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LARGE SCALE NITRIFICATION/DENITRIFICATION OF SWINE WASTE

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ABSTRACT

Premium Standard Farms, Inc. (PSF) operates a Concentrated Animal Feeding Operation (CAFO) named the Whitetail Farm in northwest Missouri. A nitrification and denitrification system has been designed, constructed and placed into operation for six individual sites of 8,800 grow-finish pigs each for a total of 52,800 head. Nitrification and denitrification occurs at a single wastewater treatment plant centrally located on the farm.

The system is designed to reduce property line odor concentrations to less than regulatory thresholds, air emissions of ammonia and hydrogen sulfide from wastewater treatment sources, and effluent nitrogen concentration of total nitrogen before land application by at least 50 percent. The reduction of land area required for effluent irrigation is expected to reduce the spill risk associated with irrigating large acreages on soils with high clay content and slopes of up to 20 percent.

Operation of the system began in April 2002 and total nitrogen reduction has averaged approximately 87%. Significant foam generation during aeration has caused operational difficulties until a defoaming agent was continuously added. Significantly less supplemental alkalinity and methanol has been needed than predicted during design. Performance data collected over the next year will help optimize design of the next system.

KEYWORDS. Wastewater treatment, nitrification, denitrification, aeration, anoxic, biosolids, swine

INTRODUCTION

PSF's Missouri farms are located in a region of rolling hills with slopes approved for irrigation of up to 20% and soils with high clay content. The topographic relief of the area results in a number of small waterways located between the closely spaced ridge tops. Any small problem during irrigation, if not detected immediately, can lead to a spill into a waterway. Failure of irrigation equipment, aboveground piping, hoses or human errors have caused spills during land application. These types of spills have been mostly a few hundred to a few thousand gallons that are quickly contained by emergency response procedures. To address concerns related to spills, air emissions and odor, PSF has entered into two settlement agreements for the Missouri farms.

In September 1999, PSF entered into an agreement with the State of Missouri to install "Next Generation Technology" on the Missouri farms. The agreement committed PSF to spend up to $25 million over a period of five years to develop and implement the technology. The technology was undefined, but must be approved by a court-appointed expert panel that reviews the work proposed by the company.

In November 2001, the PSF entered into an agreement with the U.S. EPA that requires reductions of atmospheric emissions of ammonia and hydrogen sulfide and to reduce the nitrogen concentration of effluent before land application by at least 50 percent. The effluent nitrogen baseline was three years of data from the existing anaerobic lagoons.

These agreements have resulted in the company formulating goals to reduce: 1) property line odor concentrations to less than regulatory thresholds, 2) air emissions of ammonia and hydrogen sulfide from wastewater treatment sources, 3) the effluent nitrogen concentration of total nitrogen before land application by at least 50 percent and 4) the spill risk associated with irrigating large acreages on soils with high clay content and slopes of up to 20 percent.

The Whitetail farm is the first of approximately twelve large CAFOs that PSF will retrofit with new technology during the implementation period covered in the settlement agreements. In many ways, this project, although on a rather large scale, is a prototype system that will better define the design and operational parameters for the subsequent systems.

TREATMENT SYSTEM

In order to design a treatment system that can reduce the nitrogen in the flow from the existing anaerobic lagoons by 50 percent or more without increasing the release of ammonia nitrogen to the atmosphere, a nitrification/denitrification treatment system was selected. The system was designed to allow for varying the flow rate each month to achieve the sludge age needed to accomplish nitrification. Denitrification from the system was predicted to be limited by the available biochemical oxygen demand (BOD_5) in the anaerobic lagoon effluent.

HDR Engineering and PSF designed the resulting nitrification and denitrification system specifically for this project. The system has been termed the advanced nitrification and denitrification (AND) system. It was designed, constructed and placed into operation in April 2002 for six individual sites of 8,800 grow-finish pigs each for a total of 52,800 head located at the PSF Whitetail Farm in North Central Missouri. Nitrification and denitrification occurs at a single wastewater treatment plant centrally located on the farm. The process description for the system is as follows:

- Permeable covers on each of six existing anaerobic lagoons
- Transfer of flow from each existing lagoon to the anoxic basin
- Anoxic basin for nitrate and biochemical oxygen demand reduction
- Aeration basin designed for nitrification (w/ recycle to anoxic basin)
- Biosolids storage basin
- Irrigation storage basin

