Solids Separation Enhances Reduction of Organic Strength of Swine Manure Subjected to Aeration Treatments

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Abstract. *To reduce overloading lagoons used for treating/holding animal manures, some form of pretreatment to reduce organic strength of the manure is necessary. Aerobic treatment is one such pretreatment, but the associated aeration costs most often limit use of this process. Reducing these associated aeration costs, therefore, would make this fast pretreatment method more feasible. In this study, a combination of solids/liquid separation and low−level aeration treatment processes were examined for stabilization of the swine slurry and on their effect on pertinent manure nutrients. Results indicate that solids/liquid separation and low−level aerobic treatments of swine manure enhance bio−stabilization of the separated liquid manure. In this study, 0.164 day^{-1} and 0.061 day^{-1} bio−stabilization rates were observed in the separated liquid manure and in the control (unseparated) manure, respectively. By day nine, 40% and 76% reductions in COD were achieved in the control and the treatment, respectively, i.e., the strength of the influent into the anaerobic lagoons can be reduced by as much as 76% using this combined treatment approach within nine days. The faster bio−stabilization in the separated manure liquid is believed to be a result of improved aeration efficiency and better contact between the microbial biomass and the dissolved substrate. Although aeration treatment did not result in considerable change in both TKN and TAN, effluent liquid after an overnight sedimentation process from the unprocessed manure (control) was found to retain approximately 90% of TKN, 34% of TP, and 73% of TS, while effluents from the treatment after the same overnight sedimentation retained approximately 67% of TKN, 30% of TP, and 54% of TS. The treatment, therefore, not only resulted in higher reduction of organic strength but also in substantial reductions of TKN, TP, and TS than the control in the liquid effluent after an overnight sedimentation process.*

Keywords. *Aerobic treatment, Bio−stabilization, Organic strength, Solids separation, Swine manure.*

In the majority of the warmer southern states of the U.S., lagoons are widely used to store and treat swine waste until land application (Chastain et al., 2001; Shearin et al., 2003; Chvosta and Norwood, 2003). In general, because of less odor nuisances, aerobic lagoons are more suitable for treatment and storage of these wastes than anaerobic lagoons. However, aerobic lagoons of necessity are shallow to allow aeration by natural wind currents and, therefore, usually have much larger surface areas than anaerobic lagoons. On the other hand, anaerobic lagoons treating the same volume of waste have considerably smaller surface areas than aerobic lagoons and usually can treat more organic matter per unit volume than aerobic ones. Due to the tremendous area required for aerobic lagoons to treat these wastes, almost all the lagoons are of necessity anaerobic, which is a size−cost compromise. Anaerobic lagoons, however, have been subject of much scrutiny in the last couple of years for failing to provide the required treatment of the manure and for generation of malodorous and other environmental harmful gases (Classen et al., 2000; Chastain et al., 2001; Hawkins, et al., 2001; Cheng and Liu, 2002; Shearin et al., 2003; Chvosta and Norwood, 2003; Miner et al., 2003). The major problems usually are the results of organically overloaded lagoons, which degrade the effectiveness of anaerobic treatment. To achieve proper treatments, lagoon organic loading rates must not be excessive or anaerobic treatment will be inhibited (Hawkins, et al., 2001).

An effective and practical way of reducing lagoon organic loadings is to decrease the mass loading of organic matter through pretreatment. Aerobic pretreatment of animal slurries is still an option for farmers in the management of animal waste (Burton and Farrent, 1998). It is a proven and effective way of reducing organic strengths of numerous waste streams. This technique has been widely used in treating industrial and municipal liquid wastes, and substantial reduction of chemical oxygen demand (COD) and biochemical oxygen demand (BOD) have been achieved within reasonable treatments durations (Osada et al., 1991; Bicudo and Svoboda, 1995). The biggest drawback to wider applications of this technology in the animal industry has been the economics. Research efforts needed to make this technology more attractive in the management of wastes in the swine and other animal industries should be directed towards reduction of the cost of treatment by increased aeration efficiency or other alternatives.

The impact of solids/liquid separation on organic strength reduction (i.e., stabilization) is largely determined by the amount of biodegradable organic solids and nutrient elements removed from the manure. A review of previous work on this subject by Westerman and Zhang (1997) concluded

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that finer particles in the manure decompose faster and to a greater extent than coarse particles. In addition, it is well established that during aeration treatments, the oxygen transfer rate and efficiency are affected by factors such as: the surface area in contact with air, mixing/turbulence, temperature, and the amount of solids or other constituents in the manure (Martin and Loehr, 1976; Westerman and Zhang, 1997). In general, the less the solids and the finer the solids, the better the aeration efficiency, the faster the biodegradation, and hence the lower the cost of aerobic treatment to effect bio−stabilization.

It is hypothesized that, a solids/liquid separation treatment prior to an aeration treatment will stabilize the separated liquid swine manure effectively, timely, and economically. Solids separation not only removes the coarse particles that degrade slowly and over a longer time, but also improves the oxygen transfer efficiency, thereby effecting stabilization of the liquid manure in a much shorter time. This would be both economical and environmentally friendly since odors will only be a problem within a short period of time and moreover, not only will lower aeration rates be used, but also for shorter period of time.

The objectives of this study were to determine the effect of solids/liquid separation and low−level aeration treatment on: (1) degradation of COD, (2) kinetics of bio−stabilization, and (3) dynamics of other important nutrients in the swine manure during these treatment processes.

Materials and Methods

Equipment and Instrumentation

This study was conducted in clear Plexiglas reactors (91 cm tall, 15 cm diameter) with an operating volume of 14 L of liquid manure and approximately 15 cm headspace to facilitate mixing and to provide room for frothing created by the aeration process. To aerate the manure, a positive−pressure air pump (model DOA−P104−AA, Gast Mfg., Benton Harbor, Mich.) was used to introduce air into the manure through a flexible rubber air diffuser (Catalog No. W107A, Won Brothers, Inc., Fort Washington, Md.) placed at the bottom of each reactor. A variable−area flowmeter (model P−32461−64, Cole−Parmer Instrument Co., Vernon Hills, Ill.) was used to regulate and maintain the flow of aeration air in each unit. A low−level airflow rate of 0.067 L air $\cdot$ L^{-1} manure $\cdot$ min^{-1} was maintained throughout the study period based on previous research (Luo et al, 2001; Ndegwa et al., 2002). The oxidation reduction potential (ORP) of the liquid manure was determined using a platinum band ORP probe and a voltmeter (Accumet 1003, Fisher Scientific, Hