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Solids-Liquid Separation of Swine Manure with Polymer Treatment and Sand Filtration

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Abstract. *Small particles typical of liquid swine manure often clog sand filter beds and fine filters. We evaluated the effectiveness of polymer flocculants to improve drainage and filtration performance of sand filter beds by increasing the effective particle size. A pilot unit was evaluated at the Swine Unit of the NCSU Lake Wheeler Rd. Laboratory in Raleigh, N.C., in 35 consecutive cycles during a 19-month period. The unit consisted of a homogenization tank that mixed the flushed manure, an in-line polymer mixer, and two sand filter beds (29.7 m^2) for dewatering designed to receive 30.5 cm (1-ft) depth of the polymer treated liquid.*

Flocculation improved drainage characteristics of the sand filter and prevented clogging and surface sealing. The treatment removed 98% of total suspended solids (TSS) and volatile suspended solids (VSS), 87% of BOD, and 84% of COD from the flushed manure. Along with the solids, there was a capture of 62% TKN and 76%TP. Most of the nutrients removed in the solids were organic forms. Drying time to produce removable cakes varied with the loading rate of solids applied to the sand filter bed. A load of 2 kg TSS/m^2 per drying cycle provides a balance between bed size and drying time.

Keywords. Manure treatment, animal waste, polyacrylamide, liquid-solids separation, swine wastewater, nutrient removal, phosphorus.

Introduction

Organic polymers are useful to increase separation of suspended solids and carbon compounds from liquid swine manure. Along with the solids, there is a separation of the nutrients associated with small particles typical of these wastes. With flocculation, the effective particle size is increased by agglomeration of small particles into a larger particle or floc. This larger size enhances solids retention by screens and separation of colloidal particles by settling (Vanotti and Hunt, 1999; Zhang and Lei, 1998). The use of sand filters or screens with small pore opening size (< 0.3 mm) for solids-liquid separation of liquid swine manure has been a problem in the past due to rapid clogging and sealing with the smaller particles that may constitute 80% of the total suspended solids. In this study we evaluated whether the use of polymer flocculants could improve the drainage characteristics of sand filter beds by increasing the effective particle size and preventing clogging with repeated applications.

Materials and Methods

Enhanced polymer separation of solids and nutrients from flushed swine manure was evaluated in a field prototype constructed at the Swine Unit of the NCSU Lake Wheeler Rd. Laboratory in Raleigh, N.C. The prototype unit consisted of 1) a homogenization tank that received and mixed the flushed manure, 2) an in-line polyacrylamide (PAM) injector and mixer to flocculate the manure solids in the flush, and 3) two identical sand filter beds of 4.88 x 6.10 m size (16 x 20 ft) for dewatering. Both the in-line PAM injector and filter beds were components of the Deskins[1] process (F.D. Deskins Company, Inc., Alexandria, Ind.) used for municipal and industrial sludge dewatering (fig. 1). The sand filtrate was further used to evaluate a Biogreen nitrification-denitrification process (Vanotti et al., 2001). A total of 35 cycles (runs) was conducted during a 19-month evaluation period (March 2000-Oct. 2001).

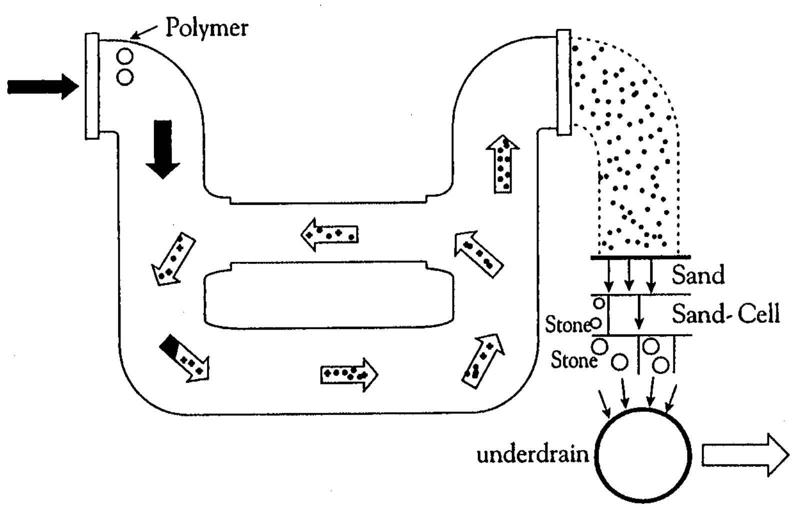

Figure 1. Polymer was injected and mixed with liquid swine manure using an in-line flocculator. The liquid was then poured into a sand filter bed with gravel substratum and underdrain system.

