19 Alternative Treatment Technologies Case Studies

One of the initial goals was to determine if the constructed wetlands system could produce an effluent that would meet stream discharge requirements.

1 Constructed Wetlands for Swine Wastewater

This study was undertaken to investigate the capacity of constructed wetlands planted with either native wetland plants or water-tolerant agronomic plants to treat swine wastewater from a lagoon. One of the initial goals was to determine if the constructed wetlands system could produce an effluent that would meet stream discharge requirements. Three sets of two, 3.5-meter (m) x 33.5-m wetland cells were constructed adjacent to the existing lagoon in 1992.

During the first year, the nitrogen (N) loading rate of 3 Kg/ha/day specified for advanced treatment for stream discharge was used, but effluent N and phosphorus (P) concentrations would not consistently meet stream discharge requirements. The goal was then changed to determine the maximum possible removal of N and P.

The second year N loading rate of 8 kg/ha/day resulted in about an 87% removal of N or about 1,880 kg/ha/yr. The third year N loading rate of 15 kg/ha/day resulted in about 83% N removal or about 3,360 kg/ha/yr. The fourth year N loading rate of 25 kg/ha/day resulted in about an 87% N removal or about 5,870 kg/ha/yr. Mass removals are for 270 days of operation per year used to protect equipment from freezing. Mass removal efficiencies for these loading rates are shown in Table 25-3. The N loading rate for the fifth year was continued at 25 kg/ha/day to determine if the same removals could be achieved as during the previous year. Preliminary testing indicates only 10% to 15% ammonia volatilization for constructed wetlands receiving lagoon liquid at a high N loading of 25 kg/na/day.

Conjunctive microcosm studies were conducted to determine the maximum N loading rate possible and determine maximum N removal with sequencing nitrification and wetland treatment. Results show that with nitrification pretreatment, wetlands have the potential to remove more than 10,000 kg N/ha for 270 days of operation per year to protect from freezing.

Table 25-3. Nitrogen loading rates and mass removal efficiencies for constructed wetlands, Duplin Co, NC (June 1993-December 1998).

N Loading, kg/ha/yr	System	% Mass Removal[1]	Average Annual N Removal, kg/ha/yr	Average Effluent N Concentration, mg/l
3	Rush/bulrush Cattails/bureed	94 94	760	8.2
8	Rush/bulrush Cattails/bureed	88 86	1,880	24.2
15	Rush/Bulrush Cattail/Bureed	85 81	3,360	29.5
25	Rush/Bulrush Cattail/Bureed	90 84	5,870	46.0

[1] Mass Removal = % mass reduction of NH_3-N + NO_3-N in the effluent with respect to the nutrient mass inflow for 270 application days per year.

Conclusions. Wetlands by themselves cannot remove sufficient N and P to meet stream discharge requirements but do show promise for high rates of N mass removal with the result that much less land is required for terminal application. Placing a nitrification pretreatment component prior to the wetlands can increase the N removal efficiency of the wetlands. Such systems could provide an alternative to anaerobic lagoons and still provide high levels of N removal with reduced ammonia volatilization and odor with the result that much less land is required for terminal application. However if a lagoon is not used prior to the constructed wetland, an alternative solids removal technology is required to minimize solids deposition in the constructed wetland.

Wetlands…show promise for high rates of N mass removal… .

References

Rice, J.M., A.A. Szogi, F.J. Humenik, and P.G. Hunt. 2000. Long Term Data for Constructed Wetlands for Swine Wastewater. In Proceedings of the Third National Workshop on Constructed Wetlands/BMPs for Nutrient Reduction and Coastal Water Protection. NCSU, 24-26.

Stone, K.C., P.G. Hunt, A.A. Szogi, F.J. Humenik, and J.M. Rice. 2000. Constructed Wetland Design and Performance for Swine Lagoon Wastewater Treatment, ASAE paper #4148.

Rice, J.M., A.A. Szogi, Stephen Broome, Frank J. Humenik, and Patrick G. Hunt. 1998. Constructed Wetland System for Swine. In *Proceedings Volume I: Animal Production Systems and the Environment*. An international conference on odor, water quality, nutrient management and socioeconomic issues. Iowa State University, Ames, July.

2 Pilot-Scale Nitrification Prior to Constructed Wetland for Swine Waste

A five-year microcosm wetland study was conducted to assess the performance of sequencing nitrification and wetland treatments. Swine lagoon wastewater enriched with nitrate was applied to the microcosm wetland units at a rate of 190-kg nitrate-N/ha for a retention time of four days. About 80% of the nitrate applied were removed. On an annual basis, this removal potential is equivalent to about 14,000-kg N/ha, which is 5.4 times higher than the N removal without nitrification pretreatment. This indicates that the capacity of mass N removal by wetlands can be significantly increased by nitrification pretreatment.

Nitrification prior to wetlands can be provided by a media filter, encapsulated nitrifying bacteria, and overland flow. Data from field evaluation of these processes is presented in Case Study #3.

References

Rice, J.M., A.A. Szogi, F.J. Humenik, and P.G. Hunt. 2000. Long Term Data for Constructed Wetlands for Swine Wastewater. In Proceedings of: The Third National Workshop on Constructed Wetlands/BMPs for Nutrient Reduction and Coastal Water Protection, NCSU, 24-26.

Stone, K.C., P.G. Hunt, A.A. Szogi, F.J. Humenik, and J.M. Rice. 2000. Constructed Wetland Design and Performance for Swine Lagoon Wastewater Treatment, ASAE paper #4148.

In overland flow, nitrification occurs when a thin film of water is in close contact with a nitrifying population at the soil surface.

Lagoon wastewater was applied as a fine spray on the surface of the media filter… .

3 Nitrification Alternatives

Nitrification alternatives evaluated include overland flow, media filter, and encapsulated nitrifiers. Typically, the lagoon liquid that served as the wastewater source contained 365 mgL^{-1} of total Kjeldahl nitrogen (N), mostly (> 95%) as ammonia-N, 93 mg L^{-1} of total phosphorus (P), 740mg/L^{-1} chemical oxygen (COD), and a pH of 8.2.

