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Generation 3 Treatment Technology for Diluted Swine Wastewater using High-Rate Solid-Liquid Separation and Nutrient Removal Processes

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Abstract. *The primary objective for this project was to construct and evaluate a third generation, innovative swine manure treatment system. The system was designed to: separate solids and liquids with the aid of settling and polymer flocculants; biologically remove ammonia nitrogen with bacteria adapted to high-strength wastewater; remove phosphorus via alkali precipitation; and reduce emissions of odorant compounds, ammonia, pathogens, and heavy metals to environmental media. Technical environmental performance standards were those identified by the State of North Carolina in 15A NCAC 02T, 2010, Swine Waste Management System Performance Standards and included: discharge of animal waste to surface waters and groundwater; emission of ammonia; emission of odor; release of disease-transmitting vectors and airborne pathogens; and nutrient and heavy metal contamination of soil and groundwater. The third generation was designed to further reduce cost of manure treatment through pre-concentration of diluted manure using a decanting tank before polymer flocculation. The treatment system was demonstrated full-scale on a farrow-to-finish farm that produced 30,450 swine per year. The treatment system was contained in tanks. The results showed that the innovative swine manure treatment system was capable of operating under steady state conditions treating flushed swine manure at a rate of approximately 75,000 gallons of manure per day. The treatment system was documented to remove, on a mass basis, approximately 99% of total suspended solids, 98% of COD, 99% of TKN, 100% ammonia, 100% odor compounds, 92% phosphorus, 95% copper, and 97% zinc from the flushed manure. Fecal coliform reductions were measured to be 99.98% (when the alkali precipitation component of the system was at a pH of 10.1). The third generation technology meets the criteria identified in the referenced NC Performance Standards. The treatment process also provides a mechanism* *and market for the solids that are separated. Collectively this treatment process, when operated and managed under the conditions during which we conducted this study, significantly reduces the potential for emissions of odor and ammonia, and the transfer of nutrients and pathogenic bacteria to surface and groundwater in the drainage basin where the animals are grown on animal feeding operations.*

Keywords. Animal waste treatment, swine wastewater, CAFO, solid-liquid separation, ammonia control, odor abatement, nitrification-denitrification, phosphorus recovery, environmentally superior technology.

Project Overview

This project evaluated and demonstrated the viability of a third generation manure treatment technology. The technology was developed as an alternative to the lagoon/spray field system typically used to treat the wastewater generated by swine farms in North Carolina. The third generation waste treatment system was constructed and demonstrated by Terra Blue Inc. (previously Super Soil Systems USA) at full scale in Jernigan farm near Mount Olive in Wayne County, NC. Technical environmental performance standards used were those identified by the State of North Carolina in 15A NCAC 02T (2010) for new or expanding swine operations and included: discharge of animal waste to surface waters and groundwater; emission of ammonia; emission of odor; release of disease-transmitting vectors and airborne pathogens; and nutrient and heavy metal contamination of soil and groundwater. The sponsor of this demonstration project was North Carolina's Clean Water Management Trust Fund project (CWMTF). The complete Technical Environmental Performance Report of this project is provided in Vanotti et al. (2013a).

Technology Description

The on-farm system used solid-liquid separation, biological nitrogen removal, and disinfection and phosphorus removal unit processes linked together into a practical system for livestock operations (Figure 1). During this demonstration, the treatment system was operated and managed by the farmer with training and oversight by Terra Blue personnel. The system used polymer flocculation to increase the efficiency of solid-liquid separation of the suspended solids and rotary press separator. In the third generation, the system was adapted to flushing systems that contained much diluted manure. This adaptation used a decanting tank, which concentrated the solids before polymer application, thus reducing separation equipment needs. Nitrogen management to eliminate ammonia emissions was accomplished as before by passing the liquid through a biological module containing high performance nitrification bacteria (HPNS) adapted to high-ammonia wastewater and low-temperature (Vanotti et al., 2013b). A phosphorus removal module was also used to precipitate phosphate and disinfect the effluent. The phosphorus precipitate was simultaneously separated with the manure. The system recycled clean water to flush the barns (Figure 2). The phosphorus treated water was stored in the former lagoon and used for crop irrigation. The solids were removed from the farm and used for the manufacture of value-added products. Details of the various system components are provided in Vanotti et al., 2013a.