[1] 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.

The filter beds were completely sealed with plastic liners and constructed with several layers of media starting with a 45-cm layer of washed stone (1.9-cm size), then a 15-cm middle layer of PVC media cells filled with pea gravel (0.95-cm size), and finished with 15 cm of coarse sand (0.5-mm size) on top. The PVC media provides surface and subsurface bed stabilization by eliminating compaction of the sand by machinery used to retrieve the solids in commercial units. However, this feature was not fully tested in the prototype because the dry solids were harvested manually using shovels and rakes.

An underdrain system consisting of a sloping bottom and drains directed the filtrate to a sump in the corner of each bed. A submergible pump emptied the liquid at the conclusion of each pour.

Set-up and Operation

Flushed manure from finishing and gestation houses in the facility was collected in a 15 m^3 (4000 gal) homogenization tank. Solids content in the flushes at the beginning of the study was very low (<1 g/L) due to the frequent flushing schedule used at the farm. After cycle 5, the flushes were held for 24 to 48 h before each run. This increased the accumulation of manure in the selected houses and resulted in higher wastewater strength more representative of flushes in commercial operations.

The liquid manure was thoroughly mixed in the homogenization tank at 84 rpm, using a 1 HP mixer (Lightnin Series 10, model 1401, Lightnin Co., Rochester, N.Y.) with 3 impeller blades (61-cm size). Jar tests were conducted on the homogenized waste prior to each of the runs to determine the optimum polymer dosage used to calibrate the injection pump. The tests were done by mixing 5-mL increments of 1% polymer stock to 1 L of wastewater until additional application did not increase flocculation and liquid clarity. A second dosage adjustment was done when the liquid started pouring in the bed using the clarity of the liquid in the jar test as reference. For polymer, we used a cationic PAM emulsion formulation with 34% active ingredient (Magnifloc c-1596, Cytec Industries, Inc., West Paterson, N.J.). Fresh water, at a rate of 30 to 42 L /min (8 to 11 gpm), was used to dilute and activate the polymer before injection. Rubber hoses of 10.2-cm size (4") were used to move the wastewater from the homogenization tank to the injection unit (80 meters) and then from the injection unit to the sand beds (20 meters). A manifold near each bed divided the flow in two polyvinyl hoses (10.2-cm size) that were placed on the sand along the bed. Immediately after polymer injection into the in-line flocculator started, the mixed raw waste was pumped into the system using a flow rate of 492 L/min (130 gpm). A doppler flow meter was used to adjust the wastewater flow to the desired level. The flocculated manure was discharged into the bed through 16 holes cut 30.5-cm apart on the upper side of the polyvinyl hoses. The last 8 holes had a larger size (3.2-cm diameter) than those closer to the manifold (2.5-cm diameter) to provide an even distribution of liquid throughout the sand bed. Both wastewater flow (130 gpm) and number of manifolds (2) were selected after a few cycles with this prototype because they minimized liquid disturbance of the sand surface.

The beds received approximately 1.1-ft depth of flocculated liquid during each pour (average 10,258-L volume or 34.5-cm depth). Once the pour was finished, the submergible pump in the sump was activated to empty the liquid from the bed. The bed was usually drained at the same rate as the pump (757 L/min or 200 gpm). The solids were left to dry on the bed until they were sufficiently dry to be removed using shovels. Solids samples were taken frequently during this drying period to measure moisture content and drying characteristics of the various manure loading rates that were applied during the evaluation period. The depth of liquid in the homogenization tank at the beginning and end of a run was used to calculate total volume applied in each pour. Similarly, the polymer container was weighed before and after each run to calculate actual amount of polymer used for separation.

Analytical Methods

Treatment performance was determined by the difference between the solids, nutrient, and BOD concentrations in the filtrate and those in the initial sample before PAM application and sand filtration. Loading rates were calculated from suspended solids retained and volume of wastewater applied. Liquid samples were taken at the beginning, middle, and end of each run from both the homogenization tank and filtrate. They were subsequently analyzed separately.

