kenaf	4.9	2.6	0.2	0.3	0.5	0.5	0.6	0.1	0.2	0.5
Mulch	4.6	1.7	0.1	0.1	0.5	0.6	0.3	0.1	0.1	0.3
Corncobs	5.2	3.3	0.8	0.3	0.5	0.3	1.1	0.1	0.2	0.9
Kenaf	ab	a	b	a	a	a	b	a	a	ab
Mulch	b	a	b	a	a	a	b	a	a	b
Corncobs	a	a	a	a	a	a	a	a	a	a

Note: Means with the same letter are not significantly different.

At day 5 the corncob media did not perform as well as the kenaf or the mulch. It was rated higher and found to be significantly different from both the mulch and the kenaf with regard to pleasantness, overall intensity, acridity, sulfur, fecal, and ammonia characteristics. No significant differences were found between the mulch and the kenaf.

At day 7, the corncob media was rated higher and found to be significantly different from the kenaf and mulch with regard to acridity and the fecal character of the wastewater. The corncob media was rated higher and found to be significantly different from the mulch with regard to unpleasantness and ammonia. Again no significant differences were found between the kenaf and mulch media.

The decreased performance of the corncob media with regard to odor control might be attributed to the microbial degradation of the corncob media itself, which can also cause foul odors. Some bacteria, while feeding on the available starches and sugars in the corncob, may produce butyric acid which has a rancid odor associated with it (Wheaton et al., 1993).

The odor panel results indicate that both kenaf and hardwood mulch are capable of reducing the overall odor intensity and the fecal characteristics of the wastewater. The corncob media on the other hand did not exhibit capabilities of significantly reducing the overall odor intensity, acridity, or fecal character of the wastewater as compared to the control system.

Summary

All of the media systems performed better than the control system. COD concentrations were reduced by 49%, 28%, and 38% by the kenaf, mulch, and corncobs, respectively. Volatile acids and phenols were reduced by at least 81% and 96%, respectively, by the media systems. All media reduced the ammonia concentration of the air above the pits as compared to the control. The kenaf and the mulch media were very effective in reducing the overall odor intensity, the acridity, and the sulfur and fecal characteristic of the wastewater. The corncob media, however, was not as effective for odor control.

CHAPTER VII

ENGINEERING SIGNIFICANCE

The need for improved odor control in the swine industry is clear. Litigation and negative public sentiment pose a serious challenge for producers. Conventional systems have devoted little direct investment in odor control. While technologies are available to reduce odor, most are not economically feasible with the present pricing. Therefore, the need for further development of cost-effective alternatives is apparent.

Based on the findings in the previous chapters, an attached growth bioreactor system may be a viable component in a wastewater remediation and odor control process for swine production facilities. Since plant material is used as the packing media, it is part of a sustainable system that can be used as a value added fertilizer or soil amendment via composting after its usefulness in the reactor is complete. Kenaf, especially, may be an economical option for use as the packing material within the attached growth system. Farmers with minimal land resources could grow and harvest their own packing media. The spent packing media (kenaf, mulch, etc.) is composted and utilized onsite as a soil amendment or packaged for sale. As environmental regulations continue to grow, the ability to economically export nutrients will be a strong factor in the final implementation of this system.

While, the attached growth bioreactor system evaluated during this study did consistently reduce the swine odor from the wastewater, the need for more testing is

evident. This reduction may or may not have an impact at the farm level. The control and BIO systems were evaluated numerous times at various temperatures and loadings throughout this study. However, the BIO/AMS, ABIO, ABIO/AMS, corncob, and mulch systems were only evaluated during one or two testing periods. Therefore, these systems need to be further evaluated at different COD loads and temperatures. Also, all testing was conducted with the same hydraulic loading rate of 22 L/min/m^3. Testing at various hydraulic loading rates would be beneficial to determine an optimal rate for the bioreactor systems. Perhaps, greater performance could be achieved at lower hydraulic rates, especially during the higher organic waste (COD) loads. More pilot-scale testing is necessary to determine the optimal operating conditions of the attached growth bioreactor system.

The aeration system used within this study was not sufficient at the high load-range to maintain aerobic conditions. The collections pits in the barn were too shallow to allow sufficient oxygen transfer to occur. Perhaps greater treatment and/or odor abatement could be achieved with a more efficient aeration system. Other aeration technologies that could be used to further enhance the bioreactor system might include the use of: hydrogen peroxide, membrane diffusion, ozone, strategic aeration, and the use of pure oxygen.

Testing of more water quality parameters would also be beneficial and give a better understanding of the processes that are taking place within the system. Testing of total suspended solids, total dissolved solids, and volatile suspended solids might help to clarify the total solids results. Also, a better understanding of the ammonia removal process could be achieved with knowledge of the concentrations of all the nitrogen

species present within the wastewater. High concentrations of TKN, with low ammonia and nitrate concentrations, would indicate that the aerobic conditions reduced the formation of ammonia. High levels of nitrate would indicate that nitrification without denitrification was occurring. However, low concentrations of all the nitrogen species would indicate either nitrification/denitrification processes or air stripping were responsible for the removal. Closer monitoring of the air above the pits would also serve to further support or oppose the air-stripping hypothesis.

The swine facility used in this research also presented several limitations. The facility only allowed the comparison of two systems at any given time. A larger facility with more collection pits would allow the direct comparisons of more systems. This would decrease variations in performance caused by temperature, waste loading, and other environmental conditions. Also, there is a need to evaluate the system using lagoon effluent instead of fresh water to fill the collection pits. This is necessary to more closely simulate large-scale swine production facilities. The research facility was not close enough to an anaerobic lagoon to allow such testing.

Another factor that needs further research is to determine how long the packing media can remain functional within the bioreactor vessel before needing replacement. Most of the research has used kenaf as the packing material. While more research is needed in this area, preliminary results indicate that kenaf can last at least two weeks before needing replacement. The calculations in Appendix I estimate that 810 m^3 (28,600 ft^3) of kenaf is needed for an 880-head finishing facility annually. This would require about 5 hectares (12 acres) of kenaf per 880-head finishing barn.

Studies by Williams et al (1989) and Bicudo and Svoboda (1995) indicate that the

minimum energy requirement for aerobic treatment to reduce odors is around 0.1

kWh/day pig place. Based on $0.07/kWhr, this would add approximately $2,250 to the

annual electricity costs for an 880-head facility. A conservative approximation of the

energy required to operate the BIO system (with no aeration) is 0.058 kWh/day pig place,

which would add approximately $1,300 to the annual electricity costs. The calculations

for the energy and cost requirements are located in Appendix J. Although more research

is needed on energy use, research findings indicate that the attached growth bioreactor

system may be a cost-effective component of an odor management system.

CHAPTER VIII

CONCLUSION

The research findings suggest that an attached growth bioreactor system may be a viable component in a wastewater remediation and odor control process for swine production facilities. An attached growth bioreactor system using organic media was evaluated against a pit recharge system, which served as the control for this study. The affects of aeration within the pits and in the bioreactor were also determined. Finally, three types of organic media (kenaf, corncobs, hardwood mulch) were tested for use within the bioreactor.

The bioreactor systems were effective in reducing orthophosphate, COD, volatile acids, and phenols concentrations of the wastewater as compared to the control system. With the exception of the corncob media, all bioreactor systems significantly decreased the overall odor intensity and the fecal characteristic of the wastewater as compared to the control system.

Specific conclusions from the research are listed below:

Water Quality

- The BIO system (without aeration) reduced the COD concentration by at least 40% for all load-ranges. Phenols were reduced by 65%, 58%, and 24% for the low, mid, and high load-ranges, respectively as compared to the control system. A 75% reduction of the volatile acids was achieved by the BIO system at the high load-range compared to the control system.

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- The bioreactor systems were not effective in reducing the conductivity, ammonia, or total solids concentration of the wastewater as compared to the control system at any load-range.

- At the mid load-range, the aeration of the pits (BIO/AMS) improved the performance of the bioreactor with regard to DO, ORP, ammonia, orthophosphate, COD, volatile acids, and phenols concentrations. However, at the high load-range, the aeration system was not as effective in improving the performance of the bioreactor. In fact, the BIO/AMS system had higher ammonia, volatile acids, and COD concentrations compared to all other bioreactor systems at the high load-range.

- The two systems with the aerated bioreactor (ABIO and ABIO/AMS) performed the best at the high load-range with regard to reductions in the phenols and volatile acids concentrations as compared to the control. Percent reductions in volatile acids and phenols were at least 92% and 83%, respectively, as compared to the control systems. These results indicate that the aeration of the bioreactor is a beneficial enhancement to the bioreactor system. However, these systems were only evaluated during one testing period. Therefore, more testing is necessary to verify these results.

- The kenaf, corncob, and hardwood mulch all have potential to be used as media within the bioreactor. They were all found to be effective in reducing the chemical oxygen demand, volatile acids, and phenols of the wastewater as compared to the control system. Percent reductions for the media systems

compared to the control were as high as 50%, 88%, and 79% for the chemical oxygen demand, volatile acids, and phenols concentrations, respectively.

- The pH of the control system decreased throughout each of the testing periods. The decrease can most likely be attributed to the increase in the volatile acids concentration. The pH of the bioreactor systems remained essentially constant throughout the testing periods. However, all systems maintained a pH within the optimum range (6.5 – 7.5) for biological activity (Metcalf and Eddy, 1991).

- The decrease in volatile acids and phenols indicated that aerobic processes were occurring within the attached growth bioreactor system even at low DO levels. This is important since malodorous compounds can be prevented and/or degraded under aerobic conditions.

Gas Analyses

- The ventilation of the barn appeared to play a role in the concentrations of ammonia in the air above the pits. As expected, when the ventilation system was not operational, higher ammonia concentrations in both the liquid and air phase were detected.

- The aeration of the collection pits at the high load-range greatly increased the ammonia concentration in the air within the barn. This increase was most likely due to increased volatilization caused by air stripping.

Odor Results

- All the bioreactor systems in the mid and high load-ranges received lower ratings and were found to be significantly different (a = 0.05) from the control with

regard to pleasantness, overall odor intensity, acridity, sulfurous, earthy, fecal, cheesy, and ammonia characteristics.

- There was no obvious improvement of odor when the pits were aerated (BIO/AMS system) when compared to the BIO system at the mid load-range.

