ADVANCED TECHNOLOGIES FOR REMOVAL OF NITROGEN FROM ANIMAL MANURE - EXPERIENCES OF THE USDA AGRICULTURAL RESEARCH SERVICE

REMOÇÃO DE NITROGENIO DE DEJETOS DE ANIMAIS – EXPERIENCIA DO AGRICULTURAL RESEARCH SERVICE (ARS/USDA – EUA)

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1. Introduction

Utilization of nutrients in manures in an environmentally sustainable manner is one of the critical management issues facing the U.S. livestock industry. Over 1,100 million tons of livestock manure are generated annually containing 12,900 million pounds of nitrogen and 3,800 million pounds of phosphorus. About half of this is produced by livestock held in confinement. The structure of animal agriculture has changed dramatically over the last two decades in the USA. Once dominated by many small operations as part of traditional crop-hog farms, hog production has become highly concentrated on large operations with production in several different sites. Considerable consolidation occurred in hog production during the 1990s. Since 1994, the percent of the hog and pig inventory on farms with 2,000 head or more increased from 37% to nearly 75%. About half of hogs and pigs were on farms with more than 5,000 head in 2001, compared with about a third in 1996 (USDA, 2003). Confined swine production is generally concentrated in the Midwest and North Carolina. The largest increases in confined operations in the last two decades are in North Carolina, Oklahoma, Arkansas, and Northern Iowa and southern Minnesota. In North Carolina alone, hog production increased from 2.6 million head in 1990 to over 9 million in 1997.

Minimizing livestock wastewater manure's impact on the environment is one of U.S. agriculture's major challenges. Problems arise when more nutrients are applied than crops or forage can use, causing excess runoff that can lead to poor drinking water and oxygen depletion in bodies of water. In addition to nutrients, manure and wastewater from animal feeding operations have the potential to contribute other pollutants such as pathogens, heavy metals, and ammonia to the environment. To address these concerns, the USDA Agricultural Research Service (ARS) has established a national research program on "Manure and Byproduct Utilization". This national program focuses on developing management practices and technologies for effective agricultural use of manure and other byproducts, while protecting environmental quality, human health, and animal health. This paper describes advances in swine manure treatment technologies at the USDA-ARS Coastal Plains Research Center in Florence, South Carolina to address environmental problem areas in confined swine operations with emphasis in nitrogen treatment technologies.

2. Alternative technologies

There are many aspects of animal residuals such as waste characteristics, operator involvement, regulations, and fiscal resources that are distinctly different than the sewage industry and require treatment technology developed specifically for animal waste systems. Site-specific, Comprehensive Nutrient Management Plans (CNMP) to minimize potential water pollutants from confinement facilities and land application of manure and organic by-products are already playing a significant role for pork producers. Using environmentally-safe alternatives to land application of manure and organic by-products could be an integral part of the overall CNMP. These alternatives are needed in areas where nutrient supply exceeds available land and/or where land application would cause significant environmental risk. More efficient and cost-effective methods are needed for manure handling, treatment, and storage. Areas in need of targeting include: (1) improved systems for solids removal from liquid manure; (2) improved manure handling, storage, and treatment methods to reduce ammonia volatilization; (3) treatment systems that transform and/or capture nutrients, trace elements, and pharmaceutically active chemicals from manure; (4) improved composting and other manure stabilization techniques; and, (5) treatment systems to remediate or replace anaerobic lagoons (USDA, 2001).

A flow diagram of various options other than spreading manure on the producer=s farm is shown in Fig. 1. Although some of the technologies are currently in the research stage, the diagram illustrates two distinct approaches to manure management. One is to develop dry systems such as the high rise and deep bedding where fresh manure is mixed with a bulking agent, or the use of inclined belts under the slatted floor to separate urine and solids so that all or part of the manure leaving a building is directly handled as a solid.