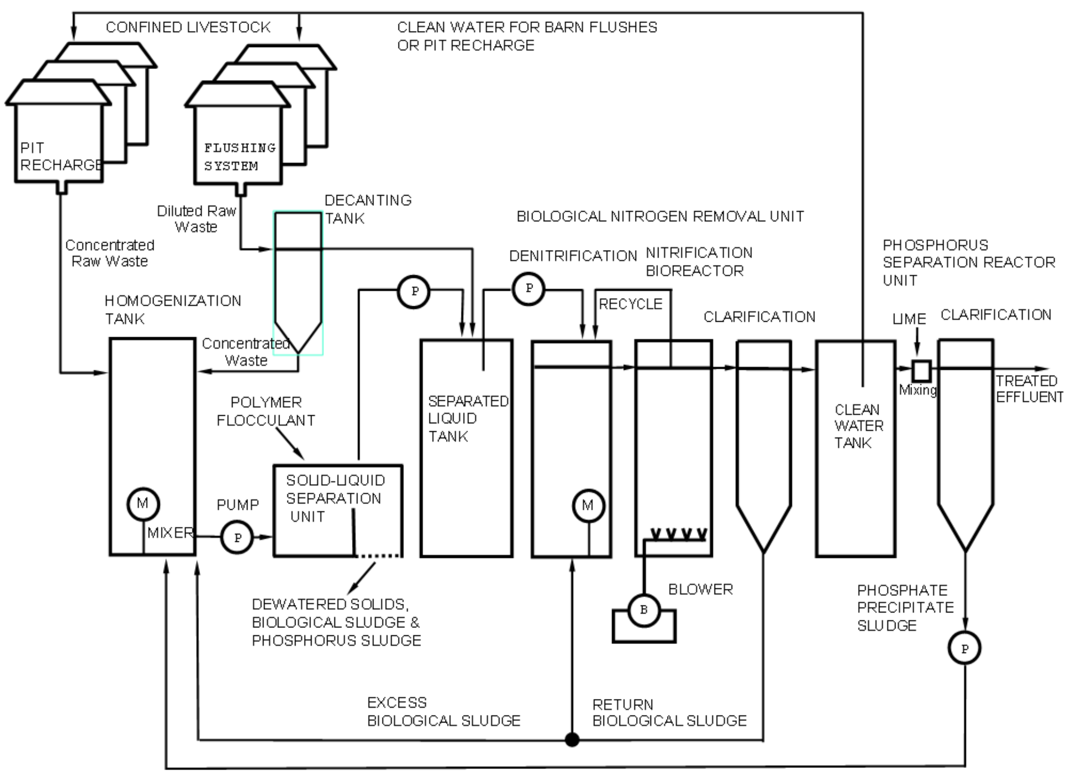

Figure 1. Schematic of the 3rd generation swine waste treatment technology using solids separation, nitrification-denitrification, soluble phosphorus removal/disinfection (Vanotti et al., 2010). Decanting tank was added in this project to the flushing system waste stream.

