EFFECTS OF SOLID LEVELS AND CHEMICAL ADDITIVES ON REMOVAL OF SOLIDS AND PHOSPHORUS IN SWINE MANURE

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ABSTRACT: Experiments were conducted to determine the effect of solid levels on natural sedimentation of swine manure. Total solids (TS) levels of 0.5, 1.0, 2.0, 4.0, and 6.0% were evaluated. Natural sedimentation was impeded at higher than 2.0% and also at lower than 1.0% TS concentrations. Two flocculants (ferric chloride and aluminum sulfate) commonly used in the municipal wastewater treatment industry were then evaluated for their enhancement of natural sedimentation and concomitant removal of phosphorus from swine manure. Each flocculant was evaluated at five levels—0 (control), 500, 1,000, 1,500, and 2,000 mg/L—on swine manure with an adjusted TS level of 1.0%. At dosage levels of 1,500 mg/L (5.4 mM Fe^{+3}), ferric chloride removed 76% suspended solids (SS) and 86% phosphorus, while aluminum sulfate at the same dosage level removed 96% SS and 78% phosphorus. Unaided natural sedimentation at this TS concentration removed 66% and 42% of the SS and phosphorus, respectively. Chemical flocculation can, therefore, be an effective method of removing solids and phosphorus in swine manure.

INTRODUCTION

The phases of a complete animal waste management system can comprise collection, storage, treatment, and utilization. The manure has to be physically handled in one or more ways in all of these phases. By far, the most common system of handling swine manure is the slurry system. In this system, the floors of the pigpens are slatted to allow both the feces and the urine to drop through into the under-slat slurry storage pit or into temporary gutters where the slurries are flushed away into lagoons or other storage tanks. These pig slurries have relatively low dry matter content due to damaged drinkers and the amount of water used for flushing manure. No matter how conservative the farmers try to be in the use of cleaning water, slurry with dry matter of higher than 5% is rare (Voermans and de Kleijn 1990; Powers et al. 1995).

In some cases, it is impossible for all the manure produced in today's concentrated animal production operations to be utilized locally without negatively impacting the environment. Many concentrated swine production operations must, therefore, transport nutrients to other farms. However, transportation of untreated slurry to locations where it can be utilized means transporting large amounts of water. A method to concentrate nutrients economically may permit some units to stay in business at their current locations, otherwise they would have to relocate to remain viable (Powers et al. 1995). Separation of slurry may offer the possibility of obtaining manure solids with a high concentration of nutrients, which becomes worthwhile to transport over longer distances.

The main options for removing solid from the liquid include: (1) screening; (2) centrifuging; and (3) sedimentation. Mechanical sieves are generally low in cost but are usually ineffective in removing fine solids that are more prone to biological action. On the other hand, centrifuges and related hydroclones, which are much more effective in removal of such fine solids, are limited by the necessarily high investment. This leaves sedimentation as the most appealing option. A sedimentation system not only requires a low capital investment, but it is also simple and can act as a temporary storage of manure. Animal agriculture has not needed to utilize sedimentation practices, such as those developed and applied to municipal waste systems. However, due to the changes from extensive to intensive (concentrated) animal agriculture and because regulatory agencies are requiring tertiary treatment of waste from municipalities and other point source discharges, agriculture is beginning to apply primary and secondary treatment techniques to animal waste (Moore et al. 1975). This trend is likely to continue in the coming years.

To improve natural sedimentation, especially for removal of fine particles, chemical flocculants have successfully been employed in conventional wastewater treatment processes. Chemical precipitation in wastewater treatment involves the addition of chemicals to alter the physical state of dissolved and suspended solids and facilitate their removal by sedimentation (Tchobanoglous and Burton 1991). It is theoretically known that the stability of colloidal suspension is promoted by the surface charge of colloids. If the particles are to be aggregated or flocculated, this stability must be overcome or broken. Most of the inert substances found in wastewater and other constituents like proteins and microorganisms all have negative charges. These charges keep them dispersed due to repulsion. The addition of multivalent metal ions (Al^{+3} and Fe^{+3}) in the wastewater results in hydrolytic reactions whose products are responsible for the reduction or the breakdown of colloidal negative charges and, therefore, promote flocculation (Sievers 1989). These reactions occur in steps and, therefore, the effectiveness of metal ions will vary with time (Tchobanoglous and Burton 1991). Therefore, it is imperative that laboratory scale or full-scale tests be conducted to determine the correct dosage and its effectiveness with time.

