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SOLIDS AND NUTRIENT REMOVAL FROM SWINE WASTEWATER USING POLYACRYLAMIDES

by

M. B. Vanotti
Soil Scientist

P. G. Hunt
Soil Scientist

A. A. Szögi
Soil Scientist

Coastal Plains Soil, Water, and Plant Research Center
U.S. Department of Agriculture, Agricultural Research Service
Florence, SC

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Summary:

Assigning nutrients to nutrient deficient areas through solids separation is critical to overcome current land limitations associated with large swine operations in the southeast region. Mechanical separation with screens can remove only 5 to 20% of the total suspended solids (TSS), organic N and P. Our evaluation of various polyacrylamide (PAM) polymers showed that cationic PAM with a 20% charge density is very effective for flocculating TSS and separating nutrients from flushing effluents. Removal efficiencies of about 80% of TSS, organic N and P were obtained with PAM rates of 25 to 100 mg L^{-1} and swine wastewater having 3.2 to 6.8 g L^{-1} total solids content.

Keywords:

Polyacrylamide, Polymers, Swine Wastewater, Solids/liquid Separation, Nutrient Removal, Animal Waste Treatment, Flushing Systems.

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INTRODUCTION

Livestock waste disposal has become a major environmental problem in the U.S. due to the rapid growth of confined animal production. Most noticeable is the case of the swine industry in North Carolina, where hog populations have increased from 2.8 million to more than 8 million in the last 5 years, and where 82 % of the production activity is concentrated in huge operations having more than 2000 pigs each (USDA, 1995). Swine waste is typically stored and treated in large anaerobic lagoons and spread on cropland. But many counties in the region already are producing more manure-nitrogen than available cropland can absorb (Barker and Zublena, 1995). These land limitations result in undersized lagoons and overloaded land applications causing odor and water pollution problems (Vanotti and Hunt, 1996).

Modern designs of swine production operations utilize some type of water conveyance system to move the waste from the swine house. Flushing systems are preferred because of their simplicity, economy and lower ammonia emissions compared to manure scrapping systems (Sievers, 1989). In many of these systems, wastewater is recycled from anaerobic waste lagoons to economize fresh water. Flushing is done at rates that vary from 500 to 2,000 L per 1,000 kg live mass per day. This high dilution results in wastewaters that have very low solid concentrations, often in the range of 0.2 to 2.5 % total solids content. Separation of suspended solids from dilute wastewaters is difficult with currently available screens and presses, and requires some type of chemical coagulation to bind together the small particles of solids into larger clumps (Sievers et al., 1994).

Swine production systems should conserve the maximum amount of nutrients that land can assimilate without causing over application or pollution. Assigning nutrients to nutrient deficient areas through solids separation and transport appears critical to overcome current land limitations associated with huge swine operations in the southeast region. Also critical is the exploitation of on-farm nitrification/denitrification processes to convert excess ammonia into N_2. Farmers could use this additional tool to regulate with precision the amount of nitrogen applied to land.

When lagoons are used for waste treatment, the maximum area available for application of the liquid animal waste is largely limited by the pumping distance. It is also difficult for the farmer to manage liquid spraying during winter or rainy weather, when fields are saturated and lagoon levels are higher. Solids and associated nutrient separation before the waste enters the lagoon provides new alternatives for waste disposal. The high nutrient concentration and low moisture of the separated solid fraction make this fraction a valuable material: It can be temporarily stored, composted, processed for refeeding or transported to nutrient deficient cropland. The total load of nutrients to be treated is drastically reduced, thereby increasing the life of existing lagoons. When combined with more sophisticated process designs, it can allow the use of advanced treatment methods that may eventually replace the anaerobic lagoon.

Polyacrylamide (PAM) flocculants have the potential for enhancing solids and nutrient separation from flushing wastewaters, but little information is available on their application to

animal waste treatment. PAM is a high molecular weight, long chain, water soluble polymer. Characteristics such as molecular weight (chain length) and type and density distribution of charge provides these polymers with a variety of performance characteristics and applications. For example PAM is extensively used as a settling agent for food processing and packing, paper production, mine and municipal wastewater treatment, as a clarifier for sugar extraction and potable water treatment, and as a soil conditioner to reduce irrigation water erosion. The long polymer molecule destabilize suspended charged particles by adsorbing them and building bridges between several suspended particles, resulting in newer, larger particles (or flocs) that settle out of the liquid.

