EXTRACTION OF SOLUBLE PHOSPHORUS IN A SWINE WASTE TREATMENT SYSTEM WITHOUT LAGOON

M. B. Vanotti, P. G. Hunt, A. A. Szogi, A. Q. Ellison[1]

ABSTRACT

We found that soluble phosphorus can be easily removed from animal wastewater, which has had a nitrification pre-treatment, in the form of calcium phosphate that can be used as a fertilizer. In the process, carbonate and ammonium buffers contained in liquid waste must be at least reduced or eliminated during the nitrification pre-treatment. This substantially reduces the overall chemical demand needed for optimum phosphorus precipitation and removal.

This research showed that the concept can be used in systems without lagoons. The proposed system uses polymer enhanced solid-liquid separation to remove organic nutrients and oxygen-demanding compounds, and biological N removal to eliminate ammonia and carbonate buffers. Efficiencies of 98% phosphate removal were obtained.

This technology not only has potential to solve current problems with excessive accumulation of phosphorus in soils receiving liquid manure, it also produces a valuable phosphorus fertilizer material and reduces the presence of pathogens due to the high pH in the process.

KEYWORDS. Phosphorus removal, animal waste treatment, swine wastewater, pathogens, CAFO, manure P, hog lagoons, calcium phosphate.

INTRODUCTION

Manure nutrients in excess of the assimilative capacity of land available on farms are an environmental concern often associated with confined livestock production. For the USA as a whole, in 1997 about 20% of the 929 million pounds of farm-level excess phosphorus (P) exceeded the assimilative capacity at the county level (Kellogg et al., 2000). This means that a substantial amount of manure P needs to be moved at least off the farms and that some needs to be transported longer distances beyond county limits to solve distribution problems of this nutrient.

Past research efforts on P removal from wastewater using chemical precipitation have been frustrating due to the large chemical demand and limited value of by-products, such as alum and iron sludges, or to both the large chemical demand and losses of ammonia at the high pH that is required to precipitate phosphorus with calcium compounds (Loehr et al., 1973). Other methods used for P removal include flocculation and separation of solids using polymer addition and filtration or settling (Vanotti and Hunt, 1999). Although polymer treatment is effective for removal of organic P forms in liquid manure, it is not effective for removal of the soluble P.

In order to solve these problems, we have developed and filed a patent on a process to remove soluble phosphorus from animal wastewater (Vanotti et al., 2001). We found that soluble phosphorus can be easily removed from animal wastewater, which has had a nitrification pre-treatment, in the form of calcium phosphate that can be used as a fertilizer. In the process,

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carbonate and ammonium buffers contained in liquid waste must be at least reduced or eliminated during the nitrification pretreatment. This substantially reduces the overall chemical demand needed for optimum phosphorus precipitation and removal.

Two applications of the process have been evaluated. The first application is to remove P from swine lagoons and has been reported by Vanotti et al. (2002a) and Szogi et al. (2003; this symposium). Since ammonia nitrogen has been converted to nitrate, increased pH used to precipitate P does not result in significant gaseous nitrogen loss. Therefore, the amount of phosphorus removed, and consequently the N:P ratio of the effluent, can also be adjusted in this process to match the N:P ratio needed by the growing crop to which it will be applied. The second application, which is reported in this paper, is for cases where lagoons are not a viable treatment or land application of both nitrogen and phosphorus is not desirable.

System Without Lagoon

In the system without lagoon that we developed, fresh flushed manure is first treated with polyacrylamide (PAM) polymer to separate > 80% of the suspended solids, then subjected to a nitrogen removal using nitrification and denitrification, and then phosphorus is precipitated. The treatment provides an effluent virtually free from N and P.

PAM is a water-soluble polymer that clumps the fine, suspended particles typical of animal manure into larger particles or flocs. This enhances the separation efficiency of both screens and filters found in wastewater treatment systems. The liquid effluent after solids removal with polymer is similar to that after anaerobic lagoon treatment, so one process can replace the other, and the nitrification treatment removes the ammonia and alkalinity so the same concept for phosphorus removal applies with either lagoons or systems without lagoons.