Phosphorus is, by and large, the limiting factor for the occurrence of eutrophication in surface waters, because most algae species are known to fix nitrogen from air. One of the major sources of phosphorus runoff from agricultural land is animal waste (Moore and Miller 1994). Clearly, land application of animal manure needs to be well managed to reduce the impact of phosphorus on the environment. Before 1970, most of the chemical treatment processes removed suspended solids (SS) from wastewater. The need to provide a more complete removal of the organic compounds and nutrients (nitrogen and phosphorus) contained in wastewater has brought renewed interest in chemical precipitation. Chemicals mostly used in wastewater treatment include alum, lime, ferrous sulfate, ferric chloride, ferric sulfate, and lime. For phosphorus removal, both ferric chloride and aluminum sulfate are com-

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monly used. Other chemicals used are ferrous sulfate and ferrous chloride, as well as polymers in conjunction with iron salts. Both Fe and Al ions precipitate phosphorus from solution, which can then be removed by subsequent solid-liquid separation, e.g., sedimentation.

Several studies have addressed the use of chemical flocculants in the solid-liquid separation of animal manure. Although valuable information has been gained from these studies, the methods of evaluating the efficacy of such flocculants have been as diverse as the studies themselves, making it extremely difficult to compare results. Hanna et al. (1985) evaluated the use of nine flocculants on flushed swine manure using 400 mL of manure at 1% solid level over a period of 100 min after an initial mixing of 20 min. Sievers et al. (1994) removed some of the faster settling solids by natural settling before evaluating use of chemical coagulants on separated liquor of swine, dairy, and poultry manures. The chemicals were introduced into 400 mL of manures in settling jars by a rapid mixing of 3 min followed by a slow mixing for 15 to 20 min, and finally quiescent settling was allowed for a period of 30 min. Powers et al. (1995) evaluated flocculation of dairy manure with solids level of 0.5, 1.0, and 1.5% using 360-mm tall graduated cylinders (65-mm diameter) on 1 L of liquid manure and detention time of 1 h. Vanotti and Hunt (1996) evaluated solid removal efficacy of alum and some other organic polymers on 0.18% total solids (TS) swine manure slurries using standard 1 L Imhoff cones for 1 h settling after an initial mixing of 10 s. Zhang and Lei's (1996) studies on the use of flocculants for solids removal used a somewhat different approach that went a step ahead of the jar tests used by past researchers. They used 90 cm (3 ft) columns, 13 cm (5 in.) in diameter that simulated some practical situations. The actual suspended solids removals in all these studies were only evaluated at the end of respective detention times and not at regular intervals. A practical and standard method for studying or evaluating settling characteristics of any flocculation has been outlined by Tchobanoglous and Burton (1991); this method recommends designing experiments to simulate the situation in which the flocculants will be used in practice.

This study used the physical simulation of the system suggested by Tchobanoglous and Burton (1991) to: (1) investigate the effect of different solids levels on natural sedimentation of swine manure; (2) evaluate effects of chemical flocculants on sedimentation using two commonly used flocculants (ferric chloride and aluminum sulfate); and (3) investigate the effective concomitant phosphorus removals during these settling processes in shallow sedimentation tanks.