Our objectives were to determine if PAM polymers are useful for solids and nutrient removal from dilute swine wastewaters, and to identify optimum PAM charge density for solids removal. Further, we evaluated solids and nutrient removal efficiency using screens with and without PAM treatment, and established optimum application rates.

MATERIALS AND METHODS

The effect of PAM on solids and nutrient separation of swine wastewater was evaluated in a series of bench experiments that used three distinct effluents from flushing system operations (Table 1). The first sample is an effluent from a nursery house containing 2600 pigs (average pig weight = 13 kg) in Duplin Co., N.C. This operation uses siphon-flush tanks that are activated four times a day. Lagoon wastewater recirculates at a rate of about 2,100 L per 1,000 kg live mass per day, which produces a very dilute wastewater (total solids= 0.18 %) with a very high TKN concentration. Most of this TKN is composed of ammonia from the lagoon wastewater used for flushing, but the organic N fraction corresponds mostly to that contained in the fresh waste being flushed. Samples 2 and 3 were obtained from a feeder-to-finish operation with four houses and a total of 4,800 head (Average pig weight at sampling= 91 kg) in Bladen Co., N.C. This is a new operation, which at the time of sampling was still filling the lagoon; therefore, the flushing was done with fresh water. Half of each house is flushed every four hours using 5 L per pig or a daily rate of about 300 L per 1,000 kg live mass. Samples 2 and 3 were obtained 5-days apart from the same pit, which collects the flushed waste from the four houses.

In the first experiment, PAMs having a wide range of particle charge type were evaluated. PAM treatments included cationic, neutral and anionic materials (Magnifloc 494C, 985N, and 844A, respectively, Cytec Industries Inc., West Paterson, NJ)[1], which were applied at a rate of 10 mg active polymer per L of wastewater. Magnifloc 494C (PAM-C) has a charge density of 20 (mole %) and a molecular weight of 5 Mg/mole, polymer 985N (PAM-N) has no charge and a molecular weight of 18 Mg/mole, and polymer 844A (PAM-A) has a 33% charge density and a molecular weight of 18 Mg/mole. An alum treatment (1.43 g $Al_2(SO_4)_3.12H_2O$

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

per L of wastewater) was also included to evaluate phosphorus removal, because alum is a material widely used to precipitate P. The alum rate applied was that recommended for wastewaters containing 100 mg P L^{-1}.

Table 1: Swine wastewater characteristics.[†]

	Sample 1	Sample 2	Sample 3
Total Solids, g L^{-1}	1.83 (0.01)	3.22 (0.08)	6.75 (0.14)
Total Suspended Solids, mg L^{-1}	335 (8)	1490 (117)	4120 (144)
Chemical Oxygen Demand, mg L^{-1}	1370 (51)	4490 (98)	10950 (161)
pH	8.1 (0.1)	8.1 (0.1)	7.6 (0.1)
Total Phosphorus mg L^{-1}	60 (2)	71 (3)	189 (6)
Organic Phosphorus, mg L^{-1}	44 (1)	39 (4)	122 (8)
Total Kjeldahl Nitrogen, mg L^{-1}	374 (4)	385 (4)	505 (7)
Organic Nitrogen, mg L^{-1}	88 (3)	115 (5)	234 (15)

[†] Means (SE), n=4.

In a second flocculation experiment, a series of cationic PAMs that had the same molecular weight (5 Mg/mole) but different charge density [Excel Ultra 5020 (20%), 5040 (40%), 5055 (55%), and 5000 (70%), Cytec Industries Inc.] were compared. Experiments one and two were performed with sample 1 (Table 1) in 1-L Imhoff cones that are used for standard settleable solids tests (APHA, 1992). Stock solutions of each chemical were prepared, and 10-mL aliquots of the appropriate treatment were added to 1-L wastewater samples. Samples were then mixed for ten seconds by hand with a rod and allowed to settle for 60 min. Flocculation performance was determined by measuring the solids and nutrient concentrations remaining in the supernatant and the solids settled in the bottom of the cone vessel. These experiments were repeated four times and included a control treatment consisting of 10 mL of water.