- When the bioreactor vessel was aerated, the odor intensity of the wastewater was reduced significantly (a = 0.05). The ABIO and ABIO/AMS systems received ratings of 1.2 and 1.5, respectively for overall odor intensity compared to the BIO system with a rating of 3.3 (based on a 0-8 scale).

- While the corncobs did reduce COD, VA, and phenols concentrations, they were not effective in reducing the overall odor intensity or fecal characteristics of the wastewater. Microbial degradation of the corncobs within the bioreactor could be to blame for its decreased odor abatement capabilities.

- Kenaf and hardwood mulch have potential for use as the organic packing media for the attached growth bioreactor system. They are capable of reducing the overall odor intensity and the fecal characteristic of the wastewater. The kenaf and hardwood mulch systems received ratings of 0.6 and 0.3, respectively for the fecal characteristic compared to the control with a rating of 2.4 (based on a 0-8 scale). The ratings for odor intensity for the mulch and kenaf media systems (1.7 and 2.6, respectively) were also lower than the control systems, which had a rating of 4.8.

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APPENDIX A

FEED INFORMATION

Table A.1. Feed Diet Ingredients

Ingredient	
Corn, yellow	1683
Soybean meal, 48%	268
Calcium carbonate	17
Dicalcium phosphate	22
Salt	7
Vitamin-trace mineral mix	3
Total	2000
Calculated Analysis	
Protein, %	13.6
Lysine, %	0.62
Tryptophan, %	0.16
Threonine, %	0.52
Methionine + cystine, %	0.53
Calcium, %	0.61
Phosphorus, %	0.50
Metabolizable energy, kcal/lb	1510

Reference: Luce, et al., 1992

APPENDIX B

PIG WEIGHT DATA

Table B.1. Approximate pig weight data from 9/1/99 – 11/11/99

Date	Day	Weight (lbs)		# Pigs
		Left Pen	**Right Pen**	
9/14/99	**1**	140	140	12
11/11/99	**59**	220	220	12
Growth Rate Equation:		**y = 1.3793x + 138.62**		

Table B.2. Average pig weight data from 2/3/00 - 5/10/00

Date	Day	Weight (lbs)		# Pigs
		Left Pen	**Right Pen**	
2/3/00	**1**	25.4	27.5	12
4/7/00	**65**	94.3	111.2	12
5/10/00	**98**	162.3	181.4	12
5/10/00	**98**	166.3	189.8	6
Growth Rate Equations:		**Left - y = 1.3651x + 19.347**		
		Right - y = 1.5488x + 22.028		

Table B.3. Average pig weight data from 7/25/00 - 9/21/00

Date	Day	Weight (lbs)		# Pigs
		Left Pen	**Right Pen**	
7/25/00	**1**	140.4167	145.4167	12
8/16/00	**23**	168.5833	171.6667	12
9/7/00	**45**	210.1667	214.5833	12
9/21/00	**59**	242.6667	251.25	12
Growth Rate Equations:		**Left - y = 1.7598x + 134.14**		
		Right - y = 1.8146x + 137.66		

Table B.4. Average pig weight data from 10/23/00 – 11/20/00

Date	Day	Weight (lbs)		# Pigs
		Left Pen	**Right Pen**	
10/23/00	**1**	134.5	139.5	12
11/20/00	**29**	197.25	201.5	12
Growth Rate Equations:		**Left - y = 2.2411x + 132.26**		
		Right - y = 2.2143x + 137.29		

APPENDIX C

SAMPLE ODOR SCORE SHEET

Number:_____   Date:_____

Pleasantness

0	1	2	3	4	5	6	7	8
Extremely Pleasant	Very Pleasant	Slightly Pleasant	Moderately Pleasant	Neither Pleasant Nor Unpleasant	Slightly Unpleasant	Moderately Unpleasant	Very Unpleasant	Extremely Unpleasant

Overall Odor Intensity

0	1	2	3	4	5	6	7	8
None At All	Very Weak	Weak	Moderate Weak	Moderate	Moderate Strong	Strong	Very Strong	Maximal

Irritation Intensity (Acrid)

0	1	2	3	4	5	6	7	8
None At All	Very Weak	Weak	Moderate Weak	Moderate	Moderate Strong	Strong	Very Strong	Maximal

Sulfurous

0	1	2	3	4	5	6	7	8

Earthy

0	1	2	3	4	5	6	7	8

Musty

0	1	2	3	4	5	6	7	8

Fecal (Skatole/Cresol Complex)

0	1	2	3	4	5	6	7	8

Cheesy/Dirty Socks

0	1	2	3	4	5	6	7	8

Sweet/Grainy

0	1	2	3	4	5	6	7	8

Ammonia

0	1	2	3	4	5	6	7	8
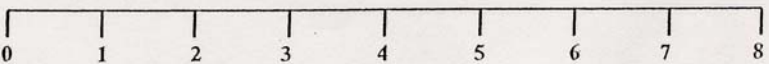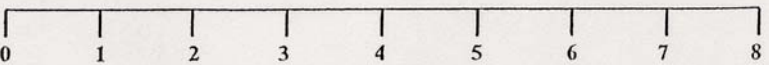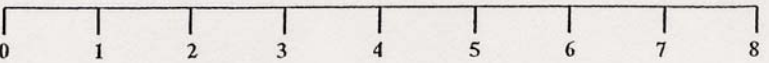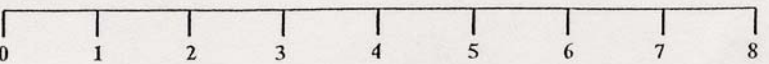
APPENDIX D

TEMPERATURE DATA

Table D.1. Average Daily Temperatures

Date	Temperature (°C)	Date	Temperature (°C)	Date	Temperature (°C)
10/14/99	21.9	02/22/00	21.5	04/02/00	16.8
10/15/99	22.6	02/23/00	21.5	04/03/00	17.0
10/16/99	21.8	02/24/00	21.5	04/04/00	17.1
10/17/99	21.9	02/25/00	21.6	04/05/00	17.2
10/18/99	21.9	02/26/00	21.6	04/05/00	21.1
10/19/99	21.9	02/27/00	21.6	04/06/00	21.1
10/20/99	22.0	02/28/00	21.6	04/07/00	21.0
10/21/99	22.0	02/29/00	21.7	04/08/00	20.9
10/22/99	22.0	03/01/00	21.7	04/09/00	20.8
10/23/99	22.1	03/02/00	21.8	04/10/00	20.7
10/24/99	22.1	03/03/00	21.8	04/11/00	20.5
10/25/99	22.2	03/04/00	21.9	04/12/00	20.3
10/26/99	22.2	03/05/00	21.9	04/13/00	20.1
10/27/99	22.3	03/06/00	22.0	04/14/00	20.0
10/28/99	22.3	03/07/00	22.0	04/15/00	19.9
10/29/99	22.4	03/08/00	22.1	04/16/00	19.9
10/30/99	22.4	03/09/00	22.2	04/17/00	20.0
10/31/99	22.5	03/10/00	22.2	04/18/00	20.0
11/01/99	22.5	03/11/00	22.3	04/19/00	20.0
11/02/99	22.5	03/12/00	22.4	04/19/00	25.8
11/03/99	22.6	03/13/00	22.4	04/20/00	22.5
11/04/99	22.6	03/14/00	22.5	04/21/00	22.4
11/05/99	22.7	03/15/00	22.6	04/22/00	22.2
11/06/99	22.7	03/16/00	22.6	04/23/00	22.0
11/07/99	22.8	03/17/00	22.7	04/24/00	21.8
11/08/99	22.8	03/18/00	22.8	04/25/00	21.6
11/09/99	22.8	03/19/00	22.8	04/26/00	21.3
11/10/99	22.9	03/20/00	22.9	04/27/00	21.1
02/10/00	21.6	03/21/00	23.0	04/28/00	20.9
02/11/00	21.6	03/22/00	23.0	04/29/00	20.7
02/12/00	21.6	03/23/00	23.1	04/30/00	20.5
02/13/00	21.6	03/24/00	23.2	05/01/00	20.3
02/14/00	21.6	03/25/00	23.2	05/02/00	20.1
02/15/00	21.6	03/26/00	23.3	05/03/00	19.9
02/16/00	21.6	03/27/00	23.4	05/04/00	19.7
02/17/00	21.6	03/28/00	23.5	05/05/00	19.6
02/18/00	21.5	03/29/00	23.5	05/06/00	19.4
02/19/00	21.5	03/30/00	23.4	05/07/00	19.3
02/20/00	21.5	03/31/00	16.6	05/08/00	19.1
02/21/00	21.5	04/01/00	16.7	05/09/00	18.9

Table D.1. (Continued)

Date	Temperature (°C)	Date	Temperature (°C)	Date	Temperature (°C)
05/10/00	18.7	06/19/00	18.9	09/13/00	27.8
05/11/00	18.5	06/20/00	18.7	09/14/00	25.7
05/12/00	18.4	06/21/00	18.4	09/15/00	21.4
05/13/00	18.2	08/07/00	24.3	09/16/00	21.2
05/14/00	18.0	08/08/00	28.0	09/17/00	23.3
05/15/00	17.9	08/09/00	31.4	09/18/00	25.1
05/16/00	17.8	08/10/00	28.6	09/19/00	23.4
05/17/00	17.7	08/11/00	28.2	09/20/00	22.2
05/18/00	17.5	08/12/00	28.2	10/21/00	22.5
05/19/00	17.3	08/13/00	28.5	10/22/00	23.5
05/20/00	17.1	08/14/00	30.4	10/23/00	22.8
05/21/00	17.0	08/15/00	32.0	10/24/00	22.8
05/22/00	16.9	08/16/00	33.7	10/25/00	22.9
05/23/00	16.8	08/17/00	32.8	10/26/00	22.9
05/24/00	16.8	08/18/00	31.6	10/27/00	22.9
05/25/00	16.8	08/19/00	30.2	10/28/00	22.8
05/26/00	16.9	08/20/00	30.3	10/29/00	22.8
05/27/00	17.0	08/21/00	28.5	10/30/00	22.8
05/28/00	17.2	08/22/00	29.9	10/31/00	22.8
05/29/00	17.3	08/23/00	31.3	11/01/00	22.9
05/30/00	17.4	08/24/00	31.6	11/02/00	22.8
05/31/00	17.6	08/25/00	29.5	11/03/00	22.8
06/01/00	17.7	08/26/00	30.8	11/04/00	22.7
06/02/00	17.8	08/27/00	31.9	11/05/00	22.7
06/03/00	17.9	08/28/00	34.4	11/06/00	22.7
06/04/00	18.0	08/29/00	33.2	11/08/00	22.0
06/05/00	18.0	08/30/00	32.0	11/09/00	13.4
06/06/00	18.1	08/31/00	31.1	11/10/00	13.0
06/07/00	18.1	09/01/00	30.0	11/11/00	12.6
06/08/00	18.2	09/02/00	31.0	11/12/00	12.3
06/09/00	18.3	09/03/00	32.0	11/13/00	11.9
06/10/00	18.4	09/04/00	28.7	11/14/00	11.5
06/11/00	18.6	09/05/00	25.2	11/15/00	11.1
06/12/00	18.8	09/06/00	20.0	11/16/00	10.7
06/13/00	19.0	09/07/00	22.3	11/17/00	10.5
06/14/00	19.1	09/08/00	24.9	11/18/00	10.3
06/15/00	19.2	09/09/00	27.5	11/19/00	10.1
06/16/00	19.3	09/10/00	28.3	11/20/00	10.1
06/17/00	19.2	09/11/00	26.3	11/21/00	10.0
06/18/00	19.1	09/12/00	27.1	11/22/00	10.0