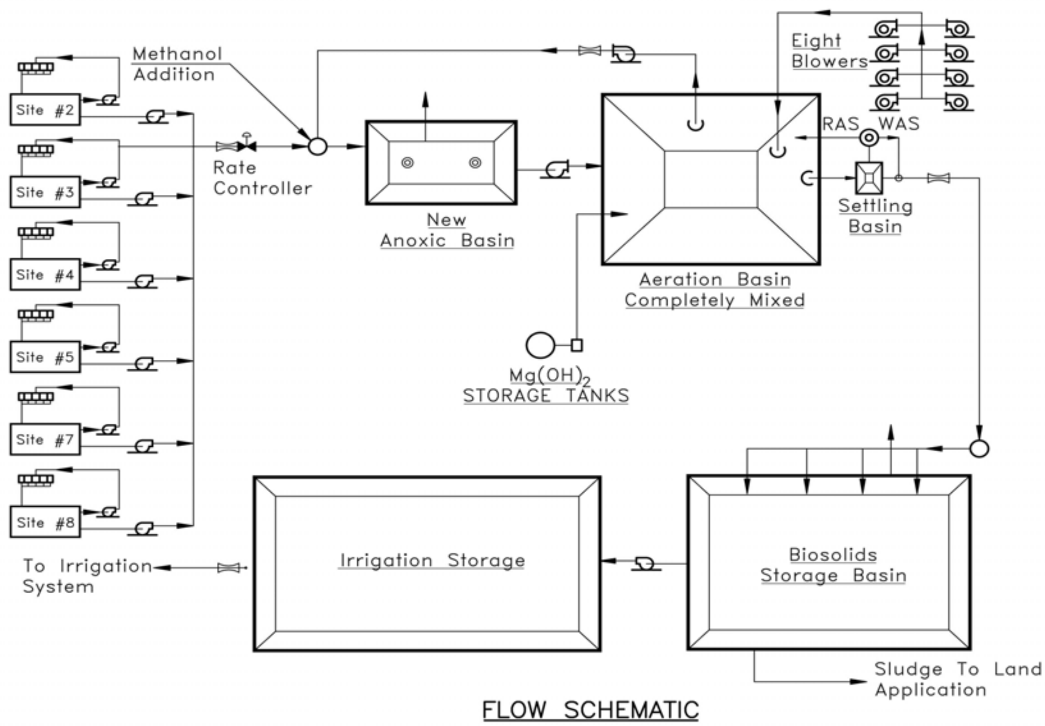

Figure 1. System Flow Diagram.

SYSTEM DESIGN

PERMEABLE COVERED LAGOONS

Anaerobic treatment is logical for swine waste given the high strength characteristics. Anaerobic systems have many advantages over fully aerobic systems. These advantages include minimal power requirements, low sludge production, potential energy production, and less operator attention. Anaerobic lagoons perform similarly to impermeable covered anaerobic digesters with respect to BOD_5, chemical oxygen demand (COD), total solids (TS) and volatile solids (VS) removal, and can perform better with respect to total Kjeldahl nitrogen (TKN), ammonia and phosphorus removal (Cheng 2000). Although anaerobic biology is a good fit with swine waste, anaerobic lagoons are the subjects of much political and regulatory criticism today. PSF's approach is to modify the lagoons for odor control.

Covers can be effective in reducing odors and gaseous emissions from lagoons, but gas tight covers will cause difficulties with other parts of the PSF operation. A gas tight cover contains odorous gases in the lagoon, but increased odors will be released from the barns when recycled lagoon water is used for flushing purposes. In addition, increased odors will occur during irrigation of lagoon liquid. Additionally, impermeable covers nearly eliminate volatilization of ammonia and thereby increase the nitrogen content of lagoon effluent. This increased ammonia load would have to be treated by the downstream nitrification/denitrification plant.

In 1999, PSF became aware of an innovative lagoon cover material. The BioCap™ (Baumgartner Environics, Inc.), cover is made of a permeable material that is a felt-like polypropylene that floats on the lagoon surface. At the Whitetail Farm, all nine existing anaerobic lagoons were covered in the spring of 2000. The covers have been effective in reducing odors from the lagoons without a significant increase in effluent ammonia loadings. The covers are reported to reduce emissions of ammonia, hydrogen sulfide, and total volatile organic compounds (VOCs) from a swine lagoon (Baumgartner 2000).

PSF has been evaluating the odor control effectiveness of permeable covers using ambient scentometry (Barnebey-Sutcliffe Scentometer) measurements at a height of 5-feet at the downwind lagoon berm. Results from the ambient monitoring show a significant improvement in ambient odor and hydrogen sulfide measurements from a covered lagoon compared to a control lagoon. Twenty-five pairs of scentometry observations were made between October 7, 1999, and October 6, 2000. The scentometry data were analyzed in terms of the frequency of observations that fall into certain classes. Two classes were defined as: observations of two dilutions to threshold (D/T) or below and observations of seven D/T or greater. The scentometry data show that observations of 2 D/T or less were significantly more frequent at the covered lagoon than at the control lagoon ($p=0.0002$). Eighty percent of the observations (twenty out of 25) at the covered lagoon were minimal compared to 28 percent at the control lagoon (seven out of 25).