In a third experiment, the effects of PAM application rate on flocculation efficiency were evaluated using Magnifloc 494-C (PAM-C) and wastewater samples 2 and 3 (Table 1). A second cationic PAM flocculant, Magnifloc 234 GD (PAM-Cg), was also included. This polymer has very low concentrations of acrylamide monomer, which is a highly toxic compound (Schechter et al., 1995). It is, therefore, recommended for food processing waste destined for solids recycling as animal feed. Seven PAM rates (0 to 200 mg of active polymer/L) were applied as previously described to 200-mL duplicate samples contained in 250-mL flasks. Samples were passed through a screen, which had a 1.0-mm opening, immediately after PAM application. Flocculation performance was determined by measuring solids and nutrient concentration (APHA, 1992) in the effluent passing the screen, and nutrient removal was determined by comparison with initial levels before PAM application and sieving.

RESULTS AND DISCUSSION

PAM type selection

Of the polyacrylamides, only the cationic PAM had a significant effect on solids and nutrient separation (Table 2). The lack of response observed with anionic and neutral PAMs was expected because organic particles suspended in neutral and alkaline wastewaters generally have a negative charge (Stumm and O'Melia, 1968). Within the cationic PAM polymers, treatments with low-charge density PAMs were more effective for removing suspended solids from swine wastewater than high-charge density polymers. This is illustrated in Fig. 1, which shows that flocculation performance decreased with increased charge density in the range of 20 to 75 %.

Table 2: Solids and nutrient remaining or settled (settleable solids) after 1-hr treatment of swine wastewater (sample 1, Table 1) with various PAMs and alum. C=cationic, N=neutral, and A=anionic PAM. Mean separation by LSD at 5% level.

Treatment	Total Solids	Suspended Solids	Dissolved Solids	Settleable Solids	pH	COD	Organic N	NH_4-N	Organic P	*O*-PO_4-P
	g L^{-1}	mg L^{-1}	g L^{-1}	mL L^{-1}		mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}	mg L^{-1}
Control	1.81 b	336 a	1.47 b	< 0.5 c	8.3 a	1330 a	67 a	296 a	31 a	15 a
PAM-C	1.70 c	227 b	1.47 b	10.2 b	8.2 a	850 b	16 b	300 a	10 b	15 a
PAM-N	1.81 b	384 a	1.43 b	< 0.5 c	8.4 a	1260 a	74 a	302 a	34 a	14 a
PAM-A	1.78 b	371 a	1.41 b	< 0.5 c	8.3 a	1250 a	60 a	293 a	32 a	14 a
Alum	2.13 a	137 c	2.00 a	139.6 a	7.1 b	580 b	37 ab	306 a	5 b	1 b

The reaction of PAM-C with the wastewater was instantaneous and produced large dark-brown flocs that rapidly settled out of the matrix wastewater, leaving a remarkably clear supernatant. Relative to initial levels shown in Table 1 (sample 1), application of 10 mg L^{-1} of PAM-C reduced 33% of the suspended solids, 38% of COD, and 82 % of the organic N, while dissolved solids, pH, and ammonia concentration remained unchanged (Table 2). Figure 1 shows a much higher suspended solids removal (73%) using a similar type of polymer (20% charge), the same wastewater sample, but a 15 mg L^{-1} PAM application rate.

Alum was more effective than PAM-C in reducing TSS, PO_4-P, and organic N and P by sedimentation (Table 2), but it has many disadvantages relative to PAM for livestock wastewater treatment. The most important is the quantity of solids generated for ultimate disposal. For example, addition of alum typically produce a 0.5-1.0 g L^{-1} solids increase per g L^{-1} of chemical used (EPA, 1973). Our data showed a significant increase of 0.5 g L^{-1} in the dissolved solids fraction and possibly a much larger increase in the precipitated fraction. In contrast, PAM was very effective for solids and nutrient separation, even though is used at