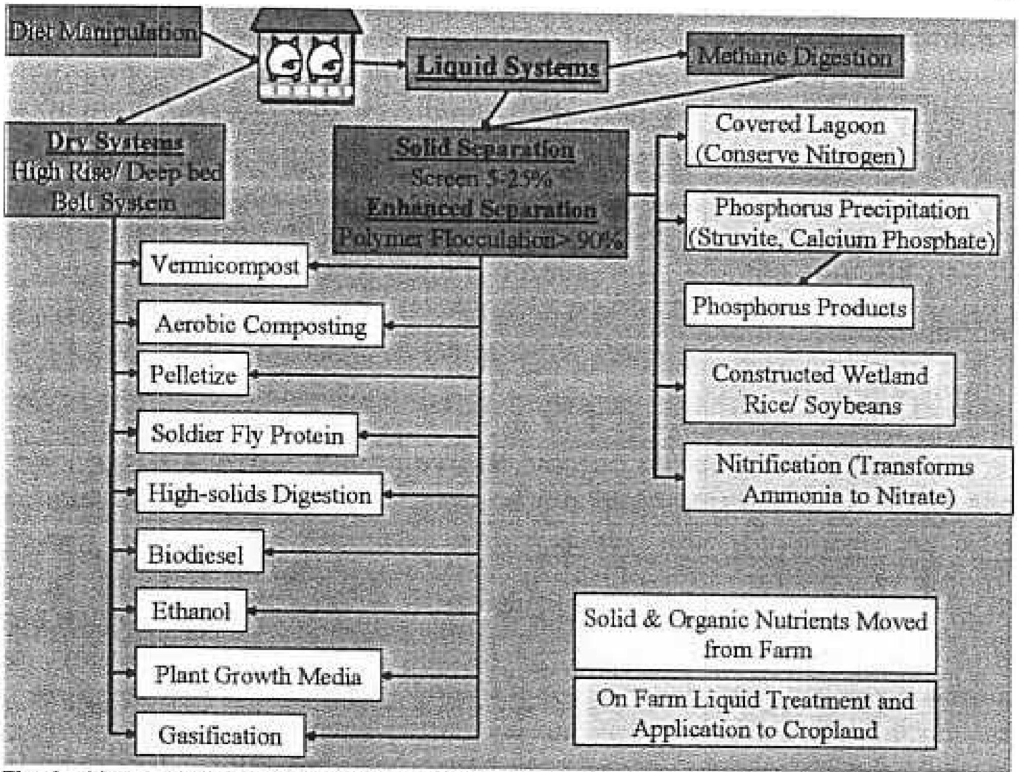

Fig.1. Alternative technologies to traditional anaerobic lagoon technology

The other approach is to improve or retrofit existing liquid treatment systems so that volatile solids and organic nutrients are separated from the fresh manure and transported and treated with a variety of technologies to generate value-added products. These products may include stabilized peat substitutes, humus, organic fertilizers, soil amendments, energy, and proteins. The remaining liquid needs to be treated in the farm. A variety of biological, physical or chemical processes can be used to achieve specific nutrient management goals. In order to significantly improve liquid systems, we need technologies that can provide effective solids/liquid separation. Such technology is for example the use of polymers where fine particles, typical in swine manure, are flocculated increasing separation above 90%. This higher recovery of solids not only removes organic nitrogen but also makes the use of advanced treatment in the liquid a more economical alternative.

3. Enhanced solids-liquid separation

We developed improved methods of manure solid-liquid separation through addition of polyacrylamide (PAM), a water-soluble polymer, to swine and dairy wastewater. High-rate separation of solids and liquids from animal wastewater is a critical step for development of alternative systems of manure management. Suspended solids can be reduced by more than 95% by improving solids flocculation as opposed to about 10% using traditional screening methods. Cationic polymers with low charge density were most useful for manure applications and treatment at higher strength was always more effective and economical. It is always more economical to use PAM to remove solids and nutrients from swine wastewater when strength is higher.

By capturing the suspended solids, most oxygen-demanding compounds and organic nutrients are removed from the liquid stream. This treatment greatly reduced the cost of treating the remaining wastewater, which had been considered prohibitively expensive. In addition, separated solids and nutrients can be transported more economically than liquid forms to nutrient deficient areas, or processed into value added products. The process separates organic nitrogen but not soluble ammonia contained in the waste. (Vanotti and Hunt, 1999; Vanotti et al., 2002).

4. Nitrification treatment

Although nearly all the organic N is removed with the suspended solids, a similar amount still remains in the soluble, ammonia fraction. Thus, after the solids are removed, the wastewater must be treated to transform the ammonia when alternatives other than land application are needed. One of the primary treatment transformations is the conversion of ammonia nitrogen to nitrate nitrogen via microbial nitrification. Aerobic treatment has been evaluated for treating animal wastewater, but in the absence of enriched nitrifying populations, aerobically treating high-ammonia animal wastewater may exacerbate environmental problems by stripping ammonia into the atmosphere.

We developed methods to enhance biological removal of N in wastewater containing high ammonia concentration through the use of bacterial immobilization technology. The technology allows an increase of about 1,000-fold more nitrifying bacteria to be retained in the reaction tanks, which increases efficiency and reduces both capital and operation cost. The research showed that with proper acclimation techniques, cultures of nitrifying bacteria could be adapted to high-ammonia strength wastewater and immobilized and used effectively to treat very concentrated (2600 ppm ammonia-N) animal wastewater. Ammonia removal rates of 915 to 990 mg N/L-reactor/day and 97 to 100% nitrification efficiency were obtained in batch treatment with no inhibition to the high ammonia concentration animal waste. The technology was effective for treatment of anaerobic lagoon wastewater and flushed manure after solids separation (Vanotti and Hunt, 2000; Vanotti et al., 2000; Vanotti et al., 2005a).