FLOW TRANSFER

Wastewater will be pumped from the six existing covered lagoons to the anoxic basin at the central treatment plant. In the winter months the wastewater temperature in the lagoons is sometimes lass than 1° C. Although this is well below the optimum temperature where nitrifying organisms function well, by increasing the sludge age some nitrification should continue. By operating all year around, instead of only during the warmer months of the year, the problem of starting up a nitrification treatment system each spring is avoided. The startup of such a system could easily take several months each year.

Based upon a year-round operation and the goal of nitrifying and denitrifying the maximum amount of nitrogen discharging to the AND system, the rate of flow treated during each month is varied depending upon the temperature of the wastewater. During the summer months (wastewater temperature of 25° C or greater) the flow rate will be 0.144 mgd (6 sites @ 0.024 mgd/site) to the aeration basin which is greater than the average flow rate of 0.090 mgd (6 sites @ 0.015 mgd/site). During the colder winter months with wastewater temperatures of 6° C or less, the flow rate will be only 0.041 mgd. The aeration basin will be sized to provide a 21-day detention time at 0.144 mgd, which provides a detention time of 74 days at 0.041 mgd.

ANOXIC BASIN

An anoxic basin is located ahead before the aeration basin at the influent point of the central treatment plant to allow utilization of the influent carbonaceous BOD_5 for biological denitrification. Flow from the aeration basin is recycled to the anoxic basin at a ratio of 1.6:1 to return nitrates for denitrification in the anoxic basin. The anoxic basin has a detention time of 1.53 days at a combined flow of 0.374 mgd (0.144 mgd inflow and 0.230 mgd recycle from aeration). There are two 20-HP floating directional mixers to maintain solids in suspension.

The concentration of BOD_5 needed to denitrify 1.0 mg/l of nitrate-nitrogen is estimated to be 4.5 mg/l (McKinney 2000). The ratio of BOD_5:NO_3-N from a lagoon at a CAFO will vary substantially throughout the year. In the summer, the ratio could be as low as 0.6:1 and in the winter the ratio could be as high as 2:1, which is still less than the desired ratio of 4.5:1 for complete denitrification. Another complicating factor is that only a minimum amount of wastewater can be treated in the winter when the ratio is higher because of the need for an increased sludge age in the aeration basin to accomplish nitrification. Depending upon the required degree of denitrification, methanol can be added to provide a source of BOD_5 without adding nitrogen.

Assuming that 4.5 lb of BOD_5 are needed to denitrify 1.0 lb of nitrate nitrogen, there is not sufficient influent carbonaceous BOD_5 to the anoxic basin for complete denitrification Design calculations predict removal of 50 – 60 percent of the nitrate. Addition of methanol could further reduce the nitrates at the rate of 1.25 lbs of nitrate nitrogen per gallon of methanol. Since the settlement agreement with the USEPA requires at least a 50 percent effluent nitrogen removal, a methanol addition system has been provided as a backup system to provide supplemental carbon should it be needed.

AERATION BASIN

The effluent from the anoxic basin discharges to the aeration basin that has a detention time of 21 days at the design flow of 0.144 mgd. The basin has an aeration system to supply the oxygen demand of 1,013 lbs of O_2/hour under standard conditions. This is based upon an effluent BOD_5 from the anoxic basin of 187 lbs/day and a TKN of 2,402 lbs/day. The waste loads to the aeration basin vary monthly as does the temperature of the wastewater.

At design conditions, 0.374 mgd of mixed liquor from the aeration basin will flow by gravity to the adjoining settling basin. Supernatant from this settling basin will enter a perforated-pipe effluent collection device and then flow by gravity to the subsequent biosolids storage basin.

Biological sludge that settles in the quiescent settling basin will flow by gravity to a sludge draw-off manhole. If necessary to increase the sludge age in the aeration basin, return activated sludge (RAS) will be pumped from this manhole back to the aeration basin. Waste activated sludge will mix with the settling basin effluent and be pumped to the biosolids storage basin.