METHODS AND MATERIALS

Experiment Design and Analysis

To determine the settling characteristics of a suspension of flocculant particles, a settling column of any diameter may be used but its height should correspond to the depth of the proposed depth of the settling pit/tank (Tchobanoglous and Burton 1991). Sampling ports are inserted at 60-cm (2 ft) intervals. The solution containing the suspended matter should be introduced into the column in such a way that a uniform distribution particle size occurs from top to bottom. Settling is allowed to take place under quiescent conditions, and at various intervals, samples are withdrawn from the ports and analyzed for SS. The percent removal is computed for each sample analyzed and is plotted against time and depth. Between the plotted points, curves of equal percent removal are drawn as shown in Fig. 1.

Determination of the amount of solids removed is made using these curves. This is equivalent to a weighted average using the depth and the percentage at the respective depth as

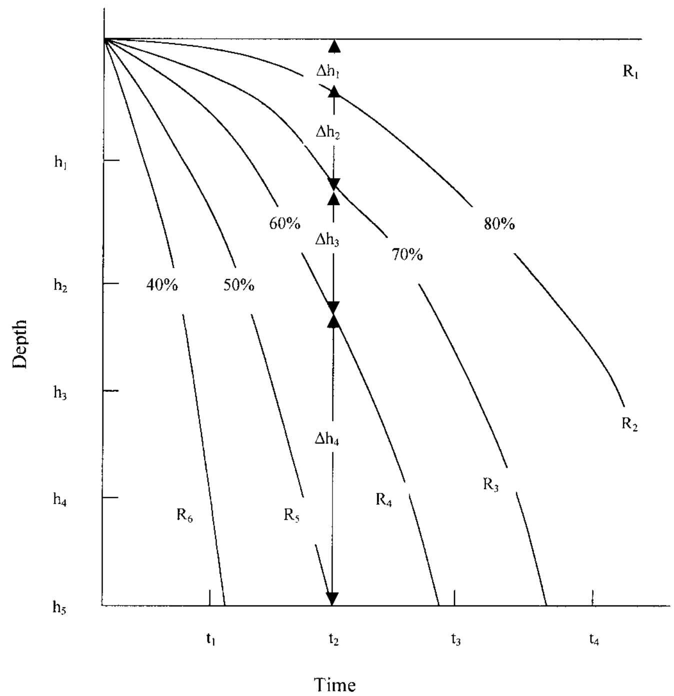

FIG. 1. Curves of Equal Percent Removal Interpolated between Plotted Points of Depth against Time as Contours on Survey Grid

the weighting parameters. The overall removal if the draw-out point is depth (h_5) after a detection time (t_2) is computed using

$$\%\text{Removal} = \frac{\Delta h_1}{h_5} \times \left[\frac{R_1 + R_2}{2}\right] + \frac{\Delta h_2}{h_5} \times \left[\frac{R_2 + R_3}{2}\right] + \frac{\Delta h_3}{h_5} \times \left[\frac{R_3 + R_4}{2}\right] + \frac{\Delta h_4}{h_5} \times \left[\frac{R_4 + R_5}{2}\right] \quad (1)$$

This method was used in this study for evaluating the removal of both the suspended solids and phosphorus. The sampling was modified to be at intervals of 30 cm (1 ft), because this study was focused on shallow pits/tanks or other similar sedimentation systems. The drawout for the 91-cm deep tanks/pits was fixed at the depth of 60 cm.

Natural Sedimentation Experiment

Manure from swine finishing barns was collected in plastic containers. The manure in each container was thoroughly stirred and two samples drawn from each for laboratory analysis of TS. The results were used in the calculation of manure to water ratios necessary for adjusting solid levels to various TS concentrations needed in the experiment. Ordinary tap water was used to adjust water content of the manure to obtain the desired solid levels of 6.0, 4.0, 2.0, 1.0 and 0.5%, respectively. The natural sedimentation experiments were done using five clear Plexiglas columns (91 cm in height and 15 cm in diameter to simulate actual sedimentation tanks/pits of similar depths) filled up to approximately 5.0 cm of headspace to facilitate stirring.