Overland flow. In overland flow, nitrification occurs when a thin film of water is in close contact with a nitrifying population at the soil surface. It also offers the advantage of partial denitrification in the underlying saturated soil layer. The treatment unit consisted of a 4-meter (m) x 20-m plot with a 2% slope. The sides and bottom of the unit were lined with plastic after excavation to a 20-cm depth and filled with the same sandy topsoil. Vegetation consisted of a mixture of fescue, coastal Bermuda grass, and reed canary grass. Lagoon liquid was applied five days a week with hydraulic rates of 2.5 to 3.0 cm/day. Preliminary tests showed that the sandy soil was highly permeable and that applying these hydraulic rates during 8-hour periods often failed to provide a surface runoff. Therefore, to obtain a functional surface flow, applications during the evaluation period (1996 and 1997) were only made during four hours each day. Hydraulic losses were similar to the expected evapotranspiration losses (0.5-0.8 cm/day).

Spatial sampling of the surface runoff water along the plot revealed that no nitrification activity occurred in the first 5 m of the plot. Beyond this point, the nitrate concentration gradually increased up to a maximum occurring at 17 m downslope. The nitrification rate also changed with time during the 4-hour application period. Highest activities were generally observed during the first two to three hours of application. Nitrogen budgets showed that losses of ammonia through volatilization were usually about 13%.

Performance data for the overland flow treatment are shown in Table 25-4. The higher application rate in 1997 reflects changes in lagoon N concentration. On a mass basis, average total N removal efficiency was 35% in 1996 and 42% in 1997, which is equivalent to 22.4 to 41.6 kg N/ha/day, respectively. The lower nitrate recovery values observed after treatment (Table 25-4) suggest that simultaneous denitrification occurred in the saturated soil layer, a typical feature of overland flow systems.

Media filter. The pilot unit evaluated consisted of a 1.5 m diameter x 0.6 m high tank filled with marl gravel. To avoid clogging by swine wastewater, gravel with a high calcium carbonate content that removes P was used instead of typical sand media. The distribution of the gravel particles was 85% in the 4.7-mm to 12.7-mm size class and 14% in the 12.7-mm to 19-mm size class, providing a pore space of 57%. Filtrate was collected for recirculation.

Lagoon wastewater was applied as a fine spray on the surface of the media filter at a hydraulic loading rate of 684 L/cubic meters (m^3) reactor volume/day. The corresponding average total N loading rate was 249 g N m^3 d^{-1}. The pilot unit was operated from March to July 1997, five days a week during 12-hour periods (6 a.m.-6 p.m.) under an intermittent flow mode to enhance aeration inside the media. The intermittent flow was controlled by a timer that turned a pump on and off at 12-minute intervals.

A six-week acclimation period was needed to develop a functional nitrifying biofilm on the media surface, indicated by stabilization of the nitrification activity. Unit performance was evaluated for 90 days after acclimation (Table 25-5). A lime supplement consisting of 100 g/day of crushed lime applied to the surface of the media filter during the second half

Table 25-4. Treatment of lagoon swine waste water with overland flow.

Year	Total N Application Rates, Kg/ha/day[1]	Evaluation Period, days	Total N Removal Efficiency, %[2]	NO_3-N Recovery, %[3]
1996	64	85	35	7
1997	99	60	42	7

[1] Total N = TKN + NO_3-N. (Inflow nitrate concentration = 0)
[2] Total N Efficiency = ([TN mass inflow - TN mass outflow]/ TN mass inflow) × 100
[3] NO_3-N Recovery = (NO_3-N mass outflow/TKN mass inflow) × 100.

of the evaluation period resulted in increased nitrification. The positive effect of lime may be due to increased inorganic carbon availability. As indicated by the total N balance, ammonia volatilization losses during treatment were small.

Encapsulated nitrifiers. The immobilization of microorganisms in polymer resins is a widely applied technique in drug manufacturing and food processing. This technique was recently applied to municipal wastewater treatment in Japan. The nitrifiers are entrapped in polymer pellets that are permeable to the ammonia, oxygen, and carbon dioxide that these microorganisms need. Swine lagoon wastewater was treated under continuous flow in a nitrification tank equipped with a screen to retain the pellets with the encapsulated nitrifiers and an aeration system to ensure appropriate fluidization of the pellets. This ensures that the desired amount of nitrifiers is maintained in an aerobic or oxidizing reactor. Pellets were added at 15% (w/v) pellet to total tank volume ratio.

Nitrogen loading rates were increased by gradually decreasing the HRT from 24 hours to 4 hours (Table 25-6). Nitrification efficiencies of more than 90% were obtained with total N loading rates lower than 438 g N m^{-3} d^{-1} and an HRT higher than 12 hours. Although higher loading rates resulted in lower treatment efficiencies, the total amount of nitrate produced was higher, with the maximum nitrate production rate obtained with an HRT of 4 hours. Higher efficiencies may be useful for total systems designed to meet stream discharge requirements. However, if the objective is to remove large amounts of N from operating lagoons on a periodic or continuing basis with a mobile unit, then a retrofit nitrification unit operated at shorter retention times is recommended. This strategy has the advantage of reducing the total cost of aeration per unit of nitrate-N produced.

Swine lagoon wastewater was treated under continuous flow in a nitrification tank equipped with a screen to retain the pellets with the encapsulated nitrifiers and an aeration system to ensure appropriate fluidization of the pellets.

Table 25-5. Treatment of lagoon swine wastewater with media filter for 90 days.

N Form	No Lime Inflow	Outflow	Lime Inflow	Outflow
TKN (mg L^{-1})	336	221	363	114
NH_4-N (mg L^{-1})	340	193	334	106
NO_3-N (mg L^{-1})	0	133	2	208
TN (mg L^{-1})	366	354	365	322
NE	26%	57%		

TN = Total N = TKN + NO_3-N.
NE = Nitrification efficiency = (NO_3-N conc. outflow/TN conc. inflow) × 100

Table 25-6. Treatment of lagoon swine wastewater with encapsulated nitrifiers.