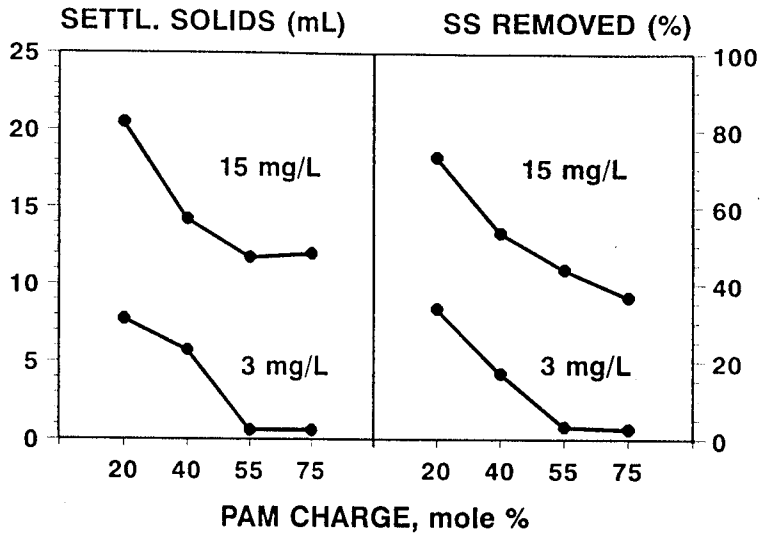

Fig. 1. Effect of PAM charge density (+) on solids removal from swine wastewater (sample 1, Table 1). Total suspended solids in supernatant and settleable solids were measured in Imhoff cone sedimentation after 1-hr of application. PAM rates were 3 and 15 mg L^{-1}. Each value is the average of two replicates.

much lower concentrations, minimizing solids generation during treatment. The settleable fraction of the alum treatment consisted of a light-grey sludge without floc formation. Alum treatment also decreased the pH of the effluent.

Solids removal by PAM flocculation and screening

Suspended solids and COD concentrations were significantly affected by rates of PAM application (Fig. 2a,b). Separation performance of the two polymers was similar, which was expected because of their similar properties. Screening without PAM application (PAM rate = 0) removed only 5.4 % of TSS and 5.0 % of COD relative to initial levels. Addition of PAM resulted in a marked decrease in both SS and COD starting with the 2 mg L^{-1} rate. Once formed, flocs were effectively retained by the 1-mm opening screen used. Application of a 25 mg L^{-1} rate removed about 81 % of SS and higher rates removed more than 90 %. If the intent is to use solids for animal feed, these high removal efficiencies may not be possible because of potential residual acrylamide monomer toxicity at higher rates. Manufacturer restrictions indicate using no more than 1.0 % of active polymer on TSS in the wastewater, and no more than 50 % of the dewatered waste in the animal feed (Cytec Industries, 1994). Thus the maximum application rate for sample 2 containing 1490 mg TSS L^{-1} is 15 mg active polymer L^{-1}. At this rate the expected TSS removal efficiency is about 70% (Fig. 2a). COD was reduced to about half its initial levels with a 25 mg L^{-1} rate, but increased PAM rates did not result in a significant change (Fig. 2b). This is because of a background COD reading from reduced inorganic compounds, such as ammonia, that are not affected by PAM treatment.