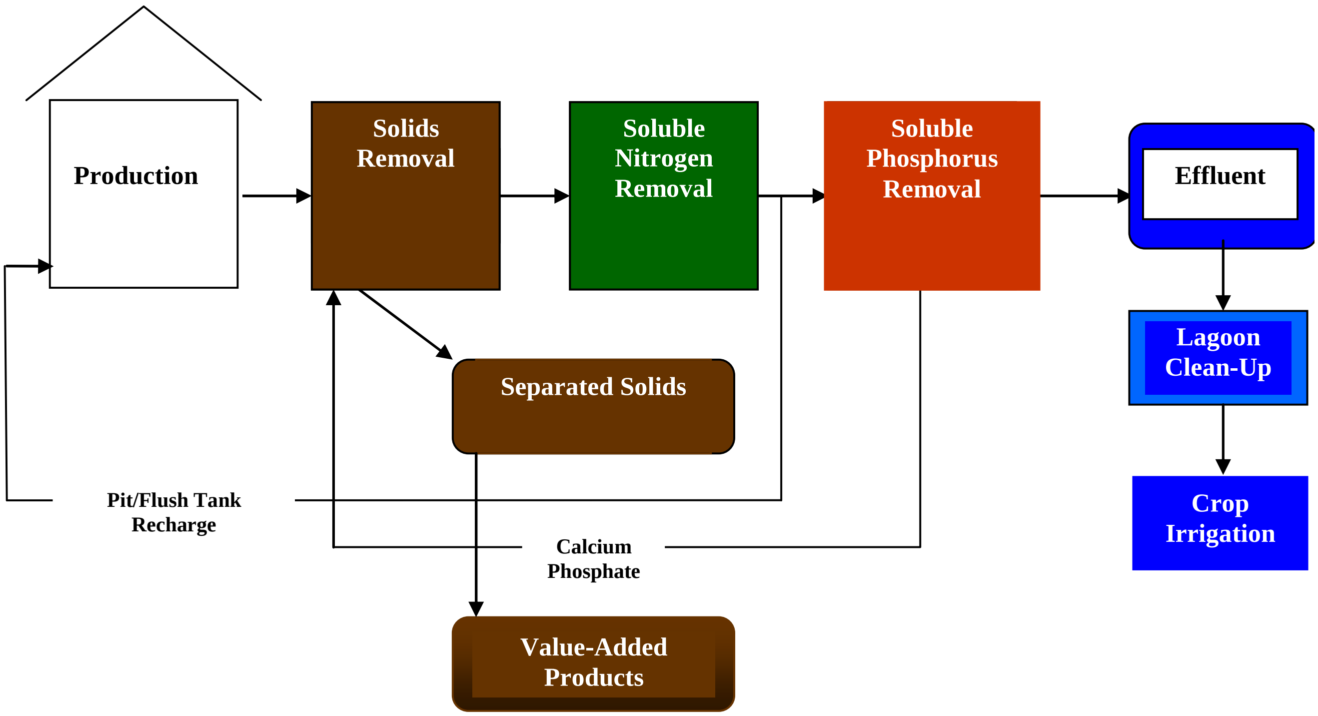

Figure 2. Schematic of the 3rd generation swine waste treatment technology. N treated water is re-used to recharge barn pits or fill the flush tanks.

Swine Farm

The technology was demonstrated full-scale on a 2,575,444 lbs. steady state live weight (SSLW) Farrow-to-Finish farm that produced 30,450 hogs per year in Wayne County, NC. The treatment system was contained in tanks and replaced two anaerobic lagoons. The system treated the entire waste stream from two operations:

1) A 1,200-sow Farrow-to-Feeder operation (Sow farm) that used flushing system and generated 37,136 gal of manure per day (Table 1), and
2) A 12,960 Feeder-to-Finish operation (Finishing farm) that used pit recharge system and generated 41,286 gal of manure per day (Table 1).

Table 1. Wastewater influent monthly volumes and flow rates from finishing and sow farms into the 3rd generation wastewater treatment system during evaluation Aug-Dec., 2012.