A full-scale system based on this research was constructed in Duplin County, NC, for demonstration and verification of Environmental Superior Technology under the Smithfield Foods/PSF and NC Attorney General program to develop alternative systems to lagoons.

The objective of this study was to evaluate the potential advantages and technical feasibility of soluble P removal in a system without lagoon. We also describe the full-scale phosphorus module, which will be tested through summer 2003 at the demonstration facility.

EXPERIMENTAL METHODS

Removal of soluble phosphorus in a prototype of a system without lagoon was evaluated at the Swine Unit of the NCSU Lake Wheeler Rd. Laboratory in Raleigh, N.C. The total system is shown in fig. 1. It included solid-liquid separation, biological N removal, and P treatment.

Solid-liquid Separation

Flushed manure from finishing houses in the facility was collected in a 15-m^3 (4000-gal) homogenization tank. For solid-liquid separation, we used an in-line PAM injector and mixer to flocculate the solids in the flush and two sand filter beds (20 x 16 ft) for dewatering. Both the in-line PAM injector and filter beds were components of the Deskins[2] process (F.D. Deskins Company, Inc., Alexandria, Ind.) used for municipal sludge dewatering. Flushed manure was homogenized and pumped to the polymer injection unit at a 130 gal/min flow rate and then poured on the sand filter bed. The polymer used was a cationic emulsion (c1596, Cytec Industries, Inc., West Paterson, N.J.). The beds received 30-cm depth of flocculated manure during each pour. Detailed information and performance evaluation on this unit was provided by Vanotti et al. (2002b). The sand filtrate was stored in a 4000 gal tank and fed into the denitrification tank.

[2] Mention of trademark, proprietary product, or vendor does not constitute a guarantee or warranty of the product by the U.S. Dept. of Agriculture and does not imply its approval to the exclusion of other products or vendors that also may be suitable.

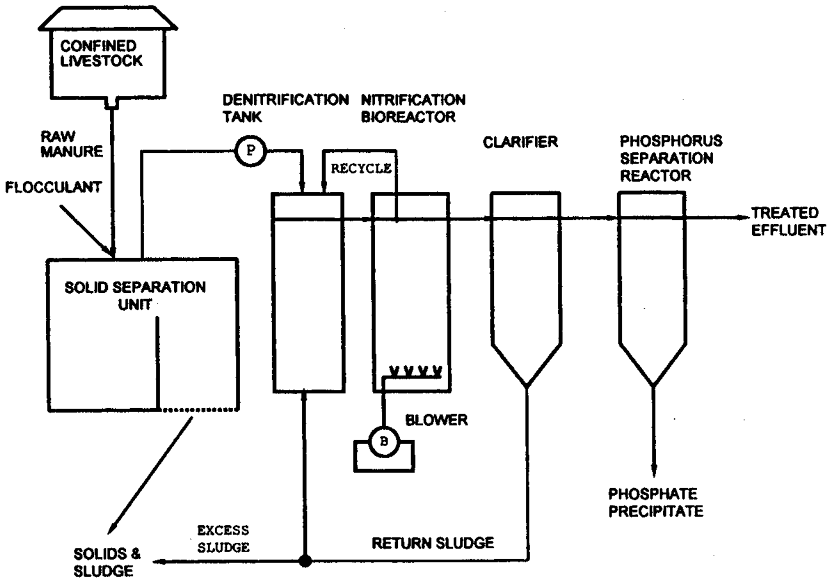

Figure 1. Schematic drawing of the pilot waste treatment system without lagoon.