APPENDIX E

DATE, COD LOAD, AND TEMPERATURE FOR TESTING PERIODS

Table E.1. Date, temperature, and COD load for the control testing periods

Date	Temperature (°C)	Load kg COD
9/30/99 - 10/6/99	ND	35
11/05/99 - 11/10/99	23	45
8/08/00 - 8/14/00	29	38
8/15/00 - 8/21/00	31	41
8/22/00 - 8/28/00	31	44
8/31/00 - 9/06/00	28	47
9/14/00 - 9/20/00	23	53
2/10/00 - 2/16/00 Left Collection Pit	18	8
2/10/00 - 2/16/00 Right Collection Pit	18	9
3/16/00 - 3/22/00 Left Collection Pit	20	19
3/16/00 - 3/22/00 Right Collection Pit	20	21
5/04/00 - 5/10/00 Left Collection Pit	24	34
5/04/00 - 5/10/00 Right Collection Pit	24	39
5/18/00 - 5/24/00	24	22
5/25/00 - 5/31/00	26	23
6/01/00 - 6/07/00	25	24
6/15/00 - 6/21/00	25	27

ND = No Data

Table E.2. Date, temperature, and COD load for the BIO testing periods

Date	Temperature (°C)	Load kg COD
9/30/99 - 10/6/99	ND	35
10/07/99 - 10/13/99	ND	37
10/15/99 - 10/20/99	21	39
10/21/99 - 10/27/99	23	41
10/29/99 - 11/03/99	24	43
2/17/00 - 2/23/00 Left Collection Pit	20	10
2/17/00 - 2/23/00 Right Collection Pit	20	11
4/06/00 - 4/12/00 Left Collection Pit	17	25
4/06/00 - 4/12/00 Right Collection Pit	17	29
5/18/00 - 5/24/00	24	19
8/31/00 - 9/06/00	28	49
10/24/00 - 10/30/00	23	34
11/02/00 - 11/08/00	20	38
11/16/00 - 11/22/00	9	46

ND = No Data

Table E.3. Date, temperature, and COD load for the BIO/AMS testing periods

Date	Temperature (°C)	Load kg COD
3/09/00 - 3/15/00 Left Collection Pit	21	16
3/09/00 - 3/15/00 Right Collection Pit	21	19
4/27/00 - 5/03/00 Left Collection Pit	20	32
4/27/00 - 5/03/00 Right Collection Pit	20	36
6/15/00 - 6/21/00	25	24

Table E.4. Date, temperature, and COD load for the ABIO testing period

Date	Temperature (°C)	Load kg COD
8/22/00 - 8/28/00	31	45

Table E.5. Date, temperature, and COD load for the ABIO/AMS testing period

Date	Temperature (°C)	Load kg COD
9/14/00 - 9/20/00	23	54

Table E.6. Date, temperature, and COD load for the corncob media testing period

Date	Temperature (°C)	Load kg COD
10/24/00 - 10/30/00	23	33

Table E.7. Date, temperature, and COD load for the mulch media testing periods

Date	Temperature (°C)	Load kg COD
11/02/00 - 11/08/00	20	37
11/16/00 - 11/22/00	9	46

Table E.8. Date, temperature, and COD load for the kenaf media testing periods

Date	Temperature (°C)	Load kg COD
10/24/00 - 10/30/00	23	34
11/02/00 - 11/08/00	20	38
11/16/00 - 11/22/00	9	46

APPENDIX F

RAW WATER QUALITY DATA

Table F.1. Raw water quality data for the control 9/30/99 – 10/06/99 testing period

Time	Sample	DO	ORP	pH	Cond	NH₃-N	PO₄-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	RC	0	--	8.0	0.52	--	--	160	--	--	--
2	RC	0.1	--	8.0	1.09	--	--	263	644	--	--
2	RS	--	--	--	--	--	--	--	--	0.22	1
2	RD	--	--	--	--	--	--	--	--	0.81	114
5	RC	0	--	7.1	3.11	--	--	1880	--	--	--
6	RC	0.1	--	7.2	4.03	401.6	--	2327	--	--	--
7	RC	0	--	7.3	5.21	442.2	--	2520	2702	--	--
7	RS	--	--	--	--	--	--	--	--	3.12	755
7	RD	--	--	--	--	--	--	--	--	0.51	1236

R – Right collection pit   Average Temperature – No Data
C – composite sample of shallow and deep   Approximate Load – 35 kg COD/test period
S – sample from shallow end of pit
D – sample from deep end of pit

Table F.2. Raw water quality data for the control 11/05/99 - 11/10/99 testing period

Time	Sample	DO	ORP	pH	Cond	NH₃-N	PO₄-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
2	RS	0.1	-139	8.3	1.41	70.0	27.39	339	788	4.76	474
2	RD	0	-280	8.7	1.95	100.0	18.91	389	928	3.65	668
7	RS	0.2	-264	7.6	5.8	540.0	60.65	2553	2208	--	--
7	RD	0.2	-288	7.8	7.06	780.0	68.48	2426	2540	--	--

R – Right collection pit   Average Temperature – 23°C
S – sample from shallow end of pit   Approximate Load – 45 kg COD/test period
D – sample from deep end of pit

Table F.3. Raw water quality data for the control 2/10/00 – 2/16/00 testing period

Time	Sample	DO	ORP	pH	Cond	NH$_3$-N	PO$_4$-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	LS	0.6	123	8.1	0.25	7.0	0.95	7	174	0.00	0
1	LD	0	140	7.3	0.25	5.0	1.23	0	138	0.00	0
2	LS	0.3	88	7.5	0.43	19.0	4.14	210	444	--	--
2	LD	0.6	78	7.6	0.47	15.0	5.51	145	316	--	--
5	LS	0	-186	7.7	1.04	36.0	10.17	367	648	0.19	1
5	LD	0	-141	7.2	1.19	52.0	16.76	578	1080	0.88	247
7	LS	--	-168	7.4	1.54	67.7	17.22	967	1110	1.03	125
7	LD	--	-160	6.9	1.65	72.2	20.35	1106	1224	1.47	252

L – Left collection pit   Average Temperature – 18°C
S – sample from shallow end of pit   Approximate Load – 8 kg COD/test period
D – sample from deep end of pit

Table F.4. Raw water quality data for the control 2/10/00 – 2/16/00 testing period

Time	Sample	DO	ORP	pH	Cond	NH$_3$-N	PO$_4$-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	RS	0.3	106	7.4	0.28	7.0	1.25	1	206	0.00	1
1	RD	0	133	7.2	0.27	5.0	1.26	0	180	0.00	0
2	RS	0.2	17	7.2	0.52	28.0	3.72	323	446	--	--
2	RD	0.3	15	7.1	0.6	22.0	4.04	244	424	--	--
5	RS	0	-187	7.3	1.27	38.0	17.22	700	1012	0.98	142
5	RD	0	-199	7.1	1.53	88.0	18.78	790	1024	1.28	155
7	RS	--	-230	7.0	1.93	86.4	24.65	1497	1440	0.56	372
7	RD	--	-210	6.8	2.11	97.7	28.83	1553	1566	0.56	377

R – Right collection pit   Average Temperature – 18°C
S – sample from shallow end of pit   Approximate Load – 9 kg COD/test period
D – sample from deep end of pit

Table F.5. Raw water quality data for the control 3/16/00 – 3/22/00 testing period

Time	Sample	DO	ORP	pH	Cond	NH$_3$-N	PO$_4$-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	LS	0.1	248	7.8	0.43	16.3	2.47	217	460	0.01	2
1	LD	0.1	226	8.2	0.46	30.7	1.56	36	256	0.01	1
2	LS	0.4	-389	7.2	0.80	32.4	6.23	610	876	--	--
2	LD	0.3	-366	8.0	0.96	63.2	5.63	220	544	--	--
5	LS	0.1	-301	7.0	1.96	184.7	21.70	1030	1328	0.18	99
5	LD	0.1	-333	7.2	2.50	30.3	18.17	1420	1418	0.12	183
7	LS	0.1	-349	7.2	3.13	177.6	27.47	1690	466	0.05	558
7	LD	0.1	-344	7.3	3.63	285.7	42.02	2110	2032	1.12	642

L – Left collection pit   Average Temperature – 20°C
S – sample from shallow end of pit   Approximate Load – 19 kg COD/test period
D – sample from deep end of pit

Table F.6. Raw water quality data for the control 3/16/00 – 3/22/00 testing period