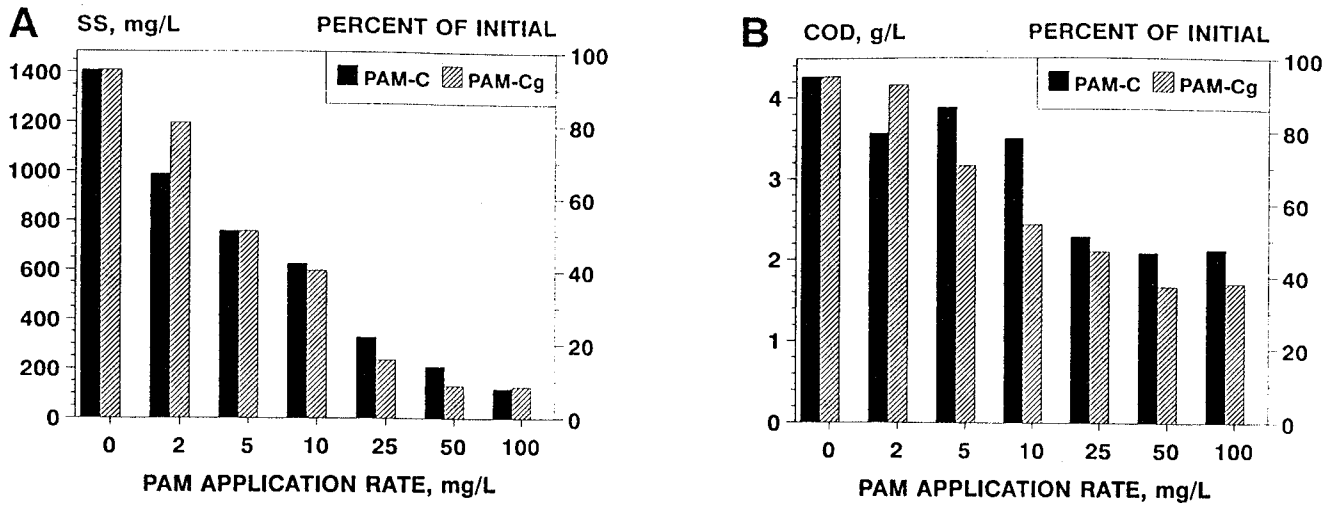

Fig. 2. Effect of PAM application rate on (A) total suspended solids and (B) COD removal from medium strength swine wastewater (sample 2, Table 1) . All samples were passed through a screen having a 1.0-mm opening immediately after PAM application. Initial TSS and COD concentration (before screening) were 1490 mg L^{-1} and 4.5 g L^{-1}, respectively. Each value is the average of two replicate samples.

Optimum PAM application rate was also affected by the amount of suspended solids contained in the wastewater. Floc formation in sample 3 (high-strength wastewater) started only when PAM application rates exceeded 10 mg L^{-1}; therefore, TSS and COD concentrations after screening were not affected by lower rate treatments (Fig. 3a,b). The larger suspended solids concentration in sample 3 (Table 1) undoubtedly affected the results. A suspended particle initially needs to be destabilized (coagulation process) to permit aggregation into a three-dimensional floc network by the formation of bridges (Stumm and O'Melia, 1968). Our data suggest that commencement of flocculation occurred only after all the surface charges of the

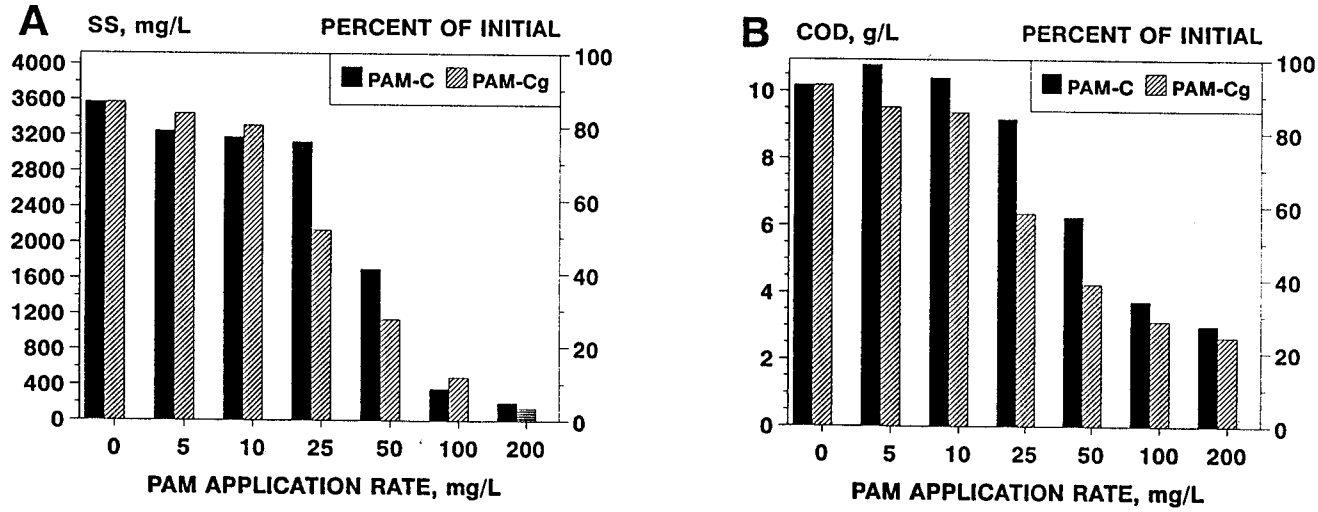

Fig. 3. Effect of PAM application rate on (A) total suspended solids and (B) COD removal from high strength swine wastewater (sample 3, Table 1) . All samples were passed through a screen having a 1.0-mm opening immediately after PAM application. Initial TSS and COD concentration (before screening) were 4120 mg L^{-1} and 10.9 g L^{-1}, respectively. Each value is the average of two replicate samples.

suspended particles in the sample were neutralized, which required about 10 mg L^{-1} of PAM. Once floc formation was initiated, additional PAM markedly increased flocculation, and removal of solids and COD (Fig. 3a,b). Application rates of 100 mg L^{-1} and sieving with a 1-mm opening screen removed 90% of TSS and 74% of COD relative to initial levels. In contrast, screening without PAM application (PAM rate = 0) removed only 13.4 % of TSS and 7.0 % of COD relative to initial levels. Volatile solids removal efficiency by PAM application (data not shown) was similar to efficiencies obtained for TSS. Volatile solids comprised 74 % of TSS (average across treatments applied to samples 2 and 3).