HRT, hours	Total N Loading Rate[1]	Ammonia Removal Rate[2]	Nitrate Production Rate[3]	Nitrification Efficiency[4]
	g N/m³ reactor volume/day			
24	238	223	240	100
20	272	254	279	100
16	342	311	327	96
12	438	363	397	1
8	668	402	417	62
6	926	498	499	54
4	1,349	604	567	42

[1]Total N = TKN + NO_3-N. (Inflow nitrate concentration = 0)
[2]Ammonia removal rate = flow × (NH_4-N conc. inflow - NH_4-N conc. outflow)
[3]Nitrate production rate = flow × (NO_3-N conc. outflow)
[4]Nitrification efficiency = (NO_3-N conc. outflow/TN conc. inflow) × 1005.

Summary. Overland flow is a low-intensity system that can remove large amounts of N per unit area through nitrification and partial denitrification. Performance data showed N removal rates of 22 to 42 kg N/ha/day.

The media filter is a medium-intensity system that is popular for small waste generators. Nitrification efficiency was 57% at total N loading rates of 249 g/m³/day.

Nitrifying pellets technology is a high-intensity system using fluidized bioreactors designed for more rapid, efficient oxidation of NH_3. Nitrification efficiencies of 91% were obtained at total N loading rates of 438 g N/m³/day and 42% at 1,349 g N/m³/day.

Current research efforts focus on the development of integrated systems for sequencing nitrification and denitrification unit processes that provide reduction of ammonia volatilization and odor and high removals of total N.

Reference

Vanotti, Matias B., Ariel A. Szogi, Patrick G. Hunt, Frank J. Humenik, and J. Mark Rice. 1999. Nitrification Options for Swine Wastewater Treatment. In 1998 Proceedings: Volume II. An International Conference on Odor, Water Quality, Nutrient Management and Socioeconomic Issues, Iowa State University, Ames, 795-800.

Flushed swine manure is...treated with chemicals to precipitate phosphorus (P) and solids in a tangential flow separation (TFS) system.

4 Tangential Flow Separator

Technology description. Flushed swine manure is pre-screened with a screening/conveying/dewatering unit (shaftless spiral screw, screening, and a flightless zone dewatering section) and subsequently treated with chemicals to precipitate phosphorus (P) and solids in a tangential flow separation (TFS) system. The system consisted of a lime slurry tank, a pre-floc mixing (reaction) tank, a TFS tank, a thickening tank and associated pumps and flow meters. Ferric chloride and polymer are injected into the flow after the pre-floc tank. The flow is then conveyed into the TFS tank at a tangent to the wall, settled solids accumulate at the bottom of the TFS unit, and finally flow into a thickening tank of similar design to the main unit. Supernatant is either recycled back to the TFS tank or discharged to a storage unit. Pretreated product streams are separated solids. Post-treated product streams are liquid effluent and biosolids. The study was conducted on a commercial farm in Southeastern North Carolina under loading conditions of approximately 20 gallons/minute.

Project results. Under the conditions tested, the pre-screening unit removed approximately 15% of the total solids and a much smaller percentage of the nutrients; the separated solids were 40% dry matter and 11% crude protein. Post-treated effluent showed P removal of more than 90% and copper and zinc removal of approximately 85%. Odor was not significantly reduced by the treatment system. With further processing, solids recovered from the TFS system may potentially be used as a soil amendment, potting media, or feed ingredient. Economic estimates of costs for a 3,600-head capacity finishing farm were as follows: initial investment of $140,000; annual operating costs of $15,000; potential revenue or other costs reduction of $15,000; resulting in net annual costs of approximately $2.60 per finished animal.

With further processing, solids recovered from the TFS system may potentially be used as a soil amendment, potting media, or feed ingredient.

Reference

http://www.cals.ncsu.edu/waste_mgt/apwmc/reports/1999 report.html

5 Aerobic Biofilter Treatment of Flushed Manure and Stabilization of Screened Solids

Technology description. The technology provider was Ekokan, Inc. Innovative Biotechnology Processes. A pilot plant with capacity to treat up to 8 cubic meters (m^3)/day was installed in May 1997 at the North Carolina State University Lake Wheeler Road Field Laboratory, Swine Educational Unit.

The main system was composed of two upflow biofilters connected in series, three blowers, and two polishing tanks, also connected in series. The biofilters had a total volume of 1.76 m^3. They were packed with plastic media with a specific surface area varying between 115 and 165 m^2/m^3. An inclined screen and a filter press were periodically used to obtain solids for extrusion and characterization.

Flushed wastes from a swine research unit with a population of about 325 sows, 25 boars, 350 nursery pigs, and 500 finishing pigs were collected into a 26.5 m^3 concrete settling basin. A small portion of the overflow from the settling basin was pumped into a 4.2 m^3 storage tank. Waste was pumped from the storage tank to the first biofilter and traveled upward inside the biofilter. The partially treated effluent exited into a pipe at the top, and gravity fed to the second biofilter. The treated effluent from the second biofilter exited from a pipe at the top and was allowed to settle in two tanks connected in series. The clarified effluent was discharged back to the settling basin.

The biofilters were aerated using three blowers (one for each biofilter and a third for air scouring during backwash) (Aerzen GM 3S, Aerzen Canada, Inc.) with a capacity of about 1.2 m^3/min @ 1,900 rpm and 400 mbar pressure. The capacity of the blowers exceeded the aeration requirements, so about 0.2 m^3/min flowed to each biofilter and about 1.0 m^3/min was bypassed (discharged directly to the atmosphere). Air was diffused through perforated pipes located at the bottom of the biofilters. A design criterion was to supply air at 25 m^3 of air per m^2 of biofilter cross-sectional area per hour. Dissolved oxygen was normally between 6 and 8 mg/l in effluent from each biofilter but ranged from about 4 to 11 mg/l.