Time	Sample	DO	ORP	pH	Cond	NH$_3$-N	PO$_4$-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	RS	0.0	66	8.8	0.54	27.6	3.31	93	302	0.01	6
1	RD	0.0	226	8.4	0.43	25.4	1.76	47	224	0.05	0
2	RS	0.4	-358	7.5	1.14	81.5	8.95	500	814	--	--
2	RD	0.3	-351	8.1	1.09	76.0	6.08	130	488	--	--
5	RS	0.2	-333	7.1	2.96	249.6	33.97	1800	1648	0.12	104
5	RD	0.1	-348	7.3	3.31	298.3	34.90	1630	1726	0.12	189
7	RS	0.1	-342	7.2	3.88	320.2	47.20	2160	2364	0.01	719
7	RD	0.0	-356	7.5	4.06	355.1	54.46	1950	2504	0.38	771

R – Right collection pit   Average Temperature – 20°C
S – sample from shallow end of pit   Approximate Load – 21 kg COD/test period
D – sample from deep end of pit

Table F.7. Raw water quality data for the control 5/04/00 – 5/10/00 testing period

Time	Sample	DO	ORP	pH	Cond	NH$_3$-N	PO$_4$-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	LS	0.0	-240	7.2	0.52	36.0	7.74	288	566	0.16	293
1	LD	0.0	-291	7.7	0.92	98.0	17.22	501	594	0.46	10
2	LS	0.1	-300	7.2	1.40	121.0	19.54	847	1080	--	--
2	LD	0.1	-325	7.0	2.16	294.0	32.11	1188	591	--	--
5	LS	0.1	-350	6.8	3.58	365.0	71.40	2350	2480	2.13	1196
5	LD	0.1	-346	6.7	4.18	394.0	79.70	2448	2574	2.67	955
7	LS	0.1	-329	6.6	4.55	409.0	92.80	2951	2768	3.57	1319
7	LD	0.3	-331	6.5	4.77	420.0	120.70	3483	2922	1.50	1400

L – Left collection pit
S – sample from shallow end of pit
D – sample from deep end of pit

Average Temperature – 24°C
Approximate Load – 34 kg COD/test period

Table F.8. Raw water quality data for the control 5/04/00 – 5/10/00 testing period

Time	Sample	DO	ORP	pH	Cond	NH$_3$-N	PO$_4$-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	RS	0.0	-263	7.1	0.86	21.0	8.78	513	608	0.17	134
1	RD	0.0	-278	7.6	1.05	87.0	13.90	536	598	0.45	2
2	RS	0.2	-294	6.7	1.07	108.0	21.61	859	524	--	--
2	RD	0.0	-317	7.1	2.06	326.0	26.28	1088	703	--	--
5	RS	0.2	-326	6.5	4.14	237.0	94.10	2747	2320	1.76	981
5	RD	0.3	-340	6.5	4.60	345.0	95.70	3660	3038	1.50	760
7	RS	0.2	-319	6.4	5.16	366.0	121.00	3913	3344	3.21	1582
7	RD	0.3	-327	6.4	5.63	449.0	134.70	4214	3278	3.27	1706

R – Right collection pit
S – sample from shallow end of pit
D – sample from deep end of pit

Average Temperature – 24°C
Approximate Load – 39 kg COD/test period

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Table F.9. Raw water quality data for the control 5/18/00 – 5/24/00 testing period

Time	Sample	DO	ORP	pH	Cond	NH$_3$-N	PO$_4$-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	RS	--	--	--	--	--	--	--	--	0.30	0
1	RD	--	--	--	--	--	--	--	--	0.42	1
5	RS	0.2	-319	6.7	2.24	88.0	41.50	1351	1432	0.90	396
5	RD	0.2	-323	6.6	2.61	178.0	38.00	662	1412	0.96	642
7	RS	0.3	-305	6.4	2.88	222.0	59.40	2226	1524	2.34	744
7	RD	0.4	-306	6.4	3.14	426.0	69.30	2046	2174	3.00	1158

R – Right collection pit Average Temperature – 24°C
S – sample from shallow end of pit Approximate Load – 22 kg COD/test period
D – sample from deep end of pit

Table F.10. Raw water quality data for the control 5/25/00 – 5/31/00 testing period

Time	Sample	DO	ORP	pH	Cond	NH$_3$-N	PO$_4$-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	RS	0.1	-326	7.4	0.65	53.0	11.20	318	328	0.45	28
1	RD	0.1	-332	7.9	0.72	31.0	5.40	302	536	0.39	25
2	RS	0.1	-333	7.1	1.17	308.0	15.50	628	604	--	--
2	RD	0.0	-330	7.2	1.19	120.0	11.30	542	622	--	--
5	RS	0.2	-329	6.7	2.56	362.0	34.60	1792	1494	1.53	761
5	RD	0.2	-329	6.6	2.90	221.0	31.20	2132	1706	2.39	820
7	RS	0.2	-311	6.6	2.91	381.0	52.50	2560	1668	2.88	624
7	RD	0.2	-321	6.7	3.53	264.0	77.40	3499	2936	1.05	--

R – Right collection pit Average Temperature – 26°C
S – sample from shallow end of pit Approximate Load – 23 kg COD/test period
D – sample from deep end of pit

Table F.11. Raw water quality data for the control 6/01/00 – 6/07/00 testing period

Time	Sample	DO	ORP	pH	Cond	NH$_3$-N	PO$_4$-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	RS	0.0	-337	8.0	0.68	38.0	6.99	420	388	0.39	0
1	RD	0.1	-340	8.0	0.70	21.0	7.77	416	314	0.23	5
2	RS	0.1	-317	7.1	1.03	44.0	12.52	578	610	--	--
2	RD	0.1	-320	7.1	1.26	37.0	10.68	651	746	--	--
5	RS	0.6	-314	6.5	2.30	206.0	28.26	1894	1176	1.80	306
5	RD	0.7	-310	6.5	2.83	470.0	21.76	2064	1370	2.07	255
7	RS	0.1	-304	6.5	2.97	262.0	59.30	2323	2354	--	--
7	RD	0.3	-313	6.4	3.49	294.0	77.50	2647	2818	--	--

R – Right collection pit   Average Temperature – 25°C
S – sample from shallow end of pit   Approximate Load – 24 kg COD/test period
D – sample from deep end of pit

Table F.12. Raw water quality data for the control 6/15/00 – 6/21/00 testing period

Time	Sample	DO	ORP	pH	Cond	NH$_3$-N	PO$_4$-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	RS	0.4	--	7.7	0.69	25.0	5.71	323	394	0.38	0
1	RD	0.8	--	8.3	0.63	17.0	5.38	268	--	0.43	0
2	RS	0.1	--	7.1	0.94	52.0	11.77	679	550	--	--
2	RD	0.0	--	7.5	1.13	72.0	13.92	550	656	--	--
5	RS	0.2	--	6.6	2.24	42.0	34.70	1729	1366	1.08	430
5	RD	0.1	--	6.7	2.61	118.0	37.13	1791	1806	1.67	529
7	RS	0.2	-361	6.7	2.79	204.0	53.40	2274	--	2.58	0
7	RD	0.2	-355	6.7	3.20	269.0	63.00	2517	--	3.30	341

R – Right collection pit   Average Temperature – 25°C
S – sample from shallow end of pit   Approximate Load – 27 kg COD/test period
D – sample from deep end of pit

Table F.13. Raw water quality data for the control 8/08/00 – 8/14/00 testing period

Time	Sample	DO	ORP	pH	Cond	NH$_3$-N	PO$_4$-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	LS	0.1	-217	7.6	0.76	23.0	9.30	742	708	0.25	13
1	LD	0.1	-281	8.1	0.86	42.0	10.20	964	344	0.50	16
2	LS	0.1	-314	7.4	1.47	15.0	23.10	382	1042	0.14	27
2	LD	0.1	-333	7.4	2.12	92.0	27.00	330	1078	0.95	254
4	LS	0.1	-332	7.5	2.88	151.0	45.40	1276	1480	2.58	545
4	LD	0.1	-357	7.7	3.42	160.0	63.80	1482	1608	2.67	379
7	LS	0.1	-455	7.6	4.55	536.0	56.70	2002	2716	4.65	583
7	LD	0.1	-457	8.5	4.56	691.0	50.90	2133	2618	5.40	738

L – Left collection pit   Average Temperature – 29°C
S – sample from shallow end of pit   Approximate Load –38 kg COD/test period
D – sample from deep end of pit

Table F.14. Raw water quality data for the control 8/15/00 – 8/21/00 testing period

Time	Sample	DO	ORP	pH	Cond	NH$_3$-N	PO$_4$-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	LS	5.6	20	7.9	0.25	72.0	1.00	79	706	0.04	0
1	LD	0.1	-162	8.7	0.89	81.0	1.76	305	820	0.48	32
2	LS	0.1	-260	8.0	1.23	274.0	11.00	440	1166	0.28	29
2	LD	0.1	-307	8.6	1.96	82.0	18.20	683	1216	0.83	160
4	LS	0.1	-333	7.8	2.43	122.0	29.35	871	1166	1.23	137
4	LD	0.1	-346	7.7	2.93	84.0	46.47	1064	1216	2.01	313
7	LS	0.9	-314	7.4	3.57	324.0	43.90	1834	2070	2.70	530
7	LD	1.0	-324	7.4	4.21	510.0	53.80	2338	2224	4.50	658

L – Left collection pit   Average Temperature – 31°C
S – sample from shallow end of pit   Approximate Load – 41 kg COD/test period
D – sample from deep end of pit

Table F.15. Raw water quality data for the control 8/22/00 – 8/28/00 testing period

Time	Sample	DO	ORP	pH	Cond	NH$_3$-N	PO$_4$-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	LS	ND	120	7.4	0.46	12.0	13.30	1141	ND	0.12	32
1	LD	ND	-197	8.9	0.80	55.0	16.70	209	430	0.78	31
2	LS	ND	-250	7.2	0.99	12.0	11.10	573	922	0.55	36
2	LD	ND	-302	7.6	0.92	156.0	15.40	367	900	1.18	136
4	LS	0.0	-290	7.4	2.18	130.0	42.30	1202	1684	1.89	318
4	LD	0.0	-322	7.3	2.96	258.0	37.20	1523	1634	2.88	575
7	LS	ND	-270	6.9	3.78	609.0	73.40	2764	2568	3.75	778
7	LD	ND	-318	7.1	4.81	887.0	79.80	3100	2636	4.68	886

L – Left collection pit   Average Temperature – 31°C
S – sample from shallow end of pit   Approximate Load – 44 kg COD/test period
D – sample from deep end of pit

Table F.16. Raw water quality data for the control 8/31/00 – 9/06/00 testing period