Month	days	Total Volume Finishing Farm	Average Flow Rate Finishing Farm	Total Volume Sow Farm	Average Flow Rate Sow Farm	Total Volume Finishing + Sow Farm	Average System Influent Flow Rate
		gal	gal/day	gal	gal/day	gal	gal/day
August	31	2,197,232	70,878	464,379	14,980	2,661,611	85,858
September	30	1,227,635	40,921	768,051	25,602	1,995,687	66,523
October	31	877,902	28,319	1,460,994	47,129	2,338,896	75,448
November	30	963,555	32,119	1,737,369	57,192	2,700,924	90,030
December	31	1,050,398	33,884	1,250,974	40,354	2,301,370	74,238
Aug.-Dec.	**153**	**6,316,722**	**41,286**	**5,681,767**	**37,136**	**11,998,489**	**78,422**

The finishing operation used pit-recharge system (Barker, 1996a) that evacuates manure from the barn once per week; it was also used at Goshen Ridge and Tyndall farms during testing of the first- and second-generation. The sow farm used flushing system (Barker, 1996b) that used flush tanks to evacuate manure form the barn several times per day producing much diluted manure. This configuration was not tested with the Terra Blue system before.

Before conversion, lagoon liquid (with 433 ± 146 mg NH4-N/L) was used to both recharge the pits (finishing farm) and fill the flush tanks (sow farm). After conversion, the N treated water (with 14 ± 26 mg NH4-N/L) replaced lagoon water to recharge the pits and fill the flush tanks; it was stored in the clean water storage tank (Figure 1).

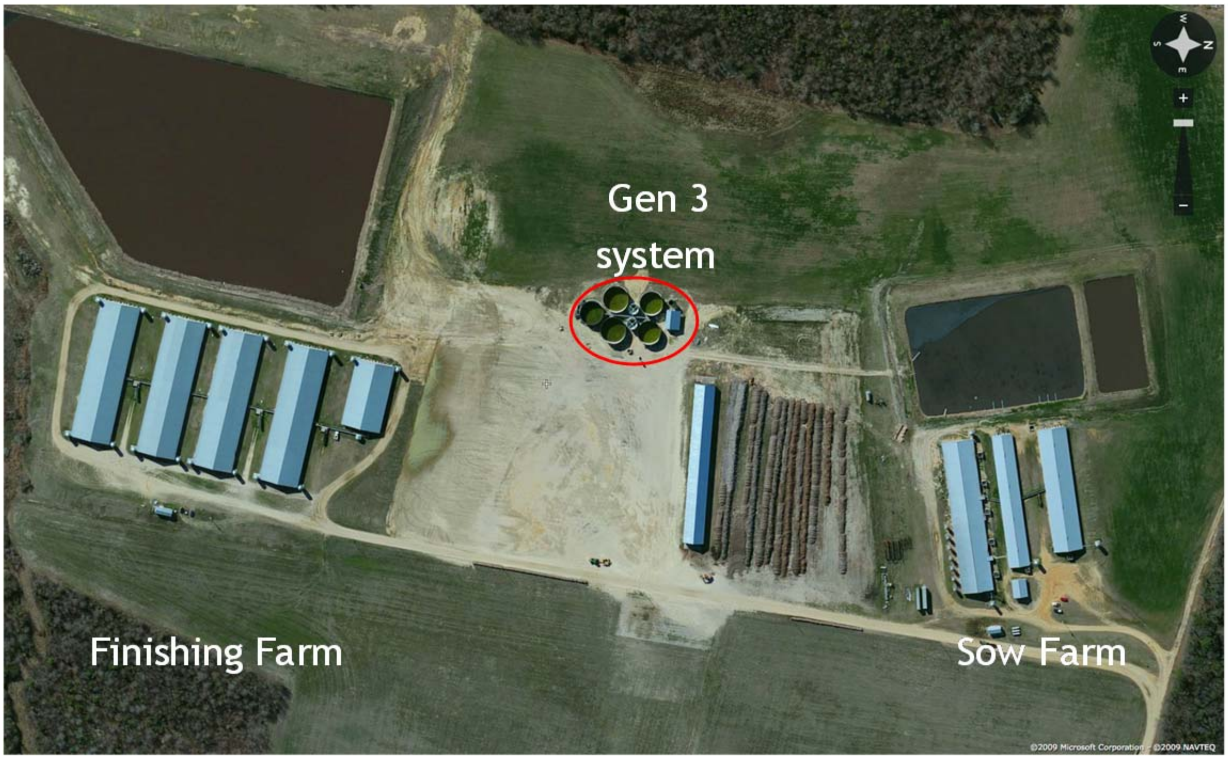

Figure 3. Third generation swine waste treatment system that replaced the lagoon treatment. The system provided treatment to all the manure from a 1200-sow farrow-to-feeder farm that used flushing system, and a 12,960-head feeder-to-finish farm that used pit-recharge system. Photo source: Flashearth.com.