The biofilters were backwashed periodically by agitating with increased airflow so that the accumulated suspended solids and newly produced biomass were removed from the system. Typically, the backwash frequency was four times per day for the first biofilter and once every two days for the second biofilter. For the backwash cycle, about 25 cm of liquid depth was removed from the biofilter (from the bottom) to prevent overflow during the increased airflow. Then, air from all three blowers was diverted to the biofilter for 3 minutes. The more concentrated liquid was removed from the bottom of the biofilter. About 25% of the biofilter water volume (75 cm of liquid depth) was removed during backwash and stored in a tank where solids settled as biosolids. The upper liquid portion of the backwash was discharged back into the settling basin. For some tests, part of the biosolids that settled in the storage tank was dewatered in a drying bed. The remaining biosolids were discharged back to the settling basin.

Project results. The loading rate of the biofilters was based on chemical oxygen demand (COD) and was about 6 kg COD/m^3-day to the first biofilter, except during September 1997 when a higher loading rate of about 9.6 kg/m^3-d was used to test the biofilter's limits. The hydraulic flow rates to the first biofilter were normally 4 to 5 m^3/day.

Using liquid influent and effluent samples, an odor panel determined that two upflow aerated biofilters in series were able to significantly reduce odor intensity and irritation. Backwash from the biofilters had a higher odor intensity and irritation than did the effluent.

...the reduction in [biofilter] concentrations from influent to effluent was 72% for COD, 57% for volatile solids, 76% for SS, 72% for TKN, 82% for NH_3-N, 49% for total N, and 26% for total P.

With an average loading of 6.6 kg COD day per m^3 of media for 12 months, the reduction in concentrations from influent to effluent was 72% for COD, 57% for volatile solids, 76% for SS, 72% for TKN, 82% for NH_3-N, 49% for total N, and 26% for total P. Temperature affected the reductions, with higher reductions at higher temperatures. Most of the reduction in concentrations occurred in the first biofilter, but the second biofilter still had significant reductions as a percentage of influent concentrations to the second biofilter. During low temperatures, the first biofilter had very little nitrification, demonstrating some advantage for having the two biofilters in series for nitrification at low temperature. The COD mass removal rate was linear with a loading rate ranging from about 2 to 12 kg COD/day per m^3 of filter.

By calculating a mass balance over the period of monitoring, it was determined that about 30% of the influent volume, 35% of the total N, and 60% of the total P was removed with the backwash from the biofilters. Potentially, the backwash could further settle and concentrate the biosolids. In any case, management and utilization of the backwash is an important consideration when implementing this type of system on farms.

Another potential result of having an aerobic treatment system that converts organic and ammonia N to nitrate is that denitrification could occur when effluent is recycled to the swine buildings for pit recharge.

Brief Project Summary

Technology description. Aerobic treatment of pre-screened flushed liquid manure for purposes of reducing COD, odor, and ammonia volatilization (by promoting nitrification) was accomplished by two upflow, fixed-media biofilters connected in a series. Plastic fixed-media within the biofilters provides surface area for a biofilm of bacteria to aerobically stabilize organic matter and convert ammonia to nitrate. Pretreated product streams are separated solids. Post-treated product streams are liquid effluent and biosolids. The study was conducted at the North Carolina State University Lake Wheeler Road Field Laboratory (Swine Education Unit) on a pilot-scale system to treat waste from the equivalent of approximately 20 finishing swine from a flush system with a flow capacity of 2,100 gallons/day.

Project results. Under the conditions tested, the treatment system was able to reduce COD by 70%, total N by 50% with organic loading up to 6.6 kg COD/m^3-day. Reductions were higher in summer as compared to winter. Ammonia was nearly completely removed and converted to nitrates and nitrites. Full denitrification to environmentally inert di-N gas would be possible by adding a carbon substrate under anaerobic conditions or perhaps by simply recycling the treated effluent to flush the swine buildings and having an adequate retention time. Odor was significantly reduced by the treatment system. Phosphorus was not efficiently removed by the system; laboratory results indicated that P could be removed from the treated effluent with the addition of a chemical coagulant. Economic estimates of costs for a 4,000-head capacity finishing farm were as follows: initial investment of $110,635; annual operating costs of $25,274 (mostly for electricity); potential revenue or other cost reduction of $16,360; resulting in net annual costs of approximately $2 per finished animal.

References

Bicudo, H., A. Kantardjieff, and P.W. Westerman. 1998. Fixed Media Biofilter Treatment of Flushed Swine Manure. ASAE paper No. 984121.
http:www.cals.ncsu.edu/waste_mgt/apwmc/te.html

6 Nitrification/Denitrification

The technology provider was Triangle Environmental, Inc. (National Environmental Technologies, Inc.), and the evaluation site was Carroll's Foods, Inc. Farm 2539.

Preliminary results

- The nitrification/denitrification process startup was not successful during winter (Dec/Jan) with high loading (manure from 6,480 finishing pigs).
- The nitrification/denitrification process startup was successful within two weeks during summer (end of July) with moderate loading (manure from 2,880 finishing pigs).
- The treatment system has shown good stability with relatively few operational problems after the foaming was reduced and the liner was weighted to prevent floating.
- Based on flows and concentrations, the estimated nitrogen (N) reduction by the treatment system during September and October was about 85%. Effluent N is > 90% organic, < 1% ammonia, and about 5% nitrate N.
- Biomass accumulation in the treatment pond results in relatively high suspended solids (about 10,000 mg/L), high organic N (about 400 mg/L), and high total P (about 600 mg/L). Biomass was "wasted" on October 27 (about 120,000 gal.).

The nitrification/ denitrification process startup was not successful during winter… .

Collected biogas is utilized to power a[n]...electricity generator.

Additional information is needed regarding

- Ability to process higher loading rates.
- Performance during winter conditions.
- Volume of discharged manure annually and changes during storage (odor, N).
- Management and maintenance requirements over long periods.