5. Denitrification treatment

Biological denitrification processes can be coupled to a nitrification reactor so that total nitrogen removal is achieved. Denitrification bacteria need a suitable source of organic carbon as an energy source. In wastewater treatment, two main types of organic carbon source can be used: either an endogenous source contained in the wastewater, or an external source like methanol, ethanol, etc. In the first case, the process leads to a pre-denitrification flowsheet that recycles a part of the nitrified effluent to an anoxic tank, in the second case, to a post-denitrification configuration. The advantage of the pre-denitrification configuration for the purposes of total N removal is that it uses a naturally available source from wastewater minimizing the need for supplemental carbon. In this process we also reduce the organic load to the nitrification tank. A Biogreen system using pre-denitrification was tested with flushed swine manure effluent after PAM separation in a study at NCSU Animal Waste Center in Raleigh, NC (Vanotti et al., 2001; Becker, 2001). Nitrogen removal efficiencies of 93% for total nitrogen and 99% for ammonia. Nitrification produces acid and consumes alkalinity, but there is usually no need for supplementation when a pre-denitrification configuration is used. An important consideration for denitrification is the ratio of COD to nitrate applied to the anoxic reactor. Low ratios are a problem. The efficiency of biological denitrification increases with an increased COD/oxidized N ratio up to an optimum value of 5 to 7 above which the performance remains constant.

Immobilized technology can also be applied to enhance the denitrification process. Using denitrifiers attached to PVA polymer beads we were able to obtain fast denitrification of swine wastewater (138 mg N/L-reactor/hour). Compared with standard denitrifying sludge, the use of immobilized denitrifiers can reduce about 10 times the size of treatment tanks, resulting in a compact system foot-print and more economical system with great advantages for animal systems.

6. Anaerobic ammonium oxidation (ANAMMOX)

We conducted research to develop process applications for the slow-growing anaerobic ammonium oxidation (Anammox) bacteria using continuous flow treatment and microbial immobilization techniques. In the Anammox process, the ammonia (NH_4^+) is converted to harmless dinitrogen gas (N_2) under anaerobic conditions with nitrite (NO_2^-) as the electron acceptor. It is more energy-efficient than traditional biological N removal systems because only part of the ammonium needs to be nitrified and there is no need for carbon addition for denitrification. The Anammox microorganisms were discovered in the sludge of a pilot plant providing nitrification treatment to anaerobic lagoon effluent in a swine farm in North Carolina. Laboratory bioreactors were seeded with the sludge isolated from the pilot reactor after acclimation with nitrate solution to remove endogenous carbon. The bioreactors were operated in continuous flow and contained polyvinyl alcohol (PVA) hydrogel biomass carrier beads for immobilization and enrichment of the slow growth microorganisms. A distinct red biomass growth, which is typical of the Anammox planctomycete, developed in the reactors after 6 months of continuous flow operation. Fluorescent in situ hybridization (FISH) analysis of the biofilm using 16S rDNA oligonucleotides Ana-1 and Amx 820 confirmed Anammox bacteria; imaging revealed a high density of cells growing in clusters. Removal of NO_2^- and NH_4^+ was simultaneous at a stoichiometric ratio characteristic of the Anammox reaction; we obtained the following equation:

$$NH_4^+ + 1.24\ NO_2^- + 0.11\ H^+ \rightarrow 1.00\ N_2 + 0.24\ NO_3^- + 2.05\ H_2O$$

Hydraulic retention time was gradually decreased from 24 to 12 h over a 16 month period to increase N load. Nitrogen removal rate obtained was 0.5 kg N/m^3/day, which is in the range of industrial bio-treatment applications. This finding may lead to development of more economical treatment systems for livestock wastewater and other effluents containing high ammonia concentration.