Biological N Removal

A system that uses nitrifying pellets in an aerated tank and denitrifying sludge in anoxic tanks was used to treat the effluent after solids separation with PAM. The pilot unit was designed to treat 1 m^3/day of liquid at 10°C water temperature. It contained a 1.3-m^3 anoxic denitrification tank (DN1) with ~ 3 g/L MLVSS to remove soluble carbon and NO_3-N, a 0.55-m^3 nitrification tank containing 100 L of polyethylene glycol (PEG) pellets for conversion of NH_4^+ to NO_3^-, and a 0.63-m^3 clarification tank for settling of suspended solids. The unit also included a second 0.63-m^3 tank with methanol injection for post-denitrification when needed and a small 20-L oxic tank to enhance settleability. The nitrifying pellets were provided by the Hitachi Plant Construction & Engineering Co. of Tokyo, Japan. The pellets were already acclimated to swine wastewater in a 60-day procedure where nitrification activity increased from 0 to an optimum of 790 g N/100-L pellets/day. Nitrified liquid was recirculated (R_N) to the denitrification tank (DN1) at a rate of 5 m^3/day and settled sludge was recycled (R_S) at 1 m^3/day. The effluent from this unit was subsequently treated in the phosphorus reactor.

Phosphorus Reactor

The phosphorus reactor was placed after the clarifier (fig. 1) to precipitate and separate the soluble P before discharge. It consisted of a 379-L (100-gallon) plastic tank with conical bottom made of XLPE resin (Nalgene, Nalge Co., Rochester, N.Y.) and a mixer with 0.25 HP, 1725 rpm and 8.9-cm impeller size (Lightin, Rochester, N.Y.). A smaller 114-L (30-gallon) tank and mixer was used to prepare the lime milk (2% hydrated lime mixture in water). A peristaltic pump connected to a pH controller was used to transfer the lime milk into the P-reactor. A magnetic flow meter measured the total amount of chemical added in each treatment. The chemical was a high-purity, commercial hydrated lime powder containing 98.5% $Ca(OH)_2$ and with a mean particle size of 3.5 micron (Codex Hydrated Lime, Mississippi Lime Company, Alton, Ill.).

Hydrated lime was injected into the stirred reactor containing wastewater effluent from biological N removal module. A pH controller stopped injection when the pH of the mixed liquid reached a set point of 10.5. Once the desired treatment pH was reached, the mixer was turned off and the liquid was allowed to settle for about 30 min. After this settling period, duplicate liquid samples were collected from the supernatant for water quality determinations. The precipitated solids were removed by gravity from the bottom of the reactor and collected in plastic containers. A total of 5 runs of the system were conducted. A run consisted on the total treatment of a 4,000 gal. (15.1 m^3) separated flush and was completed in approximately 15 days.

Analytical Methods

All the analyses were done according to Standard Methods for the Examination of Water and Wastewater (APHA, AWWA & WEF, 1998). Solids analyses of the treated and untreated liquid samples included total solids (TS), total suspended solids (TSS), and volatile suspended solids (VSS). Chemical analyses consisted of pH, alkalinity, chemical oxygen demand (COD), soluble COD, 5-d biochemical oxygen demand (BOD_5), soluble BOD_5 , ammonia-N (NH_3-N), total kjeldahl N (TKN), orthophosphate-P (PO_4), and total P. Alkalinity was determined by acid titration to the bromocresol green endpoint (pH=4.5) and expressed as mg $CaCO_3$ L^{-1}.

RESULTS AND DISCUSSION

Solids and Nitrogen Treatment

Data in table 1 show the changes in wastewater characteristics after going through solid-liquid separation and biological N treatment. Solid-liquid separation removed 98% of the TSS and VSS, 93% of the BOD, and > 80% of the organic N and P. Soluble ammonia and phosphate were not removed with solids separation and needed further treatment.

By capturing the suspended particles, most of the volatile and oxygen-demanding organic compounds are removed from the liquid stream. Instead of being used to break down organic compounds, the oxygen in the subsequent aeration treatment is used efficiently to convert ammonia to nitrate. Nitrifiers are autotrophic microorganisms that consume ammonia and carbonate alkalinity. Soluble ammonia was completely removed and alkalinity was substantially reduced during biological N removal (table 2). Both ammonia and carbonate alkalinity are the most important chemical components in liquid manure contributing to buffering capacity in the high pH range (Fordham and Schwertmann, 1977), a necessary condition to form calcium phosphate precipitate.

Table 1. Treatment of flushed swine manure using solid-liquid separation and biological N treatment. Effluent was subsequently treated for phosphorus (table 2). Data are means (SE) of five runs of the system.