Results

Highly efficient treatment performance was obtained with both high hydraulic loads typical of flushing systems and high strength wastewater typical of the pit-recharge systems.

Improved Solid-liquid Separation for Flushing Systems

During the period Aug.-Dec. (153 days), the rotary press separator processed a total of 6,470,490 gal of manure and was operated 4.99 days/week with daily runs of 8.84 hours and average processing rates of 112 gal/min. The use of the decanting tank was an adaptation of the treatment system implemented in the 3rd generation to be able to process high volumes of diluted manure from flushing systems without having to increase the solid separator press capacity. This was the case of the sow operation at the demonstration farm that used flushing system. The decanting tank concentrated the flushed manure about 15 times (from 0.3% to 4.7% TSS). This concentrated manure was subsequently treated with polymer in the separator press, while the clarified flush went to the separated water tank and N module. Approximately 4.7% of the initial flush volume generated by the sow farm was treated with polymer and rotary press during the 84-day evaluation while 95.3% of the liquid flush went directly into the N module after the rapid settling. Thus, the decanting tank reduced the volume of manure from the sow farm into the solid separator press by 25,860 gal/day. This volume reduction was about 34% of the total volume of manure generated by the complete farm that was tested (sow farm + finishing farm). This lower volume is one of the major advances of this project.

The decanting tank removed 60% of the TSS in the flushed effluent. This removal level was about 85% of the maximum TSS removal possible by settling (71%) as determined in laboratory settling tests (Vanotti et al., 2013a). The application of polymer to the concentrated sludge instead of the diluted manure saved in polymer expenses. Laboratory experiments compared polymer use efficiency when the polymer is applied to all the flushed manure or just to the settled sludge from the decanting tank. Results showed that application of polymer to the flushed manure resulted in low polymer use efficiency (52 g solids/g polymer) compared to application to the concentrated sludge (279 g solids/g polymer) resulting from settling operation. In terms of polymer usage rates, the concentration strategy reduced potential polymer use (from 2.16 to 0.40 lbs. polymer/100 lbs. solids separated), which is equivalent to 5.4-times reduction in polymer usage (Figure 4).