Solids analyses of the treated and untreated liquid samples included total solids (TS), total suspended solids (TSS), and volatile suspended solids (VSS). Total solids are the solids remaining after evaporation of a sample to constant weight at 105°C and include TSS and dissolved solids (DS). Total suspended solids (TSS) are the solids portion retained on a glass microfibre filter (Whatman grade 934-AH, Whatman Inc., Clifton, N.J.) after filtration and drying to constant weight at 105°C, while volatile suspended solids (VSS) are the fraction of the TSS that was lost on ignition in a muffle furnace at 500°C for 15 min. Therefore, the TSS and VSS are measurements of the insoluble total and volatile solids that are removable by separation. The soluble fraction or dissolved solids can be determined by subtracting the TSS from the TS. Chemical analyses consisted of pH, chemical oxygen demand (COD), 5-d biochemical oxygen demand (BOD_5), ammonia-N (NH_3-N), total organic N, orthophosphate-P (*o*-PO_4), and total organic P. All the analyses were done according to Standard Methods for the Examination of Water and Wastewater (APHA, AWWA & WEF, 1998). For COD we used the closed reflux, colorimetric method (Standard Method 5220 D). The inorganic *o*-PO_4 fraction, also termed reactive P, was determined by the automated ascorbic acid method (Standard Method 4500-P F) after filtration through a 0.45-μm membrane filter (Gelman type Supor-450, Pall Corp., Ann Arbor, Mich.). The same filtrate was used to measure NH_3-N by the automated phenate method (Standard Method 4500-NH_3 G). The Total P and TKN were determined using the ascorbic acid method and the phenate method, respectively, adapted to digested extracts (Technicon Instruments Corp., 1977). The organic P fraction is the difference between total P and *o*-PO_4 analyses and includes condensed and organically bound phosphates. The organic N fraction is the difference between Kjeldahl N and ammonia-N determinations.

Results and Discussion

Separation of Solids and BOD

Total solids strength of the flushes varied greatly during the evaluation period, from 2.2 to 18.9 g/L. Solids strength was very low during the first five cycles due to the frequent flushing schedule used in the Swine Unit facilities. Starting with cycle 6, the flushes were held for 1 to 2 days before a run. This change effectively increased the solids strength of the liquid manure (fig. 2a) to a range of values consistent with values of 5 to 20 g/L (0.5 to 2.0%) described for commercial flushing systems in the USA (Chastain et al., 1999). The TSS concentration before treatment varied from 1 to 17.5 g/L (0.1 to 1.75%), and VSS varied from 0.9 to 14.0 g/L (.09 to 1.4%). On the average, 85% of the TS were suspended and removable by liquid-solids separation and 82% of the suspended solids (TSS) were volatile solids (VSS). Separation efficiencies of 98% were consistently obtained for both TSS and VSS (table 1). The suspended solids concentration in the effluent was uniformly low in spite of the large variation in solids strength among cycles (fig. 2b and c).

Removal efficiency of suspended solids with the sand filter was higher than efficiencies of 92 to 96% reported by Vanotti and Hunt (1999) using flocculation and screening (1-mm opening size). Polymer dosage varied with the strength of the wastewater; the average application in the study was 348 mg/L of polymer formulation (118 mg PAM a.i./L). This amount was 36.9% higher than the optimum rate determined with the jar tests conducted before each run. This higher requirement was not affected by changes in wastewater flow rates in a range of 379 to 757 L/min (100 to 200 gpm) tested, suggesting that changes in polymer mixing or piping could improve performance and reduce chemical cost for separation.

Table 1: Enhanced solids and BOD separation from flushed swine manure using polymer flocculation and separation with sand filter bed*

Flush Constituent	Homogenization Tank (mg/L)	PAM Treated Effluent (mg/L)	Separation Efficiency (%)
Total Solids	8095	1705	79
Total Suspended Solids	6847	15	98
Volatile Suspended Solids	5595	122	98
BOD 5-days	2791	369	87

*Data are average of 31 trials (Cycle 6 - 36). Range of initial concentrations varied: TS = 2.2 to 18.9 g/L, TSS = 1.04 to 17.5 g/L, VSS = 0.9 to 14.0 g/L, BOD = 0.4 to 8.6 g/L, COD = 0.98 to 16.6 g/L.