Constituent	Raw Manure	After Solid-Liquid Separation	After Biological N Treatment	Total Removal Efficiency (%)
TS (mg/L)	12456 (1311)	1902 (104)	1633 (133)	87
TSS (mg/L)	10591 (1283)	190 (20)	219 (117)	98
VSS (mg/L)	8563 (1037)	145 (15)	168 (86)	98
COD (mg/L)	8273 (1069)	1320 (96)	285 (25)	97
sCOD (mg/L)	1774 (196)	1074 (103)	185 (28)	90
BOD5 (mg/L)	2932 (1178)	217 (46)	56 (14)	98
SBOD5 (mg/L)	610 (215)	136 (26)	12 (4)	98
pH	7.01 (0.06)	7.29 (0.03)	7.62 (0.06)	--
Alkalinity (mg/L)	2182 (157)	1381 (56)	338 (48)	85
TKN (mg/L)	688 (49)	232 (13)	11 (5)	98
NH_4-N (mg/L)	190 (6)	173 (9)	0 (0)	100
Organic N (mg/L)	498 (45)	59 (10)	11 (5)	98
TP (mg/L)	480 (76)	112 (25)	75 (9)	84
PO_4-P (mg/L)	33 (2)	38 (4)	54 (3)	- 64
Organic P (mg/L)	447 (75)	73 (26)	20 (9)	96

Separation of Soluble Phosphorus

The hydrated lime was added to reach a set point pH of 10.5 in order to remove all soluble P. An average of 280 mg/L of hydrated lime was needed to reach this point, corresponding to a molar ratio of 1.3 between Ca applied and P in wastewater. Corresponding chemical cost is $0.056/m^3 of liquid treated (hydrated lime cost = $0.20/kg). The reaction time of lime and P was fast. Precipitate flocs, an indication that the reaction was complete, were evident in the mixed liquid after < 1 min. of stirring (fig. 2). The precipitate settled readily and it was concentrated to < 60 L per m^3 of liquid treated. The phosphate grade in the precipitate was 23 to 29% P_2O_5.

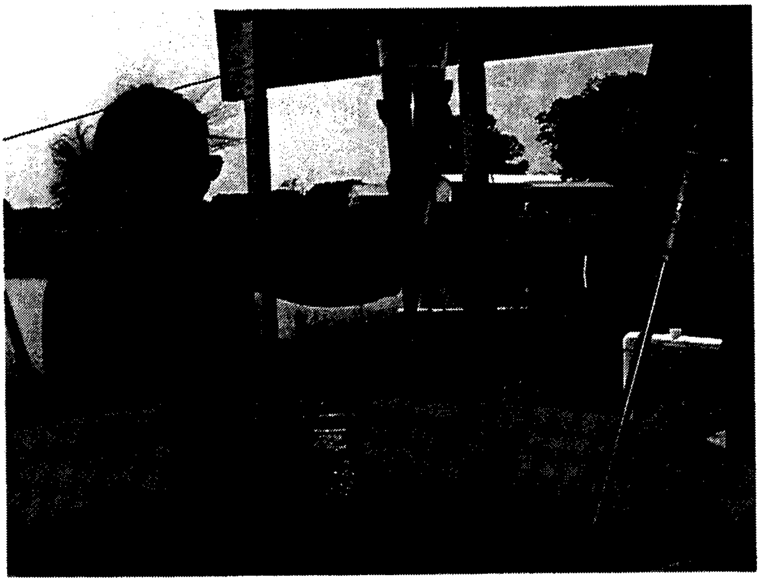

Figure 2. Phosphorus precipitate from swine wastewater obtained with lime application after solids separation and nitrification/denitrification treatement in the pilot system.

Phosphorus removal efficiencies were 98% for soluble phosphate and 91% for total P. The process also reduced BOD an additional log (table 2). After the P removal step, the effluent is virtually free from nutrients and water quality characteristics are significantly improved.

Table 2. Removal of soluble phosphorus after solid-liquid separation and biological N treatment. System efficiency calculations use raw manure values in table 1. Data are means (SE) of five runs of the system.