Prior to starting the quiescent sedimentation process, the manure in each column was thoroughly stirred to a uniform mixture using a motorized paddle stirrer. Immediately after stirring, duplicate samples were drawn from three depths—0, 30, and 60 cm. This sampling procedure was repeated at the following intervals—30, 60, and 240 min. All the samples were kept in a deep freezer until they were analyzed. Before the laboratory analysis of the frozen samples for both the SS and total phosphorus, the samples were thawed and allowed to reach the room temperature (approximately 20°C).

The concentrations of total SS and total phosphorus were determined using standard laboratory methods (APHA 1998). A well-mixed sample was filtered through a weighed, standard, glass-fiber filter, and the residue retained on the filter was dried to a constant weight in an oven at 105°C. Total phosphorus was determined using the Persulfate Digestion Method, by which all the species of phosphorus in a sample were first converted to orthophosphates. The samples were then filtered and the phosphorus measured calorimetrically using the ascorbic acid method.

Effects of Chemicals on Sedimentation

The same batch of manure used in the natural sedimentation experiment was used, but the solids level was adjusted to 1.0% by addition of tap water. The 1.0% solids level was chosen on the basis of the results of the natural sedimentation, because this level resulted in the best sedimentation of manure solids. Four columns were set up as in the natural sedimentation tests. Two sets, each of four columns were prepared for evaluating aluminum sulfate and ferric chloride at four dosage levels. Aluminum sulfate—$Al_2(SO_4)_3 \cdot 12H_2O$—and ferric chloride—$FeCl_3 \cdot 6H_2O$—were added to each of the four columns at the nominal levels of 500, 1,000, 1,500, and 2,000 mg/L, respectively, and again thoroughly stirred before commencing the simulation of the enhanced sedimentation. These nominal levels fell within the range of those commonly encountered in past manure flocculation studies and translated into approximately 1.8, 3.6, 5.4, and 7.2 mM of the Al^{+3} and Fe^{+3} ions. Duplicate samples were drawn from the surface (0 cm) and the depths of 30 and 60 cm at the beginning of the experiment (0 min) and at intervals of 30, 60, and 240 min thereafter. The TSS and total phosphorus were determined using the same standard laboratory methods described in the preceding section.

RESULTS AND DISCUSSION

Natural Sedimentation

The effects of solids concentration on the natural sedimentation are presented in Fig. 2. In general, the sedimentation process seems to have been complete during the first hour of detention time and only a marginal improvement was achieved with a detention time of 4 h. The effective SS removals above the draw-out point (60 cm) after 4 h of quiescent natural sedimentation were approximately 8, 39, 62, 66, and 37% for manure solids levels of 6.0, 4.0, 2.0, 1.0, and 0.5%, respectively. These data suggest that both too high and too low levels of solid content in the manure result in a reduced removal of SS by sedimentation. In this study, 1.0 and 2.0% solids levels gave a much better SS removal after 4 h. The general trend of these results compared well with the trend of the results of a similar study by Moore et al. (1975). Their sedimentation study with swine manure (although conducted for a longer duration) simulated at 0.01, 0.1, and 1.0%, showed that solids removal after 1,000 min were 59, 68, and 70%, respectively, i.e., the separation efficiency decreased with decreasing solids levels below 1.0%. Martinez et al. (1995) also reported somewhat similar results. In their studies, dilute slurries with less than 25 kg/m^3 (~2.5%) TS were found to be most effective for natural sedimentation, while solids with more than 40 kg/m^3 (~4.0%) TS did not separate effectively.

Effects of Chemicals on Sedimentation

The effects of addition of aluminum sulfate to swine manure prior to the quiescent natural sedimentation are presented in Fig. 3. Unlike the unaided natural sedimentation, only approximately half of the suspended solids were removed in the first hour of detention time. This may be explained by the mode of settling. The particles in the unaided natural sedimentation settle more or less individually, while with addition of flocculants, the process is governed by settlement of a mass of flocculants. These larger masses settle slower, but eventually the solids removals are much more enhanced. The SS removals after 4 h of sedimentation were 74, 81, 96, and 96% at aluminum sulfate levels of 500, 1,000, 1,500, and 2,000 mg/L, respectively. Compared to the SS removal of approximately 66% obtained in the natural sedimentation at 1.0% solids level, all aluminum sulfate levels therefore enhanced the natural sedimentation. Removal of SS was directly proportional to the addition of alum up to the 1,500 mg/L level and leveled off