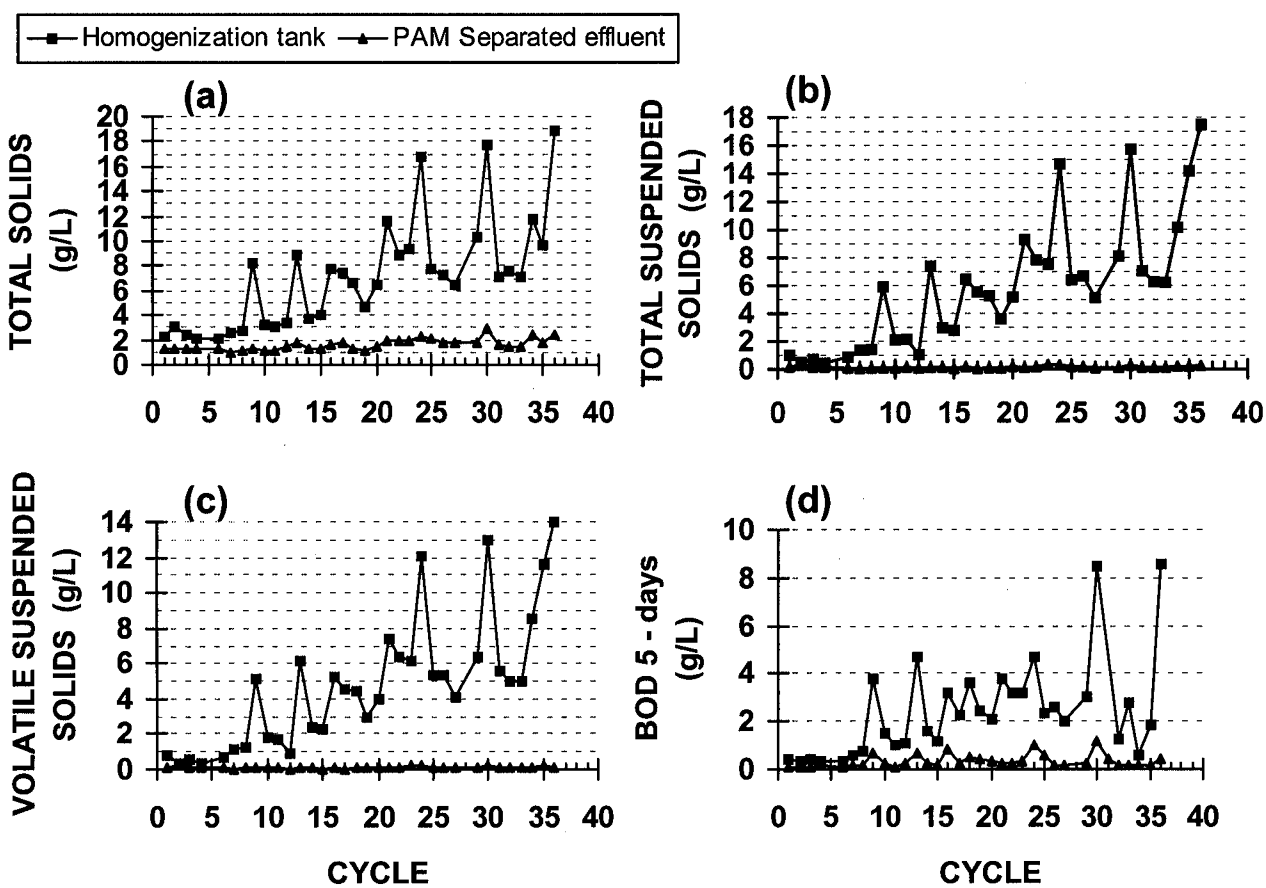

Figure 2. Solids-liquid separation with PAM and sand filtration: (a) Total Solids, (b) Total Suspended Solids, (c) Volatile Suspended Solids, (d) Biochemical Oxygen Demand 5-days.