Constituent	Before Phosphorus Treatment	After Phosphorus Treatment	Removal Efficiency of P Reactor (%)	Removal Efficiency of System (%)
TS (mg/L)	1633 (133)	1041 (193)	36	91.6
TSS (mg/L)	219 (117)	89 (7)	59	99.2
VSS (mg/L)	168 (86)	41 (11)	76	99.5
COD (mg/L)	285 (25)	176 (23)	38	97.9
sCOD (mg/L)	185 (28)	143 (27)	23	91.9
BOD5 (mg/L)	56 (14)	4 (1)	93	99.9
SBOD5 (mg/L)	12 (4)	2 (1)	83	99.7
pH	7.62 (0.06)	10.3 (0.07)	--	--
Alkalinity (mg/L)	338 (48)	364 (34)	- 8	83.3
TKN (mg/L)	11 (5)	2 (2)	82	99.7
NH_4-N (mg/L)	0 (0)	0 (0)	0	100.0
TP (mg/L)	75 (9)	7 (2)	91	98.5
PO_4-P (mg/L)	54 (3)	1 (0)	98	97.0

In addition to the phosphorus removal aspect, the high pH used in the process destroys the pathogens in liquid swine manure. The effluent samples collected in this study were also analyzed for salmonellae, enterococci, and total and fecal coliforms. Results obtained indicated that a pH set-point of 10.5 in the P-reactor produces a sanitized effluent free of salmonellae and the other pathogen indicators evaluated (Vanotti et al., 2002c).

Another potential advantage of the process is the remarkable clarity observed in the treated effluent (fig. 2). The concentration of suspended solids was also significantly reduced. Low suspended solids concentration is often an important consideration in the use of subsurface or surface irrigation equipment for land application of livestock effluents. The liquid is poorly buffered and the high pH in the effluent decreases readily once in contact with air. This is demonstrated in the data in fig. 3 showing that, due to low buffer capacity, the CO_2 in the air can create enough acidity to rapidly lower pH.

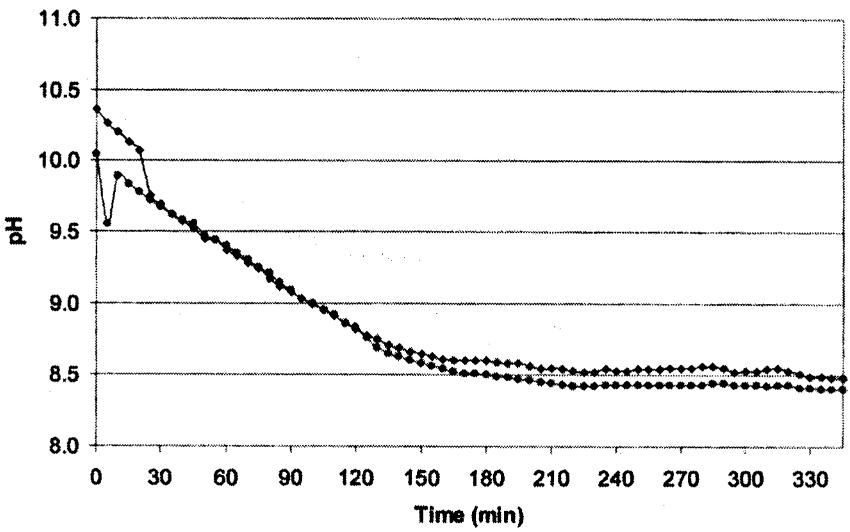

Figure 3. Reduction of pH in P-treated effluent with aeration treatment. Treatment of 1 L using 2 L/min aeration. Two replicates shown.

<u>Full-scale Phosphorus Separation Module</u>

A manure treatment system without lagoon was installed in a 4400-pig farm in Duplin County, NC. The system uses polymer liquid-solid separation, nitrification/denitrification, and soluble P removal module and was designed based on results of this research. The system was constructed by Super Soil Systems USA of Clinton, NC, and it is one of the technologies being evaluated under the Smithfield/AG Agreement program for verification of Environmental Superior Technology (Williams, 2001).