BIOSOLIDS STORAGE BASIN

The biosolids storage basin serves not only for storage of biological solids, but to provide postanoxic denitrification by creating a benthic demand from the settled sludge. The benthic demand was estimated during design to be only 120 pounds BOD_5/day (McKinney 2000) because of the long sludge age in the aeration basin. The 120 pounds of BOD_5 would have the capability of denitrifying only 45 pounds of NO_3 -N/day or approximately 16,200 pounds of nitrogen/year. The effluent from the biosolids storage basin will discharge to the irrigation storage basin.

IRRIGATION STORAGE BASIN

From the biosolids basin, effluent is pumped to the irrigation storage basin. The basin is sized to hold approximately six months of the annual design volume plus storage for a 25-year, 24-hour rainfall event.

Air Emissions

The project will involve collection of high-frequency, semi-continuous emission measurements, using micrometeorological and wind tunnel flux measurement methods (Zahn 2000), for ammonia (NH_3), hydrogen sulfide (H_2S), non-methane total volatile organic compounds (NMVOC), and odor, over a 9 month period from a control lagoon at the PSF Locus Ridge #2 swine facility, and five treatment or storage cells, which are components of the AND system at the Whitetail site. The five sampling locations from the AND system are an existing lagoon (Whitetail #4) covered with permeable cover (BioCap™), an anoxic basin, an aeration basin, a biosolids storage basin, and an irrigation storage basin.

The goal of this project is to obtain estimates of emission rates of several compounds from "baseline" facilities, as well as facilities where new technologies have been installed. These estimates will be made over approximately 12 months to provide information on seasonal variations in emissions.

Operation and Wastewater Monitoring Results

The system was first operated beginning in April 2002. PSF began to experience foaming on the aeration cell soon after startup. Foaming is an expected issue with newly established (young sludge age) biological treatment systems. To prevent the foam from being blown off the aeration cell, PSF installed timers on the blowers to run them in intermittent cycles. PSF tried varying on/off cycles for the blowers to control the foam. No one cycle seemed to perform better than the others and the system seemed to change with weather conditions. As the season progressed, PSF determined that the foaming was not just an issue of "young sludge" being developed.

This inability to run all of the blowers led to reduced DO levels in the aeration basin. In late July and August of 2002, the low DO inhibited the nitrifying bacteria in the aeration cell. At this point, PSF ceased feeding waste into the system to allow the DO to recover and the nitrifying bacteria to resume activity. Once a defoaming agent (GE Betz Foamtrol AF2760) was added daily in the aeration basin influent, the foam issue came under control. Continuing use of the defoaming agent at a rate of 5 – 20 mg/L has been required to maintain control of the foam.

Nitrogen data indicate that the system is performing well when adequate DO can be maintained. The goal for this system is a 50 percent reduction in historical average nitrogen concentrations. Specifically, the target total nitrogen concentration is 854 milligrams per liter (mg/L) in the irrigation storage cell. Table 1 and Figure 2 show the performance of the system for June 2002 through May 2003. Concentrations of nitrogen in the settling basin represent the effluent from the aeration basin and indicate the anoxic/aeration combination has achieved an average 56% reduction of total nitrogen. Total nitrogen concentrations in the downstream biosolids storage basin are much lower as indicated on the figure (average 87% reduction). Although dilution due to basin prefill water has affected the concentration of total nitrogen in the irrigation storage basin, these data indicate greater than a 95% reduction vs. the anoxic basin influent.

The temperature of the system is monitored regularly and has steadily increased with the warmer weather. The system was started when wastewater temperatures were approximately 10° C and rose to around 38° C in late summer 2002. By October, the temperatures were near 20° C and fell below 10° C during December 2002. The lowest temperature was recorded in January 2003 at 0.7° C. By mid-March 2003 the temperature increased above 10° C and approached 10° C in May. The pH in the aeration basin has fluctuated between 7.3 and 9.0, with an average of 8.2.

Table 1. Influent and Effluent Nitrogen Concentrations (mg/L)

	Influent Total N	Settling Basin Total N	Settling Basin NO3 + NO2-N	Biosolids Basin Total N	Biosolids Basin NO3+NO2-N
June 2002	1456	1070	6	NA	NA
July	1669	764	314	180	107
August	1855	681	30	254	77
September	1827	863	461	280	46
October	1867	730	563	250	65
November	1856	416	257	269	117
December	1895	680	333	211	88
January 2003	1826	849	261	Ns	Ns
February	1626	942	174	Ns	Ns
March	1916	721	68	116	80
April	1802	969	161	186	124
May	1778	701	357	221	142

** Monthly Averages. June 2002 is only based on 2 data points, Ns = no sample because basin was frozen, March 2002 Biosolids Basin data based on 2 data points