Reference

http://www.cals.ncsu.edu/waste_mgt/Field_Day_1.html

7 Covered, In-Ground Anaerobic Digester with Energy Recovery

Technology description. A 20 ft deep, 1.35 million cubic feet (ft^3) volume, anaerobic digester lagoon is covered with a modular (four section) 20 mil high-density polyethylene. Collected biogas is utilized to power a 120-kWh electricity generator. Waste heat collected from the engine radiator is utilized to heat water in a 10,000-gallon water tank that provides heat, as needed, to the farrowing houses. Effluent from the covered digester is conveyed to a non-covered secondary treatment and storage lagoon, 2.05 million ft^3 capacity, and recycled for flushing of the on-site buildings and seasonally irrigated onto Bermuda grass to remove excess nutrients. The study is being conducted on a commercial 4,000 sow, farrow-to-wean swine farm in Johnston County, North Carolina.

Project results. Significant reductions of chemical oxygen demand (COD), total solids (TS), volatile solids (VS), and pathogenic bacteria have been measured in the covered anaerobic digester. Nutrient concentrations in the secondary lagoon are approximately 40% to 60% that of a typical single-cell lagoon. Thus, less land application area is required for subsequent nutrient removal. Odor analyses have shown that odor emission from the secondary lagoon is much less than that from a typical single-cell lagoon. Biogas production from the covered lagoon is approximately 800 ft^3 per hour during the winter and approximately 1,200 ft^3 per hour during the summer. Methane content of the biogas is approximately 72%. Waste heat collected from the engine radiator has been used to heat the water in a 10,000-gallon water tank, and the hot water has been providing heat to the farrowing houses.

The modular cover developed a leak and was replaced with a 40-mil HDPE bank-to-bank cover in July 1999. The new cover has performed well since then with the added benefit of eliminating rainwater from the covered digester.

Tables 25-7 and -8 summarize the performance of the covered, in-ground anaerobic digester.

There is a high removal of COD, TS, VS, and pathogens in the covered, in-ground anaerobic digester. The nutrient level in the storage lagoon is about 40% to 60% of that in a typical single-cell lagoon, which means that less land is needed for application at agronomic rates. Odor from the storage lagoon is less than that from a typical single-cell lagoon.

Biogas production from the covered, in-ground anaerobic digester ranges from about 800 ft^3 (or 23 m^3) per hour in the winter to 1,200 ft^3 (or 34 m^3) per hour in the summer with a consistent methane content of about 72%. The methane production co-efficient is about 0.3 m^3-CH_4 per kg VS degraded.

Table 25-7. Average nutrients, solids, COD, and pathogens in water at different stages of the covered digester treatment system.

	TKN, mg/1	NH_4-N, mg/1	Total P, mg/1	o-PO_4-P, mg/1	COD, mg/1	TS, %	VS, %	*T. coliforms,* mpn/100 ml	*E. coli,* mpn/100 ml
Raw wastewater	1,529	1,015	349	193	16,600	1.04	0.63	4.1×10^9	2.8×10^8
Digester effluent	979	837	98	93	1,060	0.26	0.08	5.0×10^6	1.7×10^6
Storage lagoon water	278	210	8	42	682	0.20	0.06	4.0×10^5	5.0×10^5

Table 25-8. Percent removal of nutrients, COD, solids, and pathogens in the covered digester system.

	TKN, %	NH_4-N, %	Total P, %	o-PO_4-P, %	COD, %	TS, %	VS, %	*T. coliforms,* %	*E. coli,* %
Covered digester	38	-	72	52	94	75	88	99.88	99.39
Storage lagoon	72	75	51	55	36	22	24	92	70.59
Overall	82	75	86	78	96	81	90	99.99	99.82

References

Cheng, J., K.F. Rous, and Leland M. Saele. 1999. Covered Anaerobic Lagoon System for Swine Waste Treatment and Energy Recovery. ASAE paper 9940489.

http://www.cals.ncsu.edu/waste_mgt/apnmc/reports/1999report.html

8 Vermicomposting

Technology description. It is well established that earthworms have an important role in the recycling of organic wastes and residues. They are utilized for the decomposition of the solid fraction of swine manure, and the end product is a fine particulate matter (castings) that is valuable as a plant growth medium. Swine manure is an excellent medium for the production of castings via vermicomposting; however, excess water from the flushed manure must be removed by a solids separation process. Methods for growing earthworms in manure in North Carolina range from simple methods such as boxes and outdoor windrows, to complex automated systems with continuous-flow reactors, overhead gantries, and automated collection of castings, all done in enclosed facilities.

Project results. More than 5 tons per week of swine manure solids is being vemicomposted at a farm in Wilson, North Carolina. Manure that has passed through an automated solid separator between the swine house and lagoon is placed on a 15 ft x 15 ft concrete pad. A front-end loader transports the manure to a 30 ft x 200 ft greenhouse, and a spreader delivers manure to 2 ft x 190 ft wooden worm beds, each of which holds thousands of pounds of red worms. Temperature and moisture are controlled with greenhouse curtains, shade cloths, fans, and an automatic mister. Castings are lifted and conveyed from the beds every other month by a retrofitted machine, and a harvester separates worms and eggs from the castings.

Greenhouse trials with ornamental and vegetable crops showed that plant

Methods for growing earth-worms in manure... range from simple methods such as boxes and outdoor windrows, to complex automated systems... .

performance was enhanced (increased blooming, larger plants, and increased root growth) when vermicompost was present in the range of 15% to 35% of the total growth medium; plant performance decreased when the proportion of vermicompost increased beyond this point. Fecal bacteria in the separated manure solids decreased rapidly following addition to the worm treatment beds. When compared to no-worm treatment controls, however, the die-off was not enhanced in the presence of worms. A laboratory evaluation showed that the odor reduction (decrease in odor concentration and irritation intensity) commonly observed in enclosed worm facilities is primarily due to the manure solids separation process and is not accelerated by the worms.

Castings are sold in 2-, 10-, and 25-lb bags marked Vermicycle: Nature's Ultimate Plant Food. Less than 8 hours per week are required to manage the operation.

References

http://www.cals.ncsu/waste-mgt
http://www.cals.ncsu.edu/waste_mgt/apwmc/reports/1999report.html

9 Sequencing Batch Reactor for the Treatment of Flushed Swine Manure

Technology description. A pilot plant with a capacity to treat up to 400 gpd (1.5 m^3/day) was installed in August 1997. The system is composed of a homogenization tank, a sequencing batch reactor (SBR), and biosolids and effluent storage tanks. The treatment system has been monitored since November 1997. Four different operational strategies are being tested.