Two indicators of oxygen-demanding substances present in wastewater were evaluated, the BOD_5 and COD. The BOD_5 test measures the oxygen utilized during a 5-day incubation period for biochemical degradation while the COD is used as a measure of the oxygen equivalent of the organic matter content of a sample that is susceptible to oxidation by a strong chemical oxidant. Averaged across cycles, the polymer treatment and sand filtration reduced 87% of the BOD_5 concentration (fig. 2d) and 84% of the COD concentration (table 1). These results are significant to the producer that wishes to incorporate biological N removal processes for the purpose of ammonia control. By capturing the suspended particles, most of the volatile and oxygen-demanding compounds are removed from the liquid stream. Instead of the oxygen being used to break down organic compounds, it is used in the aeration treatment to more efficiently convert ammonia to nitrite or nitrate (Vanotti et al., 2001).

Separation of Nutrients

Polymer treatment followed by sand filtration removed 62% of the total nitrogen (TKN) and 76% of the total phosphorus (TP) from the liquid phase (table 2). For N, the organic fraction comprised 65% of the TKN while the ammonia comprised 35% of the TKN. The organic P fraction made up a large proportion (89%) of the TP in the flushes with the remaining (11%) as phosphate. Polymer treatment had no effect on inorganic nutrient concentrations (ammonia and phosphate). On the other hand, this treatment was very effective in the capture of the organic nutrients in liquid swine manure. Separation efficiencies of 89% and 91% were obtained on the average for organic N and P, respectively (table 2). Concentration of organic N and P (fig. 3b,d) was closely associated with concentration of TSS (fig. 2b). This indicates that organic nutrients in the flushed effluent were mostly contained in suspended manure particles, which in turn were efficiently separated from the liquid by flocculation treatment and sand filtration.

Table 2: Enhanced nutrient separation from flushed swine manure using polymer flocculation and separation with sand filter bed.*

Flush Constituent	Homogenization tank (mg/L)	PAM Treated Effluent (mg/L)	Separation Efficiency (%)
Total Kjeldahl Nitrogen	585	232	62
Total Phosphorus	292	71	76
Organic Nitrogen	383	41	89
Organic Phosphorus	261	23	91

* Data are average of 31 trials (Cycle 6 - 36). Range of initial concentrations varied: TKN=235 to 1140 mg/L, TP = 87 to 1008 mg/L, Organic Nitrogen = 88 to 1080 mg/L, Organic Phosphorus = 44 to 998 mg/L.