Nutrient removal by PAM flocculation and screening

Nutrient removal was calculated by subtracting total nutrient concentration after treatment from initial levels (Table 1). Total nitrogen and phosphorus removal were significantly affected by PAM application rate treatments and closely followed TSS results. Nutrient data shown in Fig. 4 were from wastewater sample 2 (medium-strength) and correspond with TSS data in Fig. 2a, whereas nutrient data in Fig. 5 were from wastewater sample 3 (high-strength) and correspond with TSS data in Fig. 3a. Screening without PAM application (PAM rate = 0) removed 10 to 20% of organic N and P (Fig. 4 and 5). Similar to TSS data, PAM application to the medium-strength wastewater resulted in a marked increase of both TKN and TP removal starting with the 2 mg L^{-1} rate (Fig. 4), but nutrient removal in the high-strength wastewater sample was prevented at the lower rates by lack of floc formation (Fig. 5). Removal efficiencies of about 80% of organic N and organic P were obtained with PAM application rates of about 25 mg L^{-1} for the medium-strength wastewater (Fig. 4), and at rates of about 100 mg L^{-1} for the high-strength wastewater (Fig. 5).

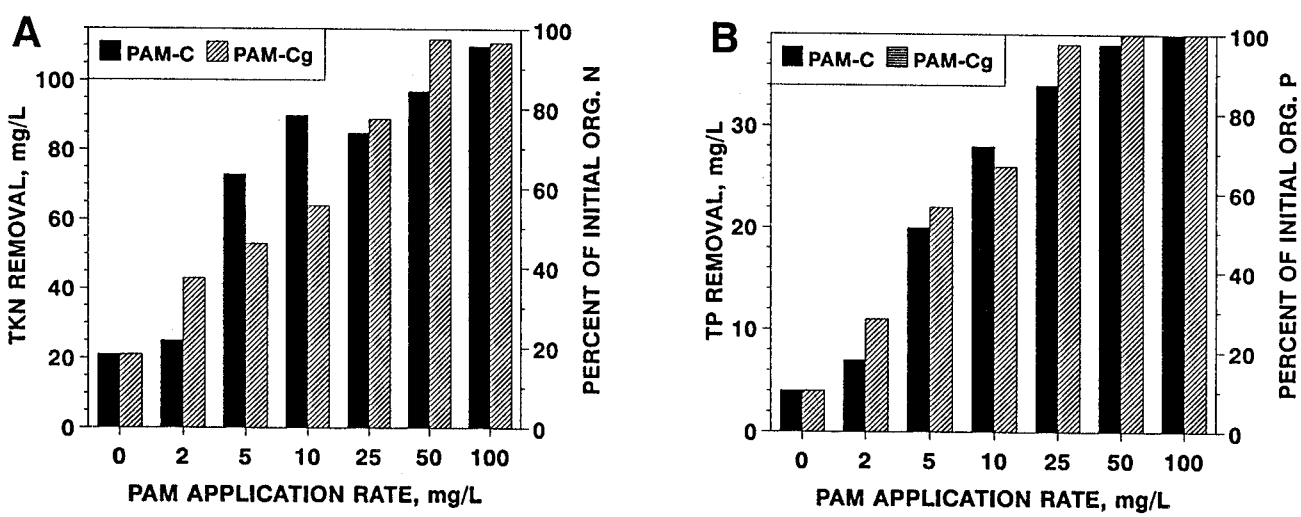

Fig. 4. Effect of PAM application rate on (A) total nitrogen and (B) total phosphorus removal from medium strength swine wastewater (sample 2, Table 1) . All samples were passed through a screen having a 1.0-mm opening immediately after PAM application. Initial TKN and TP concentrations (before screening) were 385 mg L^{-1} and 71 mg L^{-1}, respectively. Organic fractions were 115 mg N L^{-1} and 39 mg P L^{-1}. Each value is the average of two replicate samples.