An SBR is a fill-and-draw activated sludge treatment system. The unit processes involved in the SBR and conventional activated sludge systems are identical. Aeration and sedimentation/clarification are carried out in both systems. The main difference is that in conventional plants the processes are carried out simultaneously in separate tanks, while in SBR operations, the processes are carried out sequentially in the same tank.

In SBR operations, the cycle processes of fill, react, settle, draw, and idle are controlled by time to achieve the operation's objective. Each process is associated with particular reactor conditions (turbulent/quiescent, aerobic/anoxic) that promote selected changes in the chemical and physical nature of the wastewater. A complete cycle begins with the fill process, when flushed swine manure is added to the system, and ends with the draw process, when a treated effluent is removed from the system. To treat flushed swine manure, the operation may last between 12 to 24 hours. The heart of the SBR system is the control unit and the automatic switches and valves that sequence and time the different operations.

Project results. The SBR, operated under an average temperature of 74°F (23.2°C), can remove up to 93% of COD and 98% of SS with a 24-hour cycle (HRT = 10 days) and short aerating/non-aerating periods. NH_3-N can be almost completely removed and converted to nitrites and nitrates, which are then denitrified under anoxic conditions; removal of fecal coliforms varied between 1 to 3 log units (90%-99.9%).

Long aerating/non-aerating periods resulted in high removal rates for

The SBR...can remove up to 93% of COD and 98% of SS...and... . NH_3-N can be almost completely removed and converted to nitrites and nitrates, which are then denitrified... .

chemical oxygen demand (COD) (89%), TSS (95%), and fecal coliforms (2-4 log units or 99%-99.99%), but lower removals of both nitrogen (N) (60%) and phosphorus (P) (15%). The system was able to nitrify (over 99% nitrification) but lost much of its denitrification potential. The longer aerating periods allowed nitrifying bacteria to fully develop and consume most of the available organic matter and alkalinity. Apparently an unbalanced microbial population developed within the biomass. The consumption of substrate and alkalinity by predominant species (mainly nitrifying and some heterotrophic bacteria) during aerating periods resulted in a severe drop of pH, probably cell lysis, and reactor failure.

At a lower hydraulic retention time (HRT) (5 day and 12-hour cycle) and short aerating/non-aerating periods, the SBR is still capable of removing a significant amount of organic matter, solids, and N (about 65%).

The SBR was able to remove between 40% and 70% of total P and Ortho-P, on average, during short aerating/non-aerating periods. Phosphates are probably being biologically removed from the incoming wastewater under cyclic anoxic/aerobic conditions inside the reactor. Under anoxic conditions, activated sludge releases large amounts of phosphate in the surrounding water. When the biomass is aerated again, the phosphates are absorbed by bacteria, which then can be removed from the system as biosolids. The rate of absorption of phosphate is greater than the rate of release, resulting in a net phosphate elimination from wastewater.

About 25% of the incoming wastes (vol.) are removed from the system as biosolids (between 0.9% and 1.0% TS). If the biosolids removed are allowed to settle into a storage tank, then a more concentrated material is obtained (about 2% TS). A clear supernatant is obtained after settling, and this is considered to be treated effluent. Its volume can account for at least half of the total volume of the biosolids originally withdrawn from the reactor.

Energy consumption was significant and may be attributed to an oversized blower for the pilot-scale system and the need to heat the reactor during winter months.

The SBR was able to remove between 40% and 70% of total P and Ortho-P on average, during short aerating/non-aeration periods.

Brief Project Summary

Technology description. Flushed swine manure is treated in the following sequence: (1) fill (containment vessel), (2) react (aeration that is cycled on and off), and (3) settle (remove solids for disposal). The system is designed to reduce organic carbon, convert ammonia to nitrate, and then convert nitrate to di-N gas, which can be released to the atmosphere safely; P can be removed through the bio-solids generated or by chemical precipitation. The technology has been used to treat wastewater from small communities for years. This study was conducted on a commercial farm in Halifax County, North Carolina.

Project results. Under treatment loading conditions of a 10-day HRT, COD, volatile solids, total N, and total P were reduced 93%, 75%, 95%, and 70%, respectively. Odor concentration intensity and odor irritation intensity were significantly reduced in both the treated effluent and bio-solids that the treatment system generated.

Under treatment loading conditions of a 10-day HRT, COD, volatile solids, total N, and total P were reduced 93%, 75%, 95%, and 70%, respectively.

References

http:www.cals.ncsu.edu/waste_mgt/apwmc/reports/1999report.html
http://www.cals.ncsu.edu/waste_mgt

Several technologies (polymer-enhanced solids separation, impeller aeration, and activated sludge treatment system with prescreening of solids) being used for municipal and industrial wastewater treatment are being tested as manure treatment alternatives.

10 Polymer-Enhanced Solids Separation

Technology description. A solids separator inclined belt press unit, equipped with a 1/16-inch screen polyacrylamide cationic polymer, was used to increase separation efficiency. The technology is designed to remove solids and associated nutrients from flushed waste before lagoon treatment. The study was conducted on a commercial 14,400-capacity, feeder-to-finish swine farm in Bladen County, North Carolina.

Project results. Under treatment conditions tested, which included utilization of the solids separator approximately 70% of the evaluation period, the test lagoon contained approximately 13% less total Kjeldahl N, 18% less ammonia-N, 12% less total P, and 16% less ortho-phosphate-P than a control lagoon receiving nontreated flushed manure. Biosolids depth in the treated lagoon was observed to accumulate more slowly in the test lagoon as compared to the control. Bench-scale analysis indicated that a 1/32-inch screen might be a more cost-efficient choice than the 1/16-inch screen.