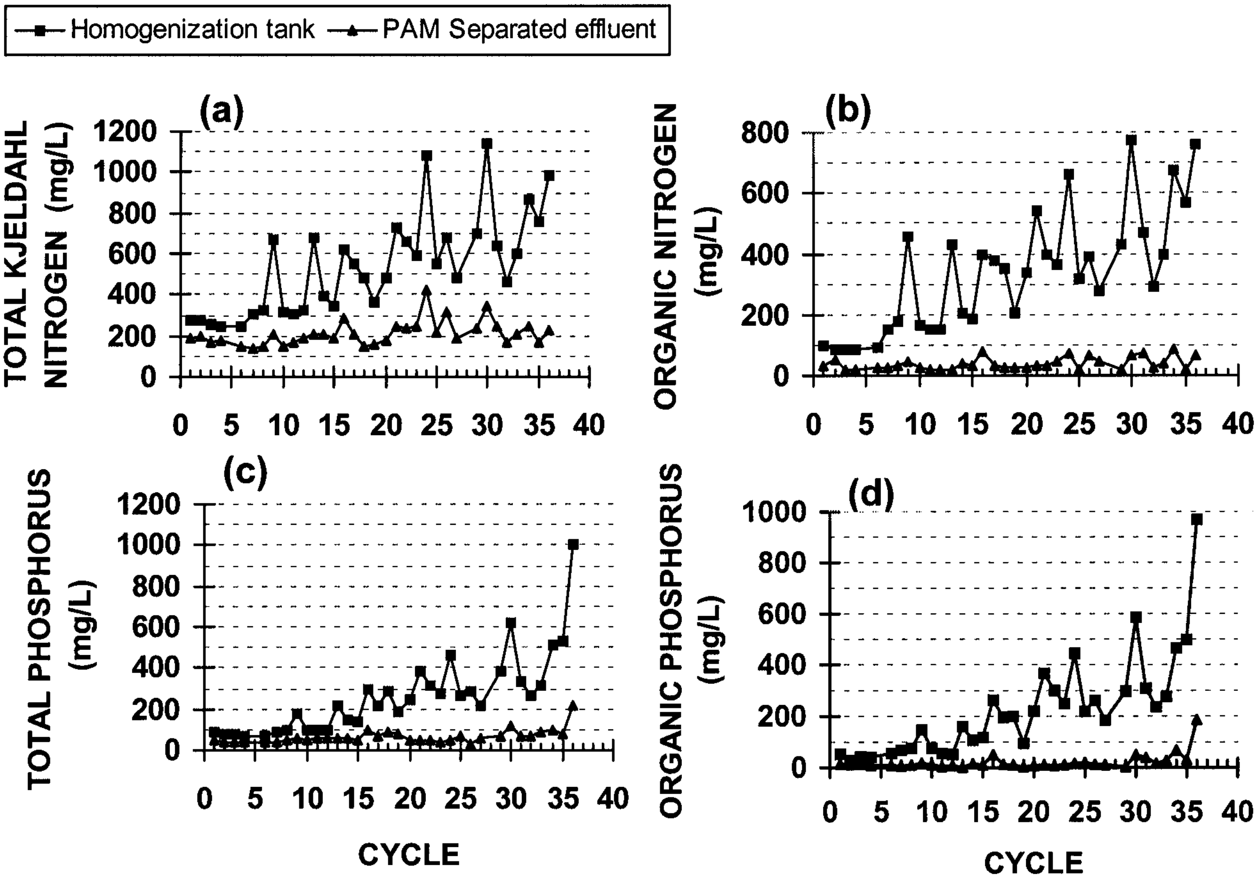

Figure 3. Nutrient removal with PAM and sand filtration: (a) Total Kjeldahl Nitrogen, (b) Organic Nitrogen, (c) Total Phosphorus, (d) Organic Phosphorus.

Drying of the Manure Solids

Drainage of the standing liquid was usually completed within one to two hours after pouring. However, the moisture content of the solids at this point was relatively high (70-90%), and a drying period was necessary to lower moisture content to levels where the solids could be harvested. This drying period varied with the loading rate of solids applied to the bed. During the first few cycles when TSS concentration was low (< 2 g/L, fig. 2b), the manure cake was thin and solids dried very fast, usually in about one day. The drying time was much longer with higher solids strength and thicker cakes even when the same amount of water was applied. The effect of loading rate on drying time was characterized based on data in figure 4 showing the decrease in solids moisture after initial drainage. Individual cycles were grouped based on loading rates of 0-1, 1-2, 2-3, and >3 kg TSS/m^2 calculated from TSS retained by the sand bed. A regression line fitted to each loading rate category was used to calculate the drying time needed for harvesting the solids (table 3). For the lower load category (< 1 kg TSS/m^2), the solids reached 50% and 40% moisture content in 0.6 and 1.1 days, respectively. The same moisture levels were reached in the second load rate group (1-2 kg TSS/m^2) after 5.4 and 9.1 days, respectively. Drying time was extended to about 10 and 15 days for the 2-3 kg TSS/m^2 load rate and 20 to 30 days for the > 3 kg TSS/m^2 loads. The manure cake usually dried from top to bottom and along cracks formed on the surface. With the higher loads, the area in the cake in contact with the sand remained wet for long periods making manual harvesting difficult.