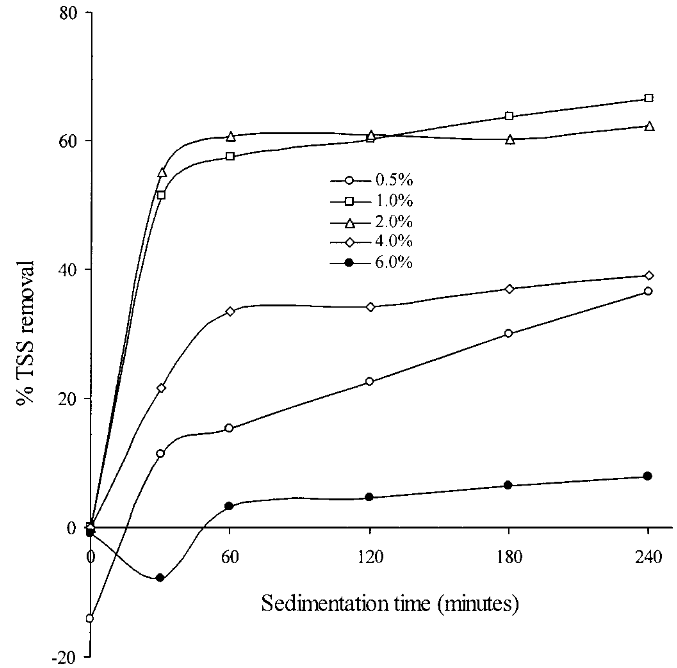

FIG. 2. Effects of Solids Concentration on Natural Sedimentation of Swine Manure

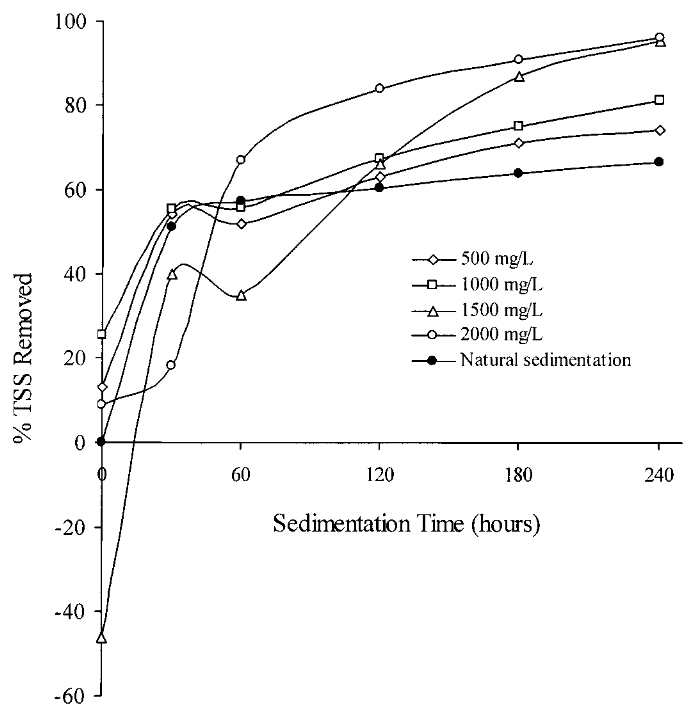

FIG. 3. Effects of Aluminum Sulfate Concentration on Sedimentation of Dilute Swine Manure