References

http://www.cals.ncsu.edu/waste_mgt
http://www.cals.mcsu.edu/waste_mgt/apwmc/reports/1999report.html

11 Impeller Aeration

Technology description. Aeration (floating aerator designed to bring liquid from deeper in the lagoon to the surface) to retrofit existing lagoon for purposes of reducing lagoon solids volume, biological oxygen demand, odor, and ammonia volatilization (by promoting nitrification). The study was conducted on a 7,300-head, feeder-to-finish swine farm in Sampson County, North Carolina.

Project results. Under aeration conditions recommended by the technology supplier, nutrient concentrations in the test lagoon during the period of April 1997 through October 1998 were less than those observed during the same period of the previous year as follows: reductions of total Kjeldahl N 18%, ammonia-N 17%, total P 22%, and ortho-phosphate-P 19%. Electrical costs for the entire 19 months were approximately $340; capital costs for the aerator were approximately $2,000.

References

http://www.cals.ncsu.edu/waste_mgt
http://www.cals.ncsu.edu/waste_mgt/apwmc/reports/1999report.html

12 Activated Sludge Treatment System with Prescreening of Solids

Technology description. Biological treatment with bacteria maintained on suspended solids. The components include an aeration basin, clarifier section with partial sludge return to aeration basin, storage for "wasted" sludge, recycle of effluent for flushing, and storage for excess effluent. The aeration basin is aerated with blown air to maintain a dissolved oxygen content of approximately 2 mg/L to promote aerobic stabilization of organic matter and conversion of nitrogen (N) to nitrate. Sludge with active bacteria is settled in the clarifier, a portion is recirculated to the aeration basin, and the rest is "wasted." The nitrate in the effluent has potential to be denitrified to di-N gas by mixing with a carbon substrate under anoxic conditions. The pretreatment product stream is coarse separated solids. Post-treatment product streams are liquid effluent and "wasted" sludge or biosolids. The study was conducted at the North Carolina Department of Agriculture and Consumer Services Cherry Farm near Goldsboro, North Carolina.

Project results. The technology supplier designed the system for treating waste from a 315-sow, farrow-to-feeder operation. Organic loading was underestimated and resulted in inadequate aeration capacity, inadequate retention time, and inadequate clarifier size. The equalization (collection) pit was also too small and resulted in overflow of flushed wastes bypassing the treatment system. System performance was variable throughout a 12-month evaluation period. Biological oxygen demand was reduced by 35% to 55%, and some brief periods of denitrification were observed. The overall mass loss of N in the system was approximately 20%, and it is likely that this was due to ammonia volatilization. Dissolved oxygen was frequently less than 1 mg/L. Settling of solids in the clarifiers was also variable, and treated effluent generally had suspended solids concentrations of approximately 7,000 mg/L. The system required a certified Class II waste treatment operator and generally one person for 4 hours/day maintenance, monitoring, and operation. Numerous problems were encountered with pumps and blowers. Odor analysis (two sampling events) showed no statistically significant treatment effect on one day and significant improvement on the other day; however, odor intensity was still evaluated to be moderately strong. Economic estimates of the partial costs for this operation were as follows: initial investment of approximately $100,000 and electricity for energy use was variable from 300 to 500 kWh/day, which at $0.09/kWh would be $9,600 to $16,400/year.

Note that activated sludge treatment is a proven technology for municipal and industrial organic waste treatment for waste stabilization, N reduction, and odor reduction. It requires proper design, trained operators, and is energy intensive.

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References

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13 Dewatering/Bio-plate Composting

Technology description. Swine manure dewatering was accomplished by a screw press and sidehill separator. Composting of the resulting solids, which were mixed with wood chips, was enhanced by an in-vessel, aerated, static pile bin system using bio-plates for efficient air distribution. The objective was to reduce nutrient lagoon loading via pre-loading solids separation and to generate a viable stabilized product from the separated solids. The study was conducted on a commercial facility near Plymouth, North Carolina.

Project results. The side hill screen was determined to be more efficient and economical than the screw press for dewatering. Finished compost was of "exceptional quality," meeting all state and federal regulations. Compost use

The side hill screen was...more efficient and economical than the screw press for dewatering.

as a supplemental component in media for ornamental and greenhouse crops showed that swine manure compost can be substituted for up to 75% of the currently used media. Rates of swine compost use depend on the soluble salts level in the compost and the plant species to be grown.

References

http://www.cals.ncsu.edu/waste_mgt
http:www.cals.ncsu.edu/waste_mgt/apwmc/reports/1999report.html

14 Vacuum Microbubble Aeration

Technology description. Aeration to retrofit existing lagoon for purposes of reducing lagoon solids volume, biological oxygen demand, odor, and ammonia volatilization (by promoting nitrification). The study was conducted on a 250-sow, farrow-to-wean farm in the North Carolina coastal plain.

Project results. Under aeration conditions recommended by the technology supplier, the technology did not have a statistically significant effect on the environmental parameters tested.

References

http://www.cals.ncsu.edu/waste_mgt
http://www.cals.ncsu.edu/waste_mgt/apwmc/reports/1999report.html

15 Electric Reactor/Solids Separation

Technology description. Flushed swine manure, approximately 2% total solids, is pumped into an enclosed tube that is receiving pulsed electric current. The tube contains electrodes with voltage output; the liquid influent closes the circuit between the electrodes, creating an electrical discharge that reacts with the solids in the manure waste stream. After treatment in the electrical tube, the effluent is subjected to solids separation via an inclined screen. The solids are taken offsite and used for vermicomposting. The treated effluent is discharged to an existing lagoon on the site. The study is being conducted on a commercial swine farm in Sampson County, North Carolina.

Project results. The results, to date, have been inconclusive. Environmental parameters including chemical oxygen demand, nitrogen, phosphorus, copper and zinc, as well as indicators of pathogenic microorganisms and odor have been measured. The liquid manure loading rate to the system has been approximately 200 to 250 gallons/minute. Some data points have shown some reductions of the parameters noted; however, most results have not been consistent. Stabilization (low odor) of the treated solids is a consistent trend. Most of the environmental parameters, including odor, have been consistently favorable for the onsite lagoon receiving the treated liquid effluent. However, the system had been in operation on this site for some time before the evaluation study. Thus, it is unclear what impact the system had on the lagoon since no pretreatment baseline of data was established. The technology supplier has recommended that the influent loading rate be decreased to 80 gallons/minute.