Figure 4 shows a schematic diagram of the phosphorus separation module, and figures 5 and 6 show pictures of the technology installed in the Duplin Co. pig farm. After biological N treatment, the liquid gravity flows to a reaction chamber where it is mixed with 30% hydrated lime. A pH controller is linked to the lime injector and keeps the process pH at 10.5. The liquid and precipitate are separated in a settling tank; the treated effluent is applied to crops using subsurface and sprinkle irrigation. The precipitated calcium phosphate sludge contains approximately 1.5% solids and is further dewatered to 85% solids in filter bags with a capacity of about 50 lb each (Fig. 5). Anionic polymer is added to the precipitate to enhance separation. Automation to the system is provided by sensors integrated to SCADA (Supervisory Control and Data Acquisition) technology and use of a programmable logic controller (PLC).

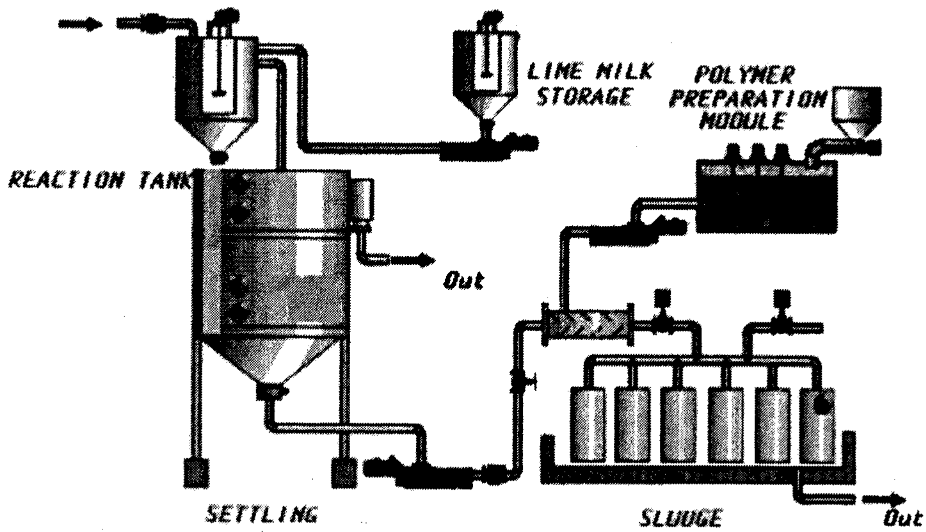

Figure 4. Schematic diagram of phosphorus separation module constructed in a full-scale manure treatment system demonstration project in Duplin County, NC.