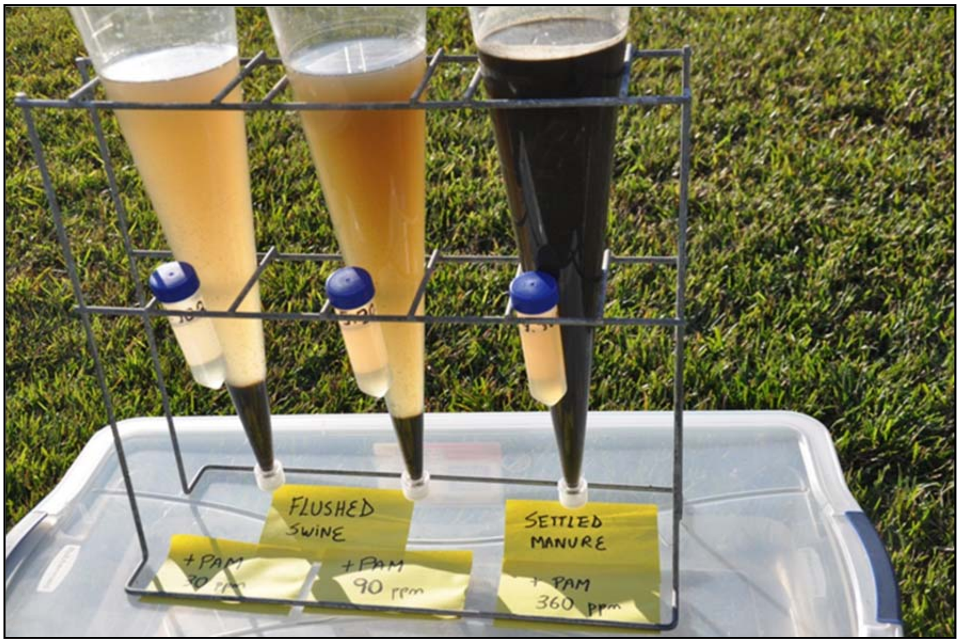

Figure 4. The two cones at left are flushed swine manure from the sow farm after 30 minutes settling in the laboratory. The cone at right is settled sludge from decanting tank. The small vials are the effluents after polymer application and screening. The decanting tank increased 5.4 times the polymer use efficiency.

Biological N Removal Performance

The N module used a high performance nitrifying sludge (HPNS) for high ammonium concentration and low temperature wastewater treatment (Vanotti et al., 2013b) (Figure 5). The biological N system removed ammonia efficiently during cold weather. The concentration of ammonia-N in the nitrification tank effluent during cold weather months was <10 mg/L (Oct. 2012- Feb. 2013).

Figure 5. Start-up of the nitrification unit with 1 liter of HPNS (high performance nitrification sludge). Picture at right shows the effluent after N treatment process.

Although the decanting tank substantially reduced both the volume of liquid into the separator press and the polymer consumption, the solids removal efficiency was lower than applying polymer to all the influent (60 vs. 91%). Compared with a situation where all the flushing system liquid received polymer treatment, the use of settling (decanting) reduced TKN separation efficiency from 31% to 17% and increased TKN loading into the biological N module by 20%. In terms of COD, the settling approach increased COD concentration in the separated liquid from 1,108 to 3,570 mg/L. This was very beneficial to the overall system performance because denitrification and biological N removal was improved as a result of a more balanced C/N ratio. For example, concentration of oxidized N (nitrite + nitrate) measured in the plant effluent was 300 ± 63 mg/L during the period June-July 2012 when only the finishing farm was treated, and 122 ± 54 mg/L during the period August-October after the saw farm effluent and the decanting tank was incorporated.

Water Quality Improvements

The wastewater treatment performance obtained is summarized in Table 2. A pooled influent concentration was calculated based on concentration from two sources and corresponding flow rates. The treatment system lowered concentration of constituents in wastewater as follow: 97.3% of total suspended solids (TSS), 97.9% of volatile suspended solids (VSS), 72.5% of total solids (TS), 93.7% of chemical oxygen demand (COD), 97.7 of TKN, 99.0% of Ammonia-N, 87.7% of TN, 88.5% of TP, and 85.3% of alkalinity (Table 5). Concentration of copper (Cu) and zinc (Zn) in the liquid effluent were reduced 95.4% and 97% relative to the concentration in the homogenization tank. On a mass basis, the treatment system removed 98.6% of total suspended solids (TSS), 99.0% of volatile suspended solids (VSS), 83.3% of total solids (TS), 98.1% of chemical oxygen demand (COD), 99.3% of TKN, 100.0% of Ammonia-N, 96.7% of Total Nitrogen (TN), 91.9% of Total Phosphorus (TP), and 89.7% of the alkalinity.

Table 2. Water quality improvements with treatment system.