References

http://www.cals.ncsu.edu/waste_mgt
http://www.cals.ncsu.edu/waste_mgt/apwmc/reports/1999report.html

16 High-Temperature Anaerobic Digestion/Solids Composting

Technology description. Flushed manure from an egg layer operation is anaerobically digested in an enclosed tank digester operating under thermophilic conditions (approximately 50°C). The biogas produced is utilized for the production of electricity and sold to a power utility. Solids from the digester are combined with composted substrates and utilized for greenhouse crop production. The study is being conducted on a commercial egg layer farm near Princeton, North Carolina.

Project results. An anaerobic digester on the farm operating at a lower temperature was converted to a thermophilic unit through cooperation with an engineering services firm. A waste-handling building has been constructed consisting of 12 aerated static pile compost bins equipped with a regenerative blower system. Problems have been encountered with separation of solids from the digester effluent (due to fine particle size), and efforts are underway to address this issue. The aerated composting bins are fully operational; manures have been blended with various bulking materials and other waste products to evaluate this system. A high-nutrient compost has been produced, and plant growth analysis trials will begin shortly.

References

http://www.cals.ncsu.edu/waste_mgt
http://www.cals.ncsu.edu/waste_mgt/apwmc/reports/1999report.html

17 Aerated Basin/Solids Reactor Cells

Technology description. Manure is flushed to an aerated basin called a “bioreactor.” Natural microorganisms are stimulated to assimilate low molecular weight compounds that can cause odors. Effluent then flows into one of two deep cells called “solids ecoreactors” where solids are recovered and dewatered. The two cells operate in parallel; as one is filling, the other is left to cure and harvest. In these cells, a soil amendment product is created. The solids ecoreactors are designed to be harvested at least yearly. Effluent from the second bioreactor can be further treated in a third bioreactor and then directed to a temporary water storage area until needed for field application. The study is being conducted on a commercial swine farm in Bladen County, North Carolina.

...solids eco-reactors are designed to be harvested at least yearly.

Project results. Data collection was initiated in January 1999. Mass inputs to the system and removal efficiencies were calculated using estimated flow rates based on pump capacities and time of operation. Removal efficiencies for chemical oxygen demand (COD) and total suspended solids (TSS) were 95% and 93%, respectively, for the system, not including the storage pond. The largest removals of COD and TSS occurred in the solids ecoreactor, although substantial removal also occurred in the first and second bioreactors. Nutrient removals observed were 53% for ammonia nitrogen (N), Duckweed covers the surface and converts the nutrients in the effluent to biomass.

A floating, permeable composite cover... reduced ammonia emissions by approximately 80%.

69% for total Kjeldahl N, and 87% for total P. Preliminary data shows that little N, but substantial P is removed from the liquid effluent in the solids ecoreactor. Therefore, based on data to date, indications are that the soil amendment product does not appear to be the endpoint for most of the N removed in this system. Removal mechanisms for N and P are being further investigated.

"Bioreactor" and "solids ecoreactor" are trade terminologies assigned by the company that represents this system.

References

http://www.cals.ncsu.edu/waste_mgt/
http://www.cals.ncsu.edu/waste_mgt/apwmc/reports/1999report.html

18 Secondary Treatment of Wastewater Using Duckweed

Technology description. This project involves a technology supplier that has developed a system consisting of a primary anaerobic digestion unit, a duckweed production unit, and a duckweed feed production process. In this system design, the primary treatment unit is lined to prevent seepage and covered to allow collection of gases; methane is collected and used for heating and drying of the harvested duckweed. Ammonia is separated and returned to the effluent from the digestion unit. This effluent is conveyed to the duckweed production units, which have large surface areas and shallow depths. Duckweed covers the surface and converts the nutrients in the effluent to biomass. A portion of the duckweed is harvested daily, and effluent from this unit is used to dilute incoming water to maintain acceptable concentrations of organics and ammonia for optimum duckweed production. Excess water is irrigated onto cropland and should contain very low concentrations of N. Harvested duckweed is stored in tanks and then dried and pelletized for use as animal feed.

References

http://www.cals.ncsu.edu/waste_mgt
http://www.cals.ncsu.edu/waste_mgt/apwmc/reports/1999report.html

19 Permeable Lagoon Cover

A floating, permeable composite cover manufactured from recycled polyethylene chips topped with a geotextile layer containing zeolite particles was evaluated under both laboratory and field conditions. Under laboratory conditions, the cover essentially eliminated odor release and reduced ammonia emissions by approximately 80%. When installed on a one-acre swine lagoon in eastern North Carolina, the cover survived severe storms and allowed even intense rainfall to pass through without causing cover inundation. Under these field conditions, the cover reduced ammonia emissions by approximately 80%. Odor emissions measured twice during one month of the study were consistently low in concentration, and an analysis by a trained odor panel determined that the emissions were near neutral relative to quality. The surface of the cover quickly became covered with an algae population within two weeks of installation. This and other vegetative growth, however, had no discernible impact on the cover's performance.

Lagoon sampling showed that constituent concentrations did not vary between sampling locations, indicating that even with a cover in place there is sufficient mixing within the lagoon to cause essentially uniform concentrations of the soluble constituents. Over time, nitrogen (N) has increased in the covered lagoon, which results in N conservation and the production of a more agronomically balanced effluent in terms of relative N and phosphorus (P) concentrations for land application but more land is required to accommodate the increased N. The surface of the cover reached a daytime temperature in excess of 120°F, but this heat was not transferred to the water surface because of the insulating properties of the covered material. The cover reduced the diurnal temperature fluctuations of the water surface to less than 2°F. It also reduced the rate at which the lagoon surface cooled in the autumn compared to a similar uncovered lagoon, resulting in a longer period of elevated temperatures to support biological activity.

Over time, nitrogen (N) has increased in the covered lagoon, which results in N conservation and the production of a more agronomically balanced effluent in terms of relative N and phosphorous (P) concentrations for land application… .

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