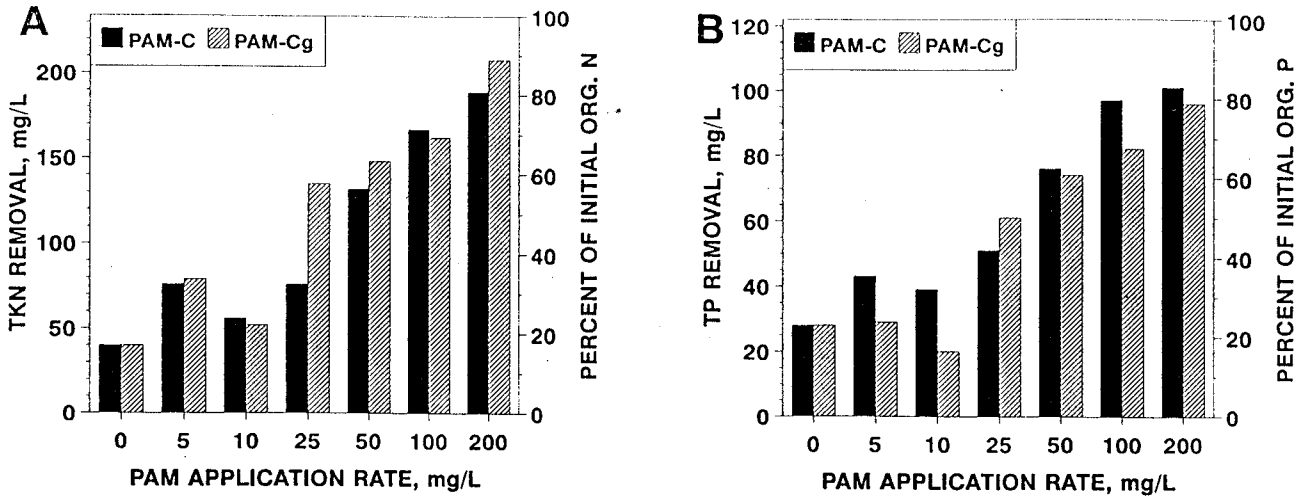

Fig. 5. Effect of PAM application rate on (A) total nitrogen and (B) total phosphorus removal from high strength swine wastewater (sample 3, Table 1) . All samples were passed through a screen having a 1.0-mm opening immediately after PAM application. Initial TKN and TP concentrations (before screening) were 505 mg L^{-1} and 189 mg L^{-1}, respectively. Organic fractions were 234 mg N L^{-1} and 122 mg P L^{-1}. Each value is the average of two replicate samples.

SUMMARY

Confined livestock production is one of the fastest growing industries in the Southeastern United States. Many counties already are producing more manure nutrients than available land can absorb, causing odor and water pollution problems. Solids and nutrient separation from flushed wastewater before entering lagoon treatment is an attractive approach for reducing the mass load of nutrients to be treated, while providing the farmer with more options for waste disposal. Most of the organic nutrients in swine wastewater effluents are contained in fine suspended particles that are not separated by available mechanical separators. The objective of this study was to determine if polyacrylamide (PAM) polymers are useful for enhancing solids and nutrient separation from dilute swine wastewater.

Our evaluation of cationic, anionic, and neutral PAMs showed that the cationic type is very effective and better than alum for separating solids and nutrient from flushed swine wastewater. Within the cationic PAM type, materials that had low-charge density were more effective than high-charge density polymers. The reaction of PAM with the wastewater was instantaneous and produced large dark-brown flocs that rapidly settled out of the matrix wastewater, leaving a remarkably clear supernatant. Screening without PAM treatment removed only 5 to 13 % of TSS, 5 to 7 % of COD, and 10 to 20 % of organic N and P. Addition of PAM treatment before screening (1-mm opening) greatly enhanced removal of TSS, COD, and organic N and P. The optimum application rate, however, varied with the concentration of TSS in the flushing effluent. Removal efficiencies of about 80 % for TSS and organic nutrients were obtained with PAM rates of 25 mg L^{-1} in a swine wastewater containing 1.5 g TSS L^{-1}. Flocculation of a higher strength wastewater (4.1 g TSS L^{-1}) started only when application rates exceeded 10 mg L^{-1} and removal efficiencies of 80 % were obtained with