7. Environmentally superior alternative technologies

Currently, there is a government-industry framework in North Carolina for conversion of anaerobic swine waste lagoons and sprayfields to alternative technologies. In July 2000, the Attorney General of North Carolina reached an agreement with Smithfield Foods, Inc. and its subsidiaries, the largest hog producing companies in the world, to develop and demonstrate environmental superior waste management technologies. Once new technologies are identified, companies will convert their facilities and phase out the current lagoons and sprayfields. In October 2000, the Attorney General reached a similar agreement with Premium Standard Farms, the second largest pork producer in the country. Taken together, Smithfield and Premium Standard represent over 75% of the hog farms in North Carolina. The agreement defines an environmentally superior technology (EST) as any technology, or combination of technology that (1) is permittable by the appropriate governmental authority; (2) is determined to be technically, operationally, and economically feasible and (3) meets the following environmental performance standards: 1. Eliminate the discharge of animal waste to surface waters and groundwater through direct discharge, seepage, or runoff; 2. Substantially eliminate atmospheric emissions of ammonia; 3. Substantially eliminate the emission of odor that is detectable beyond the boundaries of farm; 4. Substantially eliminate the release of disease-transmitting vectors and airborne pathogens; and 5. Substantially eliminate nutrient and heavy metal contamination of soil and groundwater. Selection of EST candidates to undergo performance verification involved a request of proposals and competitive review by the Agreements Designee and a Panel representing government, environmental and community interests, the companies, and individuals with expertise in animal waste management, environmental science and public health, economics and business management. This process yielded 18 technologies candidates among about 100 submitted projects. In July 2004, two of the technologies were shown to be capable of meeting the environmental performance criteria necessary for the technologies to be considered environmentally superior. One of the two technologies treat the entire waste stream from a swine farm using solids separation, nitrification/denitrification, and soluble phosphorus removal system, while the second is designed to treat the separated solids using high solids anaerobic digestion system (Williams, 2004).

8. On-farm solids separation/nitrification-denitrification/soluble phosphorus removal system

The project was a collaborative effort involving scientists, engineers and personnel from private businesses, university and USDA. The system greatly increased the efficiency of liquid/solid separation by injection of polymer to increase solids flocculation. Nitrogen management to eliminate ammonia emissions was accomplished by passing the liquid through a module where immobilized bacteria transformed nitrogen. Subsequent alkaline treatment of the wastewater in a phosphorus module precipitated calcium phosphate and killed pathogens. Treated wastewater was recycled to clean hog houses and for crop irrigation. The system went through full-scale demonstration and verification as part of the Agreements described above to identify technologies that can replace current lagoons with Environmentally Superior Technology.

The treatment plant completed design, permitting, construction, startup, and one year operation period under steady-state conditions. The full-scale demonstration facility was installed on a 4,400-head finishing farm in Duplin County, North Carolina. The system was constructed and operated by a private firm called Super Soil Systems USA of Clinton, NC.

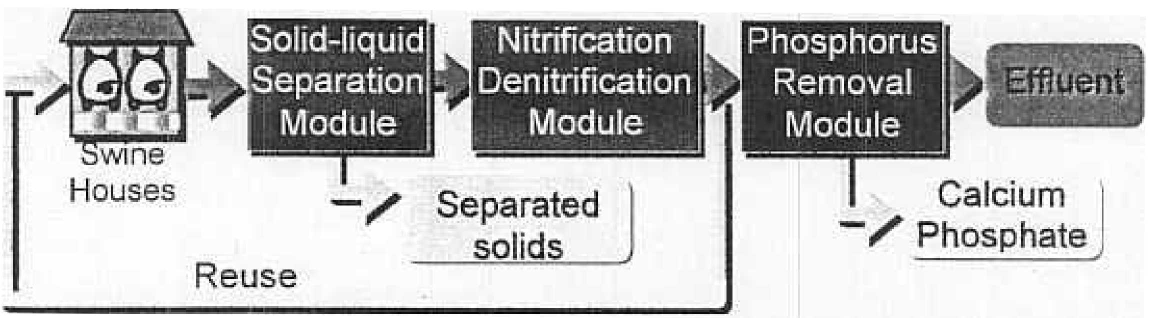

Fig.2. Diagram of wastewater treatment system installed at Goshen Ridge farm, North Carolina (Vanotti et al., 2005b).

The complete system removed 97.6% of the suspended solids, 99.7% of BOD, 98.5% of TKN, 98.7% of ammonia, 95% of total P, 98.7% of copper and 99.0% of zinc (Vanotti, 2004). The treatment system also removed 97.9% of odor compounds in the liquid and reduced pathogen indicators to non-detectable levels (Vanotti et al., 2005a). In less than a year, the anaerobic lagoon that was replaced with the treatment system was converted into an aerobic pond with ammonia concentration in the liquid of < 30 mg/L that reduced 90% of the ammonia emissions. It was verified that the technology was technically and operationally feasible. Based on performance results obtained, it was determined that the treatment system met the technical performance standards that define an Environmentally Superior Technology. These findings overall showed that cleaner alternative technologies can have significant positive impacts on the environment and the livestock industry.

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