Time	Sample	DO	ORP	pH	Cond	NH$_3$-N	PO$_4$-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	LS	-0.1	-232	7.4	0.61	108.0	3.70	315	660	0.21	1
1	LD	-0.1	-317	8.5	0.84	83.0	3.20	271	ND	0.44	1
2	LS	0.0	-287	7.1	1.20	68.0	10.10	700	942	0.41	90
2	LD	0.0	-363	7.4	1.91	119.0	11.90	817	730	0.65	185
6	LS	0.0	-332	6.9	3.76	240.0	75.88	6162	2674	2.58	904
6	LD	0.0	-341	7.1	4.18	203.0	59.91	2788	1836	2.91	941
7	LS	0.0	-318	7.0	3.90	240.0	64.50	2687	2430	3.18	727
7	LD	0.1	-334	7.2	4.67	639.0	25.40	3250	2184	3.93	864

L – Left collection pit   Average Temperature – 28°C
S – sample from shallow end of pit   Approximate Load – 47 kg COD/test period
D – sample from deep end of pit

Table F.17. Raw water quality data for the control 9/14/00 – 9/20/00 testing period

Time	Sample	DO	ORP	pH	Cond	NH$_3$-N	PO$_4$-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	LS	0.0	-211	7.4	0.75	87.0	9.50	305	712	0.52	1
1	LD	0.0	-253	8.5	1.02	101.0	14.00	322	464	1.03	1
2	LS	0.0	-250	7.3	1.45	225.0	15.91	701	1530	0.29	1
2	LD	0.0	-290	7.3	2.54	261.0	25.50	1120	ND	1.59	139
5	LS	0.1	-281	7.2	4.85	210.0	65.90	2305	2454	3.48	696
5	LD	0.0	-317	7.4	5.14	340.0	53.80	2626	2494	4.62	979
7	LS	0.0	-286	6.7	6.06	571.0	84.30	3975	3316	3.45	1290
7	LD	0.1	-304	7.0	6.70	553.0	81.90	4036	3376	4.77	1240

L – Left collection pit   Average Temperature – 23°C
S – sample from shallow end of pit   Approximate Load – 53 kg COD/test period
D – sample from deep end of pit

Table F.18. Raw water quality data for the BIO 9/30/99 – 10/06/99 testing period

Time	Sample	DO	ORP	pH	Cond	NH$_3$-N	PO$_4$-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	LC	0.0	--	7.9	0.82	--	--	358	--	--	--
2	LC	0.1	--	7.8	1.66	--	--	590	1250	--	--
2	LS	--	--	--	--	--	--	--	--	0.14	14
2	LD	--	--	--	--	--	--	--	--	0.16	13
5	LC	0.0	--	7.7	3.64	--	--	1615	--	--	--
6	LC	0.1	--	7.8	4.05	361.4	--	1787	--	--	--
7	LC	0.0	--	7.9	5.07	413.8	--	1558	2626	--	--
7	LS	--	--	--	--	--	--	--	--	0.78	266
7	LD	--	--	--	--	--	--	--	--	1.17	3

L – Left collection pit   Average Temperature – No Data
C – composite sample of shallow and deep   Approximate Load – 35 kg COD/test period
S – sample from shallow end of pit
D – sample from deep end of pit

Table F.19. Raw water quality data for the BIO 10/07/99 – 10/13/99 testing period

Time	Sample	DO	ORP	pH	Cond	NH$_3$-N	PO$_4$-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	LS	0.1	-208	7.4	1.40	103.9	--	469	--	--	--
1	LD	0.1	-230	7.4	1.40	--	--	432	--	--	--
2	LS	0.0	-238	7.6	2.20	173.4	--	319	1084	0.83	59
2	LD	0.0	-257	7.7	2.20	170.0	--	466	984	0.29	49
5	LS	0.0	-307	7.9	3.70	--	--	--	--	--	--
5	LD	0.0	-342	7.8	3.80	--	--	--	--	--	--
7	LS	0.1	-341	8.0	4.50	416.5	15.37	1405	2064	1.46	275
7	LD	0.1	-346	7.9	4.50	420.0	15.39	1251	1958	2.18	357

L – Left collection pit   Average Temperature – No Data
S – sample from shallow end of pit   Approximate Load – 37 kg COD/test period
D – sample from deep end of pit

Table F.20. Raw water quality data for the BIO 10/15/99 – 10/20/99 testing period

Time	Sample	DO	ORP	pH	Cond	NH$_3$-N	PO$_4$-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
2	LS	0.0	-126	8.1	2.80	271.8	14.84	746	992	0.67	81
2	LD	0.0	-251	8.1	2.80	263.6	14.72	667	986	0.59	89
5	LS	0.1	-228	8.1	--	--	--	--	--	--	--
5	LD	0.0	-287	8.1	--	--	--	--	--	--	--
6	LS	0.1	-341	8.4	5.81	--	--	--	--	--	--
6	LD	0.0	-248	8.3	5.80	--	--	--	--	--	--
7	LS	0.2	-230	8.4	6.18	565.5	18.15	2153	2368	2.84	590
7	LD	0.1	-296	8.4	6.16	563.3	18.28	2739	2378	0.33	488

L – Left collection pit   Average Temperature – 21°C
S – sample from shallow end of pit   Approximate Load – 39 kg COD/test period
D – sample from deep end of pit

Table F.21. Raw water quality data for the BIO 10/21/99 – 10/27/99 testing period

Time	Sample	DO	ORP	pH	Cond	NH$_3$-N	PO$_4$-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	LS	2.9	85	8.4	1.27	--	--	--	--	--	--
1	LD	0.1	45	8.2	1.26	--	--	--	--	--	--
2	LS	4.3	187	8.2	2.44	76.7	9.07	903	836	0.07	71
2	LD	0.3	47	8.1	2.47	77.2	9.32	964	470	0.15	65
5	LS	0.1	-194	8.0	5.20	--	--	--	--	--	--
5	LD	0.0	-222	8.0	5.25	--	--	--	--	--	--
6	LS	0.1	-264	7.9	5.94	--	--	--	--	--	--
6	LD	0.0	-283	7.9	5.93	--	--	--	--	--	--
7	LS	0.1	-319	7.8	6.40	520.0	97.83	2055	2702	1.54	412
7	LD	0.1	-312	7.9	6.21	760.0	86.74	2233	2644	2.00	460

L – Left collection pit   Average Temperature – 23°C
S – sample from shallow end of pit   Approximate Load – 41 kg COD/test period
D – sample from deep end of pit

Table F.22. Raw water quality data for the BIO 10/29/99 – 11/03/99 testing period

Time	Sample	DO	ORP	pH	Cond	NH$_3$-N	PO$_4$-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
2	LS	0.1	-191	8.1	3.22	260.0	64.57	777	1528*	0.34	64
2	LD	0.0	-224	8.1	3.20	420.0	71.09	732	3080*	0.90	83
7	LS	0.1	-212	8.0	6.08	180.0	54.78	1571	2462	--	--
7	LD	0.1	-238	8.0	6.13	180.0	48.92	1617	2450	--	--

L – Left collection pit   Average Temperature – 24°C
S – sample from shallow end of pit   Approximate Load – 43 kg COD/test period
D – sample from deep end of pit

Table F.23. Raw water quality data for the BIO 2/17/00 – 2/23/00 testing period

Time	Sample	DO	ORP	pH	Cond	NH$_3$-N	PO$_4$-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	LS	--	192	7.4	0.38	10.8	5.20	142	290	0.00	0
1	LD	--	191	7.3	0.37	14.9	5.10	151	360	0.00	0
2	LS	--	107	7.4	0.70	22.6	8.06	328	476	--	--
2	LD	--	49	7.4	0.68	21.8	7.68	387	540	--	--
5	LS	0.0	80	7.5	1.49	80.8	13.28	358	888	0.00	0
5	LD	0.0	-97	7.5	1.50	81.5	13.40	362	682	0.00	25
7	LS	0.0	-140	7.6	1.95	110.8	19.74	473	1002	0.12	712
7	LD	0.0	-154	7.6	1.95	105.6	19.44	527	958	0.30	721

L – Left collection pit   Average Temperature – 20°C
S – sample from shallow end of pit   Approximate Load – 10 kg COD/test period
D – sample from deep end of pit

Table F.24. Raw water quality data for the BIO 2/17/00 – 2/23/00 testing period

Time	Sample	DO	ORP	pH	Cond	NH₃-N	PO₄-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	RS	--	123	7.3	0.36	11.6	3.22	124	424	0.00	0
1	RD	--	176	7.2	0.36	12.4	3.24	136	322	0.00	0
2	RS	--	50	7.5	0.73	25.1	5.43	459	528	--	--
2	RD	--	23	7.4	0.72	24.4	5.89	413	490	--	--
5	RS	0.0	-21	7.6	1.90	118.1	13.40	620	1334	0.00	29
5	RD	0.0	-85	7.7	1.89	119.5	12.93	397	946	0.00	0
7	RS	0.0	-149	7.5	2.68	187.1	19.76	860	1422	0.12	809
7	RD	0.0	-185	7.6	2.68	181.8	19.10	720	1372	0.72	796

R – Right collection pit   Average Temperature – 20°C
S – sample from shallow end of pit   Approximate Load – 11 kg COD/test period
D – sample from deep end of pit

Table F.25. Raw water quality data for the BIO 4/06/00 – 4/12/00 testing period

Time	Sample	DO	ORP	pH	Cond	NH₃-N	PO₄-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	LS	1.6	-18	7.9	1.17	47.7	9.46	492	554	0.11	15
1	LD	0.1	-306	8.2	1.19	101.4	11.10	560	754	0.15	50
2	LS	0.1	-296	7.4	2.10	131.0	21.45	892	1286	--	--
2	LD	0.1	-343	7.5	2.46	149.0	21.61	1006	1020	--	--
5	LS	0.2	-344	7.6	4.20	442.0	40.74	1284	1994	--	270
5	LD	0.1	-319	7.4	4.20	490.0	44.08	1170	1934	--	169
7	LS	0.1	-312	7.5	5.30	897.0	52.07	1319	2476	--	241
7	LD	0.1	-353	7.5	5.38	441.0	45.23	1429	2326	--	329