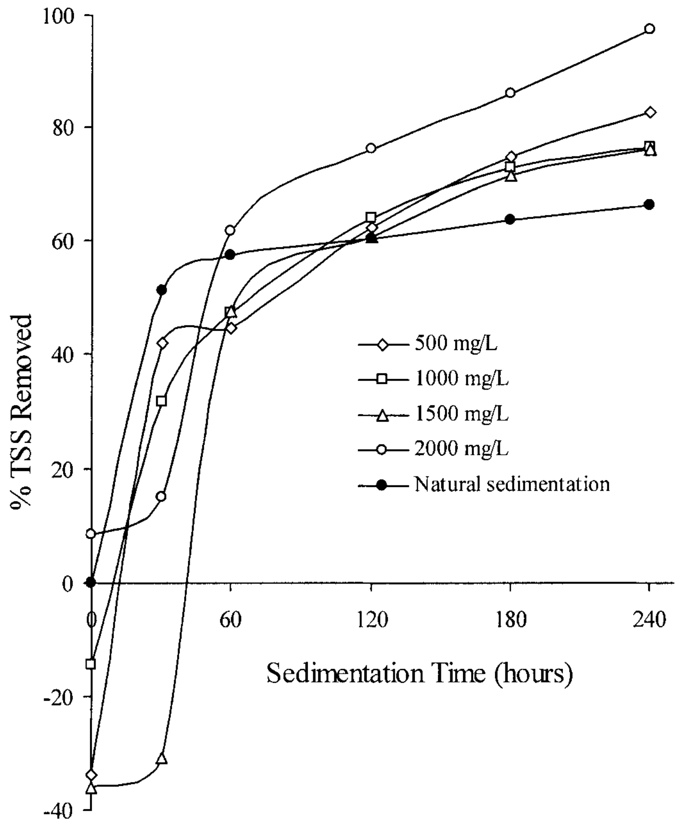

FIG. 4. Effects of Ferric Chloride Concentration on Sedimentation of Dilute Swine Manure

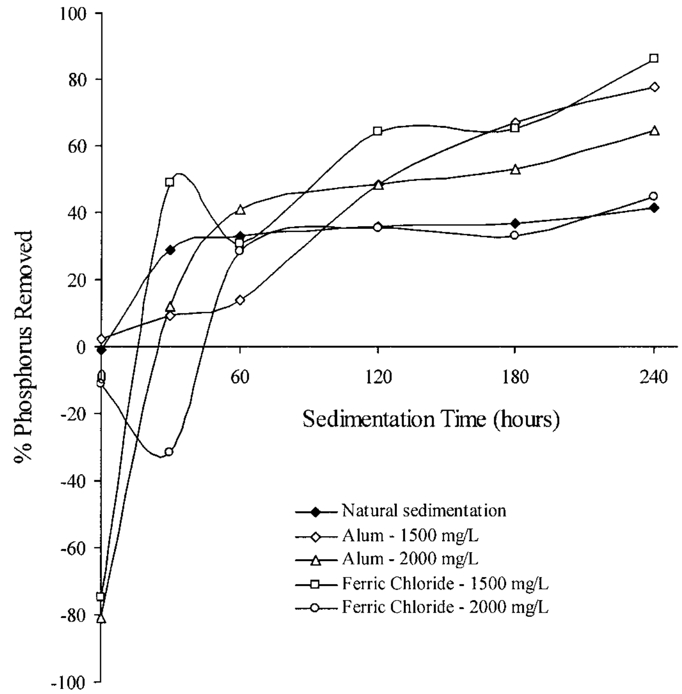

FIG. 5. Effects of the Flocculant Concentrations on Removal of Phosphorus from Dilute Swine Manure

after that, so that at the 1,500 g/L and 2,000 mg/L levels the removals were the same at the level of approximately 96%. This suggests an optimal dosage of 1,500 mg/L of aluminum sulfate to the swine manure at this level of solid concentration.

The effects of ferric chloride on natural sedimentation are presented in Fig. 4. The SS removal after 4 h using 500, 1,000, 1,500, and 2,000 mg/L of this flocculant were 82, 77, 76, and 98%, respectively. Again, compared to separation efficiency of 66% achieved by unaided natural sedimentation at 1.0% solids level, the effect of ferric chloride on the natural's sedimentation is evident. The solids removal percentage after 4 h of sedimentation at the dosage levels of 500, 1,000, and 1,500 mg/L of ferric chloride to the swine manure were not significantly different while at the 2,000 mg/L, the removal rate was significantly increased. This seems to suggest that the 2,000 mg/L is the critical or threshold amount of ferric chloride needed to achieve significant solids removal.