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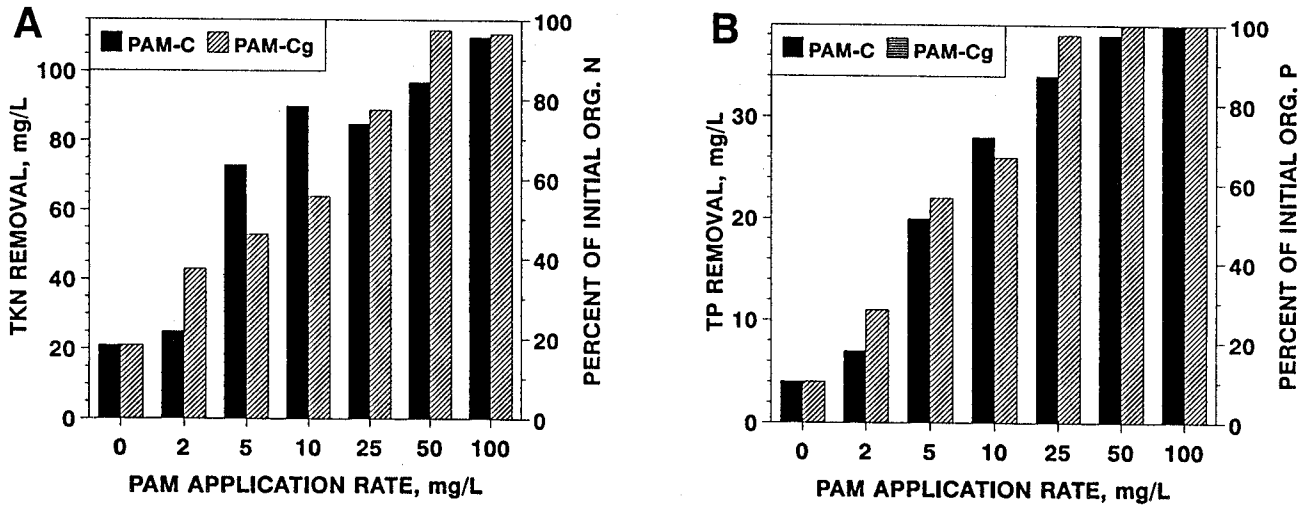

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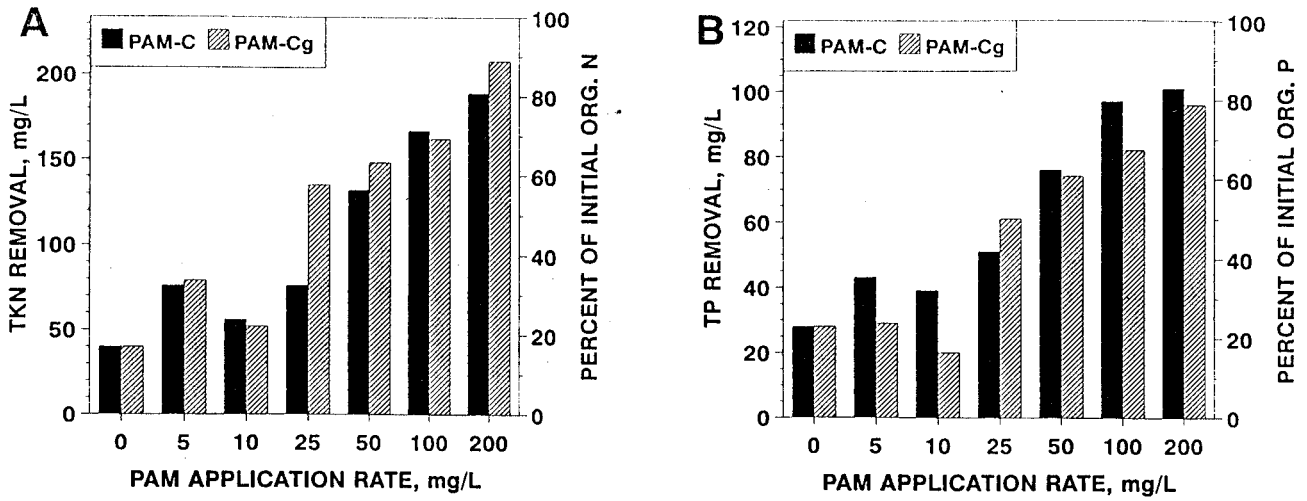

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PAM rates of about 100 mg L^{-1}. Our results indicate that PAM polymers have a potential for enhancing solids and nutrients in flushed swine operations.

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