L – Left collection pit   Average Temperature – 17°C
S – sample from shallow end of pit   Approximate Load – 25 kg COD/test period
D – sample from deep end of pit

Table F.26. Raw water quality data for the BIO 4/06//00 – 4/12/00 testing period

Time	Sample	DO	ORP	pH	Cond	NH$_3$-N	PO$_4$-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	RS	5.2	-31	8.0	1.35	83.0	10.44	510	840	0.07	39
1	RD	0.0	-286	8.2	1.29	88.8	10.70	518	772	0.13	24
2	RS	2.7	-182	7.6	2.53	161.0	21.16	1128	1244	--	--
2	RD	0.1	-324	7.6	2.64	205.0	24.04	1110	1216	--	--
5	RS	2.2	272	7.6	5.10	348.0	49.78	1302	2532	--	461
5	RD	0.1	-284	7.5	5.10	564.0	26.06	1624	2090	--	338
7	RS	0.1	-279	--	6.21	1075.0	36.57	1153	2334	--	141
7	RD	0.1	-338	7.8	6.19	655.0	34.87	1284	2368	--	139

R – Right collection pit   Average Temperature – 17°C
S – sample from shallow end of pit   Approximate Load – 29 kg COD/test period
D – sample from deep end of pit

Table F.27. Raw water quality data for the BIO 5/18/00 – 5/24/00 testing period

Time	Sample	DO	ORP	pH	Cond	NH$_3$-N	PO$_4$-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	LS	--	--	--	--	--	--	--	--	0.07	0
1	LD	--	--	--	--	--	--	--	--	0.09	1
5	LS	0.1	-311	7.4	2.24	219.0	31.80	199	1348	0.45	97
5	LD	0.1	-320	7.3	2.24	176.0	30.30	873	1230	0.30	140
7	LS	0.1	-304	7.2	2.59	189.0	42.30	1320	1704	0.78	117
7	LD	0.1	-314	7.2	2.63	73.0	51.00	1326	1412	0.63	174

L – Left collection pit   Average Temperature –24°C
S – sample from shallow end of pit   Approximate Load – 19 kg COD/test period
D – sample from deep end of pit

Table F.28. Raw water quality data for the BIO 8/31/00 – 9/06/00 testing period

Time	Sample	DO	ORP	pH	Cond	NH$_3$-N	PO$_4$-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	RS	3.7	7	8.0	0.88	92.0	5.40	259	374	0.03	3
1	RD	0.0	-256	7.8	0.88	81.0	6.50	327	450	0.07	1
2	RS	0.0	-130	7.8	1.65	104.0	18.10	408	918	0.08	1
2	RD	0.0	-258	7.9	1.66	101.0	20.40	424	800	0.17	1
6	RS	0.1	-295	8.2	3.72	251.0	43.63	1917	2030	0.78	88
6	RD	0.1	-323	8.2	3.77	558.0	44.48	1623	1938	0.81	181
7	RS	0.0	-289	8.3	4.05	318.0	12.00	1502	2334	0.87	195
7	RD	0.1	-312	8.3	4.09	288.0	16.50	1691	2284	0.66	240

R – Right collection pit   Average Temperature – 28°C
S – sample from shallow end of pit   Approximate Load – 49 kg COD/test period
D – sample from deep end of pit

Table F.29. Raw water quality data for the BIO 10/24/00 – 10/30/00 testing period

Time d	Sample Location	DO mg/L	ORP mV	pH	Cond mS/cm	NH$_3$-N mg/L	PO$_4$-P mg/L	COD mg/L	TS mg/L	Phenol mg/L	VA mg/L
1	RS	8.2	247	7.9	0.75	48.2	15.20	274	564	0.08	-1
1	RD	1.4	240	7.8	0.72	42.8	13.27	256	532	0.22	0
2	RS	7.5	219	7.8	1.46	56.0	24.78	582	510	0.02	1
2	RD	0.0	193	7.8	1.44	95.0	18.85	227	522	0.07	4
4	RS	0.0	--	7.6	2.79	183.0	40.27	929	2002	0.24	35
4	RD	0.0	--	7.8	2.83	132.0	38.71	961	1498	0.21	27
7	RS	0.0	-46	7.9	3.97	536.0	38.19	1161	2450	0.00	0
7	RD	0.1	-138	7.9	4.05	--	34.27	975	1898	0.18	1

R – Right collection pit
S – sample from shallow end of pit
D – sample from deep end of pit
Average Temperature – 23°C
Approximate Load – 34 kg COD/test period

Table F.30. Raw water quality data for the BIO 11/02/00 – 11/08/00 testing period

Time d	Sample Location	DO mg/L	ORP mV	pH	Cond mS/cm	NH$_3$-N mg/L	PO$_4$-P mg/L	COD mg/L	TS mg/L	Phenol mg/L	VA mg/L
1	RS	7.1	328	7.4	0.91	104.0	14.48	434	784	0.00	0
1	RD	2.3	301	7.4	0.87	94.0	14.74	199	532	0.06	1
2	RS	4.6	236	7.5	1.72	132.0	23.00	802	104	0.48	0
2	RD	0.1	280	7.6	1.65	119.0	25.20	310	446	0.21	1
5	RS	0.0	-11	7.9	3.31	427.0	39.03	1393	2420	0.81	43
5	RD	0.0	-9	7.9	3.31	447.0	83.35	1265	2444	0.69	55
7	RS	0.0	-111	8.2	4.34	377.0	31.90	1475	2410	1.05	180
7	RD	0.0	-109	8.2	4.35	567.0	28.30	1373	2268	0.72	136

R – Right collection pit
S – sample from shallow end of pit
D – sample from deep end of pit
Average Temperature – 20°C
Approximate Load – 38 kg COD/test period

Table F.31. Raw water quality data for the BIO 11/16/00 – 11/22/00 testing period

Time	Sample	DO	ORP	pH	Cond	NH₃-N	PO₄-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	RS	3.0	210	8.0	1.48	131.0	18.90	457	1038	0.40	1
1	RD	0.8	214	8.0	1.48	139.0	17.90	462	854	0.40	1
2	RS	0.0	149	8.4	2.72	234.0	16.10	743	1266	0.33	105
2	RD	0.0	178	8.4	2.68	213.0	14.50	622	1044	0.12	6
5	RS	0.2	--	8.1	4.82	445.0	16.40	1659	2800	1.77	73
5	RD	0.0	--	8.1	4.79	368.0	13.20	1630	2348	0.93	151
7	RS	0.0	63	8.3	5.80	461.0	10.20	1879	3164	1.77	255
7	RD	0.0	67	8.4	5.88	482.0	28.80	2055	3202	0.93	183

R – Right collection pit   Average Temperature – 9°C
S – sample from shallow end of pit   Approximate Load – 46 kg COD/test period
D – sample from deep end of pit

Table F.32. Raw water quality data for the BIO AMS 3/09/00 – 3/15/00 testing period

Time	Sample	DO	ORP	pH	Cond	NH₃-N	PO₄-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	LS	7.8	143	7.8	0.78	32.2	9.51	205	652	0.00	0
1	LD	7.9	135	7.9	0.79	31.2	9.54	163	554	0.00	0
2	LS	1.4	102	7.8	1.18	53.5	15.18	375	856	--	--
2	LD	7.1	105	8.0	1.17	55.9	15.56	284	738	--	--
5	LS	2.7	88	8.1	2.32	144.0	27.70	740	1260	0.02	7
5	LD	2.7	104	8.1	2.33	147.3	28.28	780	1224	0.02	4
7	LS	0.1	-309	8.0	2.88	178.7	33.40	1730	1962	0.05	1
7	LD	0.1	-71	8.2	2.88	184.5	33.83	930	1884	0.43	0

L – Left collection pit   Average Temperature – 21°C
S – sample from shallow end of pit   Approximate Load – 16 kg COD/test period
D – sample from deep end of pit

Table F.33. Raw water quality data for the BIO AMS 3/09/00 – 3/15/00 testing period

Time	Sample Location	DO	ORP	pH	Cond	NH$_3$-N	PO$_4$-P	COD	TS	Phenol	VA
d		mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	RS	4.4	108	8.0	0.98	46.1	10.09	409	726	0.00	0
1	RD	4.4	133	8.1	0.97	46.1	9.54	219	602	0.00	0
2	RS	0.1	12	7.9	1.50	87.6	16.24	384	816	--	--
2	RD	3.9	98	8.1	1.50	91.6	16.68	358	838	--	--
5	RS	0.1	-1	8.0	2.85	199.6	29.68	770	1538	0.04	10
5	RD	3.1	100	8.3	2.80	196.9	28.45	640	1364	0.09	5
7	RS	0.0	-245	8.1	3.60	243.5	26.53	1110	1904	0.04	61
7	RD	0.0	-158	8.1	3.57	254.1	27.90	860	1910	0.59	0

R – Right collection pit

S – sample from shallow end of pit

D – sample from deep end of pit

Average Temperature – 21°C

Approximate Load – 19 kg COD/test period

Table F.34. Raw water quality data for the BIO AMS 4/27/00 – 5/03/00 testing period

Time	Sample Location	DO	ORP	pH	Cond	NH$_3$-N	PO$_4$-P	COD	TS	Phenol	VA
d		mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	LS	0.1	65	7.3	1.51	111.0	9.18	675	926	--	--
1	LD	0.0	36	7.4	1.54	56.0	9.49	670	984	--	--
2	LS	0.3	-101	7.7	2.26	120.0	8.38	1116	1352	0.12	0
2	LD	0.0	-112	7.7	2.22	64.0	11.64	1338	1426	0.22	0
5	LS	0.1	-324	7.6	3.95	386.0	19.44	2659	2814	0.12	808
5	LD	0.0	-295	7.7	3.92	312.0	18.76	2699	2746	0.22	773
7	LS	0.1	-347	7.6	4.50	924.0	26.22	3506	3156	0.94	1161
7	LD	0.1	-354	7.5	4.47	880.0	26.12	2769	2850	1.12	1158

L – Left collection pit

S – sample from shallow end of pit

D – sample from deep end of pit

Average Temperature – 20°C

Approximate Load – 32 kg COD/test period

Table F.35. Raw water quality data for the BIO AMS 4/27/00 – 5/03/00 testing period