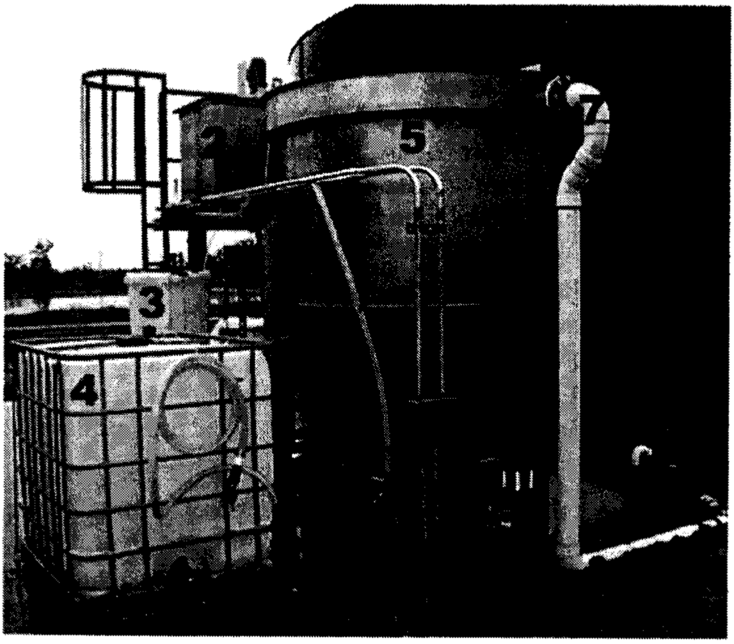

Figure 5. Phosphorus separation reactor installed on a hog farm in Duplin County, NC. Storage tank (1) in background holds wastewater from which ammonia nitrogen and carbonate buffers have already been removed. This wastewater is pumped to reaction chamber (2) along with a slurry of water and hydrated lime suspended in mixing chamber (3). More lime slurry is stored in a container (4) until needed. Liquid flows from the reaction chamber (2) into cone-shaped settling tank (5). There, phosphorus sludge settles to the bottom (6) and is later removed, filtered, and dried in filter bags (Fig. 6). Cleaned wastewater flows from top of settling tank via the white pipe (7) and is delivered to sump (8). An underground pipe carries cleaned wastewater to nearby subsurface irrigation system for crops.

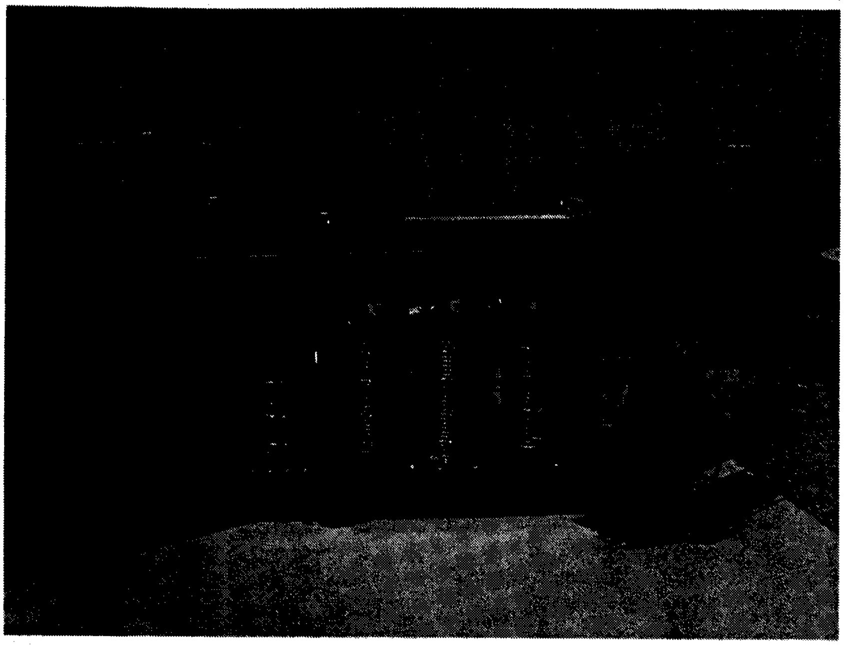

Figure 6. Phosphorus separation module installed on a hog farm in Duplin County, NC. Precipitated calcium phosphate produced in reactor (Fig. 5) is removed, filtered, and dried in filter bags.

CONCLUSION

We found that soluble phosphorus can be easily removed from animal wastewater, which has had a nitrification pre-treatment, in the form of an alkaline earth metal-containing phosphate that can be used as a fertilizer. In the process, carbonate and ammonium buffers contained in liquid waste must be at least reduced or eliminated during the nitrification pre-treatment. This substantially reduces the overall chemical demand needed for optimum phosphorus precipitation and removal. The concept may be used in systems without lagoons and in systems with lagoon.

The system described in this paper where a solids separation step is added with PAM before nitrification/phosphorus removal sequence (solids separation with polymer → biological nitrogen removal using nitrification/denitrification → phosphorus removal, fig. 1) has the advantage that treatment lagoons are not required and the land area required for nutrient disposal is substantially reduced.

This technology not only has the potential to solve current problems with excessive accumulation of phosphorus in soils receiving liquid manure, it also produces a valuable phosphorus fertilizer material and reduces the presence of infectious microorganisms due to the high pH in the process. The aspect of reuse is important because, unlike nitrogen, the world phosphorus reserves are limited.

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