Water Quality Parameter	Homogenization Tank (mg/L)	Decant Tank (mg/L)	Pooled Influent (mg/L)	Effluent (mg/L)	Removal Efficiency (%)
TSS	10,082 ± 2,860	1,332 ± 588	6,845	193 ± 37	97.3
VSS	7,932 ± 1,960	1,047 ± 488	5,385	120 ± 17	97.9
TS	11,532 ± 1,764	4,183 ± 749	9,016	2,476 ± 210	72.5
COD	12,762 ± 2,350	4,095 ± 1,249	9,794	620 ± 344	93.7
TKN	1,581 ± 290	493 ± 100	1,209	28 ± 11	97.7
Ammonia-N	775 ± 101	322 ± 92	620	6 ± 7	99.0
Nitrite+nitrate	6 ± 6	19 ± 23	10	122 ± 54	--
Total N	1,587 ± 290	512 ± 101	1,219	149 ± 62	87.7
Total P	558 ± 166	166 ± 64	439	50 ± 19	88.5
Alkalinity	3,998 ± 497	1,714 ± 415	3,215	472 ± 181	85.3
Copper (Cu)	15.03 ± 6.04	--	--	0.69 ± 0.13	95.4
Zinc (Zn)	20.09 ± 9.78	--	--	0.61 ± 0.23	97.0

Reduction of Pathogens

Due to the high pH in the phosphorus module, the system was effective killing pathogens when operated at a pH of 10.1 or higher. With the pH of 10.1, the concentration of Fecal Coliforms was 3,530 MPN/100 mL and the microbial reduction was 99.98%. This level of reduction in pathogen indicators met the new Swine Waste Management System Performance Standards (15A NCAC 02T, 2010) for pathogens (Fecal coliforms < 7,000 MPN/100 mL)(< 3.84 log10).

Table 3. High process pH (> 10) in phosphorus module resulted in significant pathogen destruction.

Sampling Date	Lab ID	Indicator Microorganism	Raw Flush (HT Tank) log_{10} MPN per 100 mL	Clean Water Tank (after biological N Treatment) log_{10} MPN per 100 mL	Plant Outflow (after P treatment) Log_{10} MPN per 100 mL]	Process pH	Log_{10} Reduction
11/12/2012	1	Fecal Coliforms	7.26	--	3.55	10.1	3.71
		E. Coli	6.89	--	3.34		3.56
		Enterococci	6.76	--	3.58		3.18
11/29/2012	2	Fecal Coliforms	6.76	4.62	2.26	10.8	4.50

Reduction of Odors

The potential of effluent to produce offensive odors was quantified by measuring in the liquid the concentration of compounds typically associated with malodors in animal waste according to the published method of Loughrin et al. (2009). Data are summarized in tables 4 and 5. The largest reduction was observed after the liquid passed through nitrogen treatment. Odor compound removal efficiencies by the treatment system were 100%.

Table 4. Reduction of aromatic malodorant compounds by 3rd generation treatment.

Aromatic Malodorants	HT Tank (sd)	Decant Tank (sd)	Separated Water Tank (sd)	Clean Water Tank (sd)	Plant Effluent (sd)	Removal Efficiency
	ppb	ppb	ppb	ppb	ppb	%
Phenol	5,937 (3,847)	8,408 (6,497)	935 (398)	0	0	100
Total Cresols	5,888 (6,825)	659 (608)	163 (78)	0	0	100
Indole	627 (598)	459 (169)	0	0	0	100
Skatole	993 (420))	1,606 (1,676)	528 (56)	0	0	100
Total	**13,446 (8,109)**	**11,133 (8,478)**	**1,626 (364)**	**0**	**0**	**100**

Conclusions

The major goals in the demonstration and verification of a 3rd generation wastewater treatment system for swine manure were achieved.

These goals included:

1) replacement of anaerobic lagoon treatment,
2) meeting environmental standards for new or expanding operations in NC,
3) adaptation of the system to flushing systems, which produce high volumes of very diluted manure, and
4) efficient environmental performance when installed in larger swine farms.

Based on the technical environmental performance results the 3rd generation technology meets the criteria identified in the referenced NC Swine Waste Management System Performance Standards. Under current NC regulations this would enable producers to incorporate the technology onto swine farm sites proposed for new and/or expanding operations and/or retrofit of existing operations with no expansion pending permit approval by NC Departmental of Environment and Natural Resources (NCDENR).

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