Time	Sample	DO	ORP	pH	Cond	NH₃-N	PO₄-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	RS	0.0	57	7.6	1.68	60.0	11.86	539	554	--	--
1	RD	0.0	57	7.6	1.66	193.0	10.52	502	588	--	--
2	RS	0.0	-85	7.8	2.47	104.0	13.40	744	1344	0.04	0
2	RD	0.0	-93	7.9	2.46	144.0	10.15	684	1204	0.20	0
5	RS	0.0	-319	7.9	4.22	642.0	15.68	1864	2716	0.04	276
5	RD	0.0	-280	8.0	4.18	410.0	13.74	1885	2592	0.20	548
7	RS	0.1	-350	7.4	4.84	432.0	27.72	2964	3232	0.92	775
7	RD	0.1	-356	7.6	5.13	1491.0	24.85	3255	3194	0.63	975

R – Right collection pit   Average Temperature – 20°C
S – sample from shallow end of pit   Approximate Load – 36 kg COD/test period
D – sample from deep end of pit

Table F.36. Raw water quality data for the BIO AMS 6/15/00 – 6/21/00 testing period

Time	Sample	DO	ORP	pH	Cond	NH₃-N	PO₄-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	LS	3.9	--	7.6	0.68	34.0	8.02	253	454	0.01	0
1	LD	0.8	--	7.5	0.67	23.0	8.66	281	442	0.05	0
2	LS	0.1	--	8.0	1.12	76.0	10.60	833	742	--	--
2	LD	1.7	--	8.1	1.07	36.0	11.80	511	590	--	--
5	LS	0.1	--	7.8	2.30	85.0	23.86	1009	1392	0.12	88
5	LD	0.1	--	8.1	2.28	117.0	21.23	896	1360	0.14	164
7	LS	0.0	-409	7.7	2.32	194.0	31.00	1172	1616	0.51	0
7	LD	0.2	-304	8.1	2.42	405.0	24.80	1154	1720	0.03	0

L – Left collection pit   Average Temperature – 25°C
S – sample from shallow end of pit   Approximate Load – 24 kg COD/test period
D – sample from deep end of pit

Table F.37. Raw water quality data for the ABIO 8/22/00 – 8/28/00 testing period

Time	Sample Location	DO	ORP	pH	Cond	NH$_3$-N	PO$_4$-P	COD	TS	Phenol	VA
d		mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	RS	--	35	8.5	0.87	34.0	33.70	320	514	0.04	1
1	RD	--	-80	8.3	0.87	69.0	25.20	298	462	0.08	1
2	RS	--	86	8.2	1.76	34.0	22.00	1240	1718	0.58	96
2	RD	--	-282	7.5	1.58	83.0	21.70	729	1156	0.50	97
4	RS	0.0	-172	8.4	2.58	261.0	38.40	679	1602	0.21	5
4	RD	0.0	-286	8.3	2.65	166.0	40.10	828	1570	0.51	73
7	RS	--	-280	8.1	3.18	392.0	34.70	2430	2188	0.54	1
7	RD	--	-294	8.0	3.24	591.0	34.10	2974	2368	0.66	1

R – Right collection pit Average Temperature – 31°C
S – sample from shallow end of pit Approximate Load – 45 kg COD/test period
D – sample from deep end of pit

Table F.38. Raw water quality data for the ABIO AMS 9/14/00 – 9/20/00 testing period

Time	Sample Location	DO	ORP	pH	Cond	NH$_3$-N	PO$_4$-P	COD	TS	Phenol	VA
d		mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	RS	4.8	26	8.2	1.21	111.0	14.60	302	626	0.14	1
1	RD	1.8	-28	8.2	1.22	116.0	13.70	301	516	0.24	1
2	RS	0.0	-100	8.1	2.19	336.0	29.64	649	1214	0.29	1
2	RD	0.8	-118	8.1	2.14	323.0	25.57	563	1068	0.40	9
5	RS	0.0	-240	8.5	4.42	183.0	27.00	1545	3448	0.18	72
5	RD	0.0	-246	8.6	4.64	370.0	15.40	1340	2612	0.15	46
7	RS	0.0	-251	8.3	5.30	242.0	17.00	2043	3382	0.39	90
7	RD	0.0	-240	8.3	5.37	687.0	19.90	1743	2870	0.39	65

R – Right collection pit Average Temperature – 23°C
S – sample from shallow end of pit Approximate Load – 54 kg COD/test period
D – sample from deep end of pit

Table F.39. Raw water quality data for the corncobs 10/24/99 – 10/30/99 testing period

Time	Sample	DO	ORP	pH	Cond	NH$_3$-N	PO$_4$-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	LS	7.6	238	--	--	--	--	--	--	--	--
1	LD	4.4	238	7.8	0.68	38.2	18.42	247	522	0.52	-1
2	LS	6.9	219	--	--	--	--	--	--	--	--
2	LD	0.9	198	7.8	1.34	95.0	20.67	286	--	0.16	1
4	LS	--	--	--	--	--	--	--	--	--	--
4	LD	0.0	--	8.0	3.19	100.0	41.06	1148	2092	1.11	92
7	LS	--	--	--	--	--	--	--	--	--	--
7	LD	0.0	-103	8.1	4.59	260.0	34.14	1826	2976	1.14	140

L – Left collection pit   Average Temperature – 23°C
S – sample from shallow end of pit   Approximate Load – 33 kg COD/test period
D – sample from deep end of pit

Table F.40. Raw water quality data for the mulch 11/02/99 – 11/08/99 testing period

Time	Sample	DO	ORP	pH	Cond	NH$_3$-N	PO$_4$-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	LS	8.3	323	7.5	0.78	72.0	4.57	322	838	0.27	52
1	LD	4.7	299	7.4	0.90	459.0	4.99	314	634	0.36	48
2	LS	2.3	234	7.7	1.65	120.0	16.66	666	746	0.81	1
2	LD	0.0	279	7.7	1.63	138.0	18.36	580	1104	1.17	7
5	LS	0.0	137	8.0	3.37	389.0	56.32	1499	1610	0.90	88
5	LD	0.1	144	8.0	3.35	456.0	22.70	1504	1980	0.84	125
7	LS	0.0	-154	8.3	4.40	491.0	38.02	1872	2654	0.60	123
7	LD	0.0	-83	8.3	4.43	609.0	42.61	1867	2462	0.84	115

L – Left collection pit   Average Temperature – 20°C
S – sample from shallow end of pit   Approximate Load – 37 kg COD/test period
D – sample from deep end of pit

Table F.41. Raw water quality data for the mulch 11/16/99 – 11/22/99 testing period

Time	Sample	DO	ORP	pH	Cond	NH$_3$-N	PO$_4$-P	COD	TS	Phenol	VA
d	Location	mg/L	mV		mS/cm	mg/L	mg/L	mg/L	mg/L	mg/L	mg/L
1	LS	9.0	230	7.5	1.09	112.0	12.70	1762	1810	1.98	267
1	LD	3.7	224	7.6	1.10	112.0	14.20	2214	1796	2.55	297
2	LS	3.8	184	8.1	1.97	140.0	20.40	1732	2860	2.25	436
2	LD	0.5	212	8.1	2.05	155.0	14.00	1603	1842	2.76	372
5	LS	0.0	--	8.1	4.29	321.0	39.90	2245	3846	0.66	362
5	LD	0.0	--	8.2	4.28	347.0	34.90	2082	2674	0.48	230
7	LS	0.0	157	8.4	5.34	361.0	31.20	2366	2870	0.66	385
7	LD	0.0	153	8.4	5.30	394.0	17.60	2311	2814	0.81	152

L – Left collection pit   Average Temperature – 9°C
S – sample from shallow end of pit   Approximate Load – 9 kg COD/test period
D – sample from deep end of pit

APPENDIX G

AVERAGED WATER QUALITY DATA

Table G.1. Average water quality results for control and BIO system at the low loading range

		Control Treatment				Bioreactor Treatment			
		Day				Day			
		1	2	5	7	1	2	5	7
DO	mg/L	0.23	0.35	0.00	ND	ND	ND	0.00	0.00
ORP	mV	125	49	-178	-192	171	57	-31	-157
pH		7.5	7.4	7.3	7.0	7.3	7.4	7.6	7.6
Conductivity	mS/cm	0.26	0.51	1.26	1.81	0.37	0.71	1.70	2.32
NH$_3$-N	mg/L	6.0	21.0	53.5	81.0	12.4	23.5	100.0	146.3
NO$_3$-N	mg/L	96.0	ND	168.8	54.3	28.3	ND	10.7	180.0
PO$_4$-P	mg/L	1.17	4.35	15.73	22.76	4.19	6.76	13.26	19.51
COD	mg/L	2	231	609	1281	138	397	434	645
TS	mg/L	175	408	941	1335	349	509	963	1189
Phenol	mg/L	0.00	ND	0.83	0.91	0.00	ND	0.00	0.32
VA	mg/L	0.3	ND	136.3	281.5	0.3	ND	13.5	759.5

Table G.2. Average water quality results for control and BIO system at the mid loading range

		Control Treatment				Bioreactor Treatment			
		Day				Day			
		1	2	5	7	1	2	5	7
DO	mg/L	0.17	0.18	0.23	0.18	1.72	1.72	0.45	0.07
ORP	mV	-71	-346	-324	-331	-160	-286	-218	-317
pH		8.0	7.4	6.8	6.8	8.1	7.5	7.5	7.4
Conductivity	mS/cm	0.59	1.07	2.59	3.30	1.25	2.43	3.85	4.72
NH$_3$-N	mg/L	28.5	88.6	204.0	288.4	80.2	161.5	373.2	555.0
NO$_3$-N	mg/L	408.2	ND	709.7	1976.0	5.8	ND	330.0	2388.0
PO$_4$-P	mg/L	5.16	10.26	31.32	56.91	10.43	22.07	37.13	43.67
COD	mg/L	244	509	1608	2334	520	1034	1075	1305
TS	mg/L	356	651	1490	2084	730	1192	1855	2103
Phenol	mg/L	0.23	ND	1.08	1.67	0.11	ND	0.38	0.71
VA	mg/L	5.7	ND	392.8	617.4	21.5	ND	245.8	190.2

Table G.3. Average water quality results for control and BIO system at the high loading range