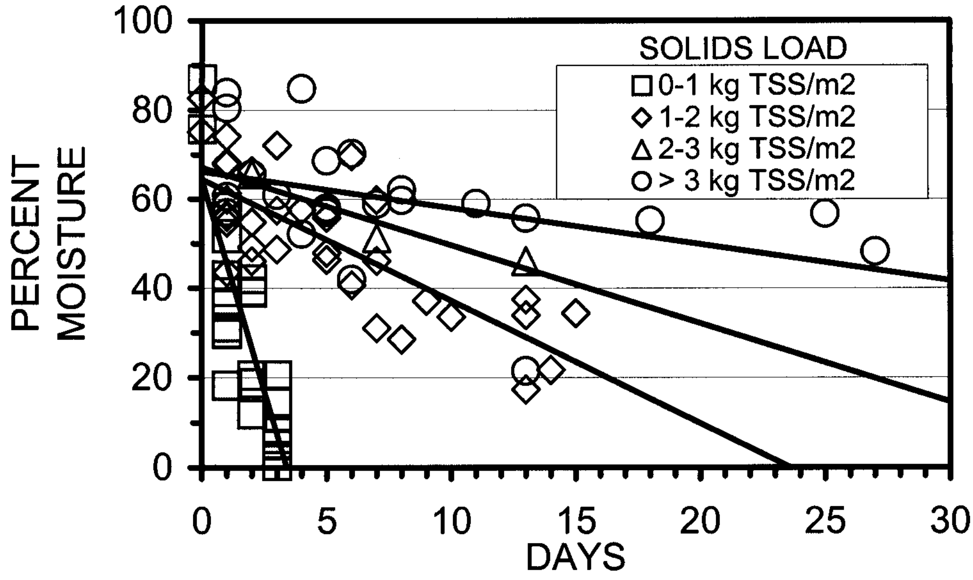

Figure 4. Decrease in solids moisture content as affected by manure loading rates.

Table 3: Effect of loading rate on manure drying time.

Loading Rate (Range) *	Average TSS Concentration in Flush	Average Liquid Applied	Loading Rate (Average)	Drying Time†	
				50% Moisture	40% Moisture
kg TSS/m^2	g/L	cm	kg TSS/m^2	---------days---------	
0-1	1.14 ± 0.63‡	36.6 ± 8.6	0.4 ± 0.2	0.6	1.1
1-2	4.97 ± 1.23	35.0 ± 3.8	1.6 ± 0.3	5.4	9.1
2-3	7.19 ± 1.28	33.6 ± 2.3	2.4 ± 0.3	9.8	15.5
>3	12.10 ± 4.23	34.5 ± 2.8	4.3 ± 1.3	19.8	32.0

* Individual cycles were grouped based on loading rates calculated from TSS retained by sand.

† Drying time to reach 50 and 40% solids moisture calculated from data shown in Figure 4 and the following equations:

Loading rate 0-1 kg TSS/m^2: moisture = 59.3 - 16.785 days, R^2=0.66

Loading rate 1-2 kg TSS/m^2: moisture = 64.6 - 2.691 days, R^2=0.57

Loading rate 2-3 kg TSS/m^2: moisture = 67.1 - 1.752 days, R^2=0.90

Loading rate > 3 kg TSS/m^2: moisture = 66.2 - 0.817 days, R^2=0.19

‡ Mean ± standard deviation.

The longer the manure remains wet on the bed, the higher the potential for odor and fly problems. Therefore, a loading rate of 2 kg TSS/m^2 is suggested based on conditions of this study. For a TSS production rate of 5.05 kg/1000 kg live pig mass/day (NRCS, 1992), a removal efficiency of 98%, and a drying cycle of 9 days (40% moisture), the total surface of sand filter bed needed to treat the waste from a 1000-head finishing operation (50 to 220 lb) is 3000 m^2 or about 3 m^2/pig. The corresponding surface area for a drying cycle of 5.4 days (50% moisture) is reduced to 1800 m^2 or 1.8 m^2/pig. Other considerations beyond the scope of this study, such as climate, the end use of the solids, transport cost, and capacity of machinery to harvest the solids at the higher moisture level, should be considered for selecting target solids moisture for bed design purposes. But this study indicates that sand bed size and construction could be an important component of the overall cost of the technology.

Conclusions

A pilot treatment unit for liquid solids separation using polymer treatment with an in-line flocculator and sand-bed filtration was evaluated for 19 months at the NCSU Lake Wheeler Rd. Field Laboratory to determine separation efficiency and function of the bed with repeated applications. With the polymer, the small particles in swine wastewater are agglomerated into larger particles or flocs. Collectively, our findings indicate:

- Flocculation improved drainage characteristics of the sand filter and prevented clogging and surface sealing.
- Polymer flocculation and sand filtration removed 98% of TSS and VSS, 87% of BOD and 84% of COD from the flushed manure.
- Along with the solids, there was a capture of 62% TKN and 76%TP; most of the nutrients removed in the solids were organic forms.
- Polymer needed for optimum flocculation was 37% higher than jar test.
- The sand filter beds drained quickly, usually within one to two hours after pouring.
- Drying time to produce removable cakes was affected by solids loading rate; a load of 2 kg TSS/m^2 per drying cycle affords a reasonable balance between bed size and drying time.

Acknowledgements

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