Whitetail Advanced Nitrification/Denitrification - Nitrogen Data

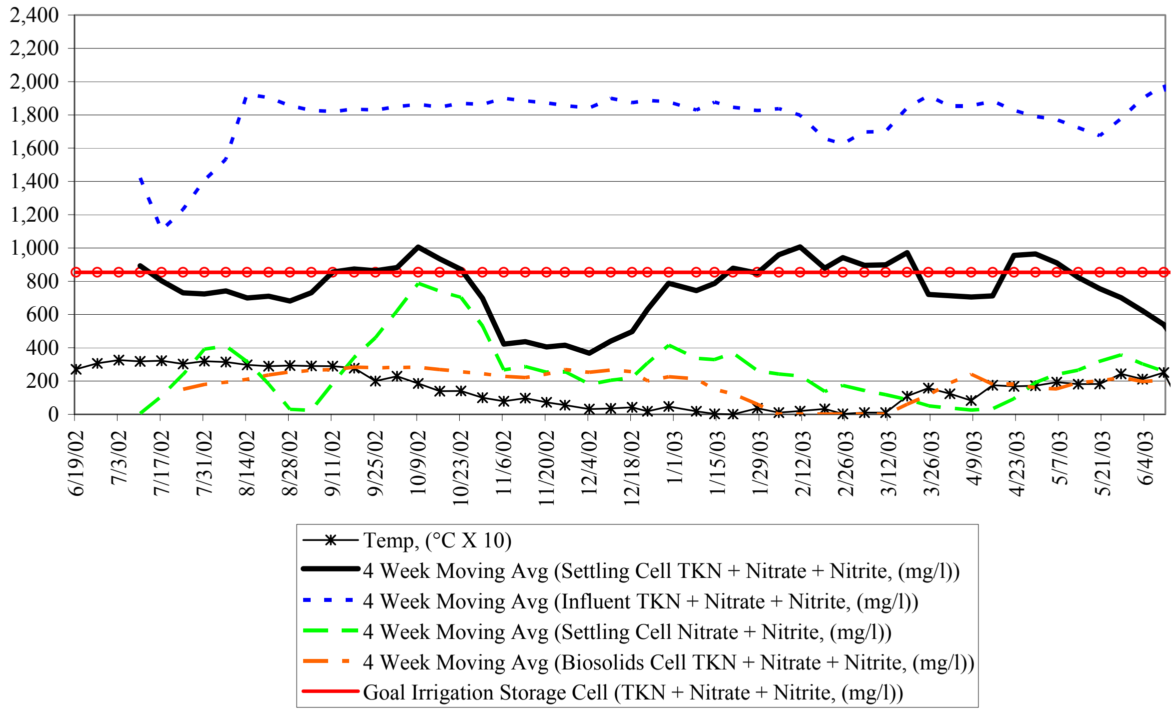

Figure 2.

Mixed Liquor Suspended Solids (MLSS) concentrations in the aeration basin have been monitored to evaluate the growth of aerobic biomass. MLSS concentrations were consistently below 1,000 mg/L until June 2002, about the same time nitrification began. MLSS concentrations have since been maintained in the 2,500 - 3,000 mg/L range. Alkalinity has been monitored as an indicator of nitrification. Alkalinity is consumed when ammonia is oxidized. Alkalinity in the influent to the anoxic basin has consistently been in the 8,500 – 9,000 mg/L range and seems to tend to stabilize around 1,500 – 1,800 mg/L in the aeration basin during periods of significant nitrification. No supplemental alkalinity has been added to the system. Approximately 10,000 gallons of methanol was added to the anoxic basin during start-up to provide additional carbon for biomass growth. No methanol has been needed for the denitrification achieved to date. Feed rates up to 18,000 gallons per month were predicted to achieve a 50% reduction in nitrogen.

Conclusion

The nitrification and denitrification system has been in operation since April 2002. The system has performed better than expected with regard to removal of total nitrogen. Predictions during design for significant addition of alkalinity for nitrification and methanol for denitrification have also proven conservative. Total nitrogen reductions of greater than 80 percent have been consistently achieved when sufficient dissolved oxygen is maintained in the system. No supplemental alkalinity and very little methanol have been added to the system to date. Foam production during aeration is a significant issue with swine waste; however, continuous addition of a defoaming agent has shown the ability for foam control. The system was operated through winter 2002/2003 to determine the effect of operation at temperatures under 10° C. Nitrification continued even with temperatures as low as 0.7° C. The system responded very well to increased loading during the spring of 2003 and has continued to perform well. Water quality and air emissions data will be collected over the next year and serve as the design basis for future systems.

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