		Control Treatment				Bioreactor Treatment			
		Day				Day			
		1	2	5	7	1	2	5	7
DO	mg/L	0.46	0.06	0.07	0.22	2.29	1.00	0.04	0.07
ORP	mV	-200	-288	-330	-327	82	-12	-221	-198
pH		7.9	7.5	7.2	7.1	7.8	7.9	8.0	8.1
Conductivity	mS/cm	0.74	1.58	3.62	5.00	1.09	2.23	3.92	5.16
NH$_3$-N	mg/L	64.7	145.2	231.4	527.4	92.9	172.9	351.4	440.5
NO$_3$-N	mg/L	42.5	87.8	707.5	560.8	17.0	368.6	155.8	215.1
PO$_4$-P	mg/L	9.31	19.69	61.49	75.81	13.30	24.61	39.89	34.73
COD	mg/L	443	652	2292	2952	357	605	1444	1688
TS	mg/L	601	989	2047	2700	641	924	2185	2451
Phenol	mg/L	0.40	1.17	2.49	3.51	0.16	0.31	0.78	1.15
VA	mg/L	40.5	165.3	691.4	1018.3	0.8	39.3	81.6	252.6

Table G.4. Water quality results for BIO and BIO/AMS systems (mid loading range)

		BIO Treatment				BIO/AMS Treatment			
		Day				Day			
		1	2	5	7	1	2	5	7
DO	mg/L	1.72	1.72	0.45	0.07	4.86	2.38	1.47	0.07
ORP	mV	-160	-286	-218	-317	130	79	73	-249
pH		8.1	7.5	7.5	7.4	7.8	8.0	8.1	8.1
Conductivity	mS/cm	1.25	2.43	3.85	4.72	0.81	1.26	2.43	2.95
NH$_3$-N	mg/L	80.2	161.5	373.2	555.0	35.4	66.8	48.3	243.3
NO$_3$-N	mg/L	5.8	ND	330.0	2388.0	144.7	ND	400.8	928.0
PO$_4$-P	mg/L	10.43	22.07	37.13	43.67	9.22	14.34	26.53	29.58
COD	mg/L	520	1034	1075	1305	255	458	806	1159
TS	mg/L	730	1192	1855	2103	572	763	1356	1833
Phenol	mg/L	0.11	ND	0.38	0.71	0.01	ND	0.07	0.27
VA	mg/L	21.5	ND	245.8	190.2	0.0	ND	46.3	10.1

Table G.5. Water quality results for BIO and BIO/AMS systems (high loading range)

		BIO Treatment				BIO/AMS Treatment			
		Day				Day			
		1	2	5	7	1	2	5	7
DO	mg/L	2.29	1.00	0.04	0.07	0.04	0.10	0.04	0.06
ORP	mV	82	-12	-221	-198	54	-98	-304	-352
pH		7.8	7.9	8.0	8.1	ND	ND	7.8	7.5
Conductivity	mS/cm	1.09	2.23	3.92	5.16	ND	ND	4.07	4.74
NH_3-N	mg/L	92.9	172.9	351.4	440.5	105.0	108.0	437.5	931.8
NO_3-N	mg/L	17.0	368.6	155.8	215.1	ND	465	160	362.5
PO_4-P	mg/L	13.30	24.61	39.89	34.73	10.26	10.89	16.91	26.23
COD	mg/L	357	605	1444	1688	597	971	2277	3124
TS	mg/L	641	924	2185	2451	763	1332	2717	3108
Phenol	mg/L	0.16	0.31	0.78	1.15	ND	0.15	0.15	0.90
VA	mg/L	0.8	39.3	81.6	252.6	ND	0	601.3	1017.3

Table G.6. Water quality results for ABIO and ABIO/AMS systems (high loading range)

		ABIO Treatment				ABIO/AMS Treatment			
		Day				Day			
		1	2	5	7	1	2	5	7
DO	mg/L			0.01		3.30	0.40	0.02	0.02
ORP	mV	-22	-98	-229	-287	-1	-109	-243	-246
pH		8.4	7.8	8.4	8.1	8.2	8.1	8.5	8.3
Conductivity	mS/cm	0.87	1.67	2.62	3.21	1.22	2.17	4.53	5.34
NH_3-N	mg/L	51.5	58.5	213.5	491.5	133.5	329.5	276.5	464.5
NO_3-N	mg/L	21.8	51.5	52.5	63.5	13.5	34.0	133.5	183.0
PO_4-P	mg/L	29.45	21.85	39.25	34.40	14.15	27.60	21.20	18.45
COD	mg/L	309	985	754	2702	302	606	1443	1893
TS	mg/L	488	1437	1586	2278	571	1141	3030	3126
Phenol	mg/L	0.06	0.54	0.36	0.60	0.19	0.35	0.17	0.39
VA	mg/L	1	96.5	39	1	1	5	59	77.5

Table G.7. Water quality results for kenaf, hardwood mulch, and corncob media treatments

		Kenaf				Hardwood Mulch				Corncob			
		Day				Day				Day			
		1	2	5	7	1	2	5	7	1	2	5	7
DO	mg/L	3.80	2.03	0.04	0.03	6.43	1.67	0.04	0.02	6.01	3.88	0.02	0.02
ORP	mV	256	209	-10	-46	269	227	140	18	238	209	ND	-103
pH		7.7	7.9	7.9	8.1	7.5	7.9	8.1	8.4	7.8	7.8	8.0	8.1
Conductivity	mS/cm	1.04	1.95	3.64	4.73	0.97	1.83	3.82	4.87	0.68	1.34	3.19	4.59
NH_3-N	mg/L	93.2	141.5	333.7	484.6	188.8	138.3	378.3	463.8	38.2	95.0	100.0	260.0
NO_3-N	mg/L	21.0	39.8	92.7	99.3	51.2	110.5	202.0	216.5	24,9	26.0	75.0	43.0
PO_4-P	mg/L	15.75	20.41	38.49	28.61	9.11	17.39	38.45	32.36	18.43	20.68	41.06	34.14
COD	mg/L	347	548	1306	1486	1153	1145	1824	2104	247	286	1148	1826
TS	mg/L	717	649	2252	2565	1270	1638	2528	2700	522	ND	2092	2976
Phenol	mg/L	0.19	0.21	0.78	0.78	1.29	1.75	0.72	0.73	0.52	0.16	1.11	1.14
VA	mg/L	0.3	19.5	64.0	125.8	166.0	204.0	201.3	193.8	0.0	1.0	92.0	140.0

APPENDIX H

MICROBIOLOGICAL COUNTS FOR KENAF

Table H.1. Bacterial counts of Kenaf

	Actinomycetes	**Fungi**	**Total Bacteria**
Fresh Kenaf	920,000	50,000	6,300,000
Spent Kenaf	1,100,000	3,100,000	170,000,000

* Colonies per mL (Average of 2 reps)

APPENDIX I

CALCULATIONS - KENAF REQUIREMENTS FOR AN 880 HEAD

SWINE FACILITY PER YEAR

Calculations of the kenaf requirements for an 880 head swine facility per year:

Kenaf module density calculations

Assumptions:
1. Kenaf module dimensions: 32 ft x 8 ft x 8 ft
2. Module weight: 6 tons

$$\frac{6 \text{ tons}*2000 \text{ lb/ton}}{32 \text{ ft} * 8 \text{ ft} * 8 \text{ ft}} = \textbf{5.86lb/ft}^\textbf{3}$$

The approximate kenaf module density is 5.86 lb/ft^3.

Volume of kenaf in a module at the bioreactor density

Assumptions:
1. Approximate kenaf density in reactor: 4.76 lb/ft^3

$$\frac{(5.86 \text{ lb/ft}^3 - 4.76 \text{ lb/ft}^3) * 100\%}{5.86 \text{ lb/ft}^3} = 18.77\%$$

$$1.1877 * 32 \text{ ft} * 8 \text{ ft} * 8\text{ft} = \textbf{2432 ft}^\textbf{3}$$

The approximate volume of kenaf in a module at the bioreactor density of 4.76 lb/ft^3 is 2432 ft^3.

Volume of kenaf needed per year for an 880 head facility

Assumptions:
1. 2.5 ft^3 of kenaf per pig place (30 ft^3/12 pig place)
2. The kenaf in the bioreactor will be replaced every two weeks (26 change outs/yr)
3. Fifty percent of the spent kenaf will be recycled back into the bioreactor

$$2.5 \text{ ft}^3/\text{pig place} * 880 \text{ pig place} * 26 \text{ weeks/yr} * 0.5 = \textbf{28,600 ft}^\textbf{3}$$

Kenaf land requirements

Assumptions:
1. One module produces 2,432 ft^3 of kenaf at a density of 4.76 lb/ft^3
2. One module of kenaf is generated from 1 acre of land
3. 28,600 ft^3 of kenaf is needed per year

$$28,600 \text{ ft}^3/2432 \text{ ft}^3/\text{module} = 11.75 \text{ module} = \textbf{12 modules per year}$$

The land requirement for growing kenaf for an 880 head swine facility per year is **12 acres**.

APPENDIX J

CALCULATIONS – ENERGY REQUIREMENTS FOR AN

880 HEAD SWINE FACILITY

Calculations of the approximate energy requirements of the bioreactor system at an 880 head swine facility:

Horsepower Calculations

Assumptions:
1. No aeration is involved
2. Hydraulic loading rate is 0.167 gpm/ft^3
3. 2200 ft^3 of kenaf is used per facility (2.5 ft^3/pig place * 880 pig place)
4. Twenty feet of head
5. Pump efficiency of 65%

$$\frac{0.167 \text{ gpm/ft}^3 * 2200 \text{ ft}^3 * 20 \text{ ft}}{3960 * 0.65} = \textbf{2.85 hp}$$

The horsepower required to run the bioreactor system is 2.85 hp.

Energy costs calculations for the bioreactor system

Assumptions:
1. The cost per kWhr is $0.07.

2.85 hp * 0.7457 kW/hp *24 hr/d *365 d/yr * $0.07/kWhr = **$1303.20/yr**

The approximate energy cost to run the bioreactor system is approximately $1300 per year.

Energy cost calculations for an aeration system

Assumptions:
1. Energy cost is 0.11 kWhr/day pig place

0.11 kWhr/day pig place * 800 pig place * 365 d/yr *$0.07/kWhr = **$2473.24**

The approximate energy cost to run an aeration system is approximately $2475 per year.