The SS removals in aluminum sulfate-aided natural sedimentation at the two levels of 1,000 and 1,500 mg/L were almost complete (100%) within 4 h, while this was not the case with the ferric chloride aided natural sedimentation. After 4 h of sedimentation with ferric chloride as the additive, only at 2,000 mg/L dosage was the removal of SS nearly total (100%). Some negative values of separation efficiencies were also observed during some of the sedimentation processes. This is because the sedimentation process is characterized by a settling front, i.e., as sedimentation proceeds there is distinct demarcation between the settling solids and separated liquid liquor. Obviously, the more advanced this demarcation/front is, the thicker the solid below it will be. Any location below the front will, therefore, have more solids than it started with which manifests as negative separation efficiency.

Removal of Phosphorus

Removal of phosphorus by unaided natural sedimentation and chemically aided natural sedimentation is presented in Fig. 5. The removal of phosphorus by unaided natural sedimentation after 4 h of detention time was approximately 42%, while those of aluminum sulfate-aided natural sedimentation were approximately 78 and 65% at the level of 1,500 and 2,000 mg/L, respectively. The removal of phosphorus by ferric chloride on the other hand was on average approximately 86 and 45% at the level of 1,500 and 2,000 mg/L, respectively. In the previous section, the removal of SS seemed to increase with an increase of chemical additives. However, the removal of phosphorus seems to fall significantly by going from 1,500 to 2,000 mg/L of the flocculants to the manure, at least within the detention time used in these tests.

On the basis of the removal of phosphorus presented in this section and that of the SS presented in the preceding section, it was apparent that the 1,500 mg/L of each flocculant to the swine manure at this level of solids concentration would be the most optimal dosage level for both flocculants for the removal of both the SS and phosphorus. Because equal molar concentrations of both metal ions were used, it can also be inferred that Al^{+3} ions are more efficient than Fe^{+3} ions in the removal of phosphorus, while Fe^{+3} ions are better in removal of the SS than Al^{+3} ions from dilute swine manure in shallow sedimentation pits/tanks.

SUMMARY AND CONCLUSIONS

Solids above 2.0% or below 1.0% levels were found to affect natural sedimentation negatively. Solids levels between 1.0 and 2.0% in the swine manure were found to be suitable for effective natural sedimentation of swine manure stored in a sedimentation tank.

It is possible to improve solid/liquid separation of dilute swine manure in shallow sedimentation tanks from 66 to 76% and 96% by addition of 1,500 mg/L (5.4 mM) of ferric chloride and aluminum sulfate, respectively, with 4 h of detention time.

The same dosage levels of flocculants were able to concomitantly improve phosphorus removal from 42 to 86% and 78% for ferric chloride and aluminum sulfate, respectively. Based on the flocculants' removal efficiencies of both phosphorus and SS on a 4 h detention time, Al^{+3} ions are more efficient in the removal of SS while Fe^{+3} ions are more efficient in the removal of phosphorus.

Use of chemical flocculants can, therefore, be a useful treatment for improving the handling characteristics of swine manure in shallow sedimentation tanks. The resulting liquor from the separation could perhaps be used for irrigating the land near swine production facilities, cleaning/flushing the swine facilities so that no or only a little fresh water is introduced, or it can easily be taken through further (tertiary) treatment for disposal into surface water. On the other hand, the solids can probably be economically transported to remote areas where higher nutrient concentration is required or processed into value added products like feeds or compost, products whose value vis-à-vis the transportation cost is favorable.

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NOTATION

The following symbols are used in this paper:

h = depth;
R = percentage removal of suspended solids or phosphorus;
t = time; and
Δh = change in depth.

Subscripts

i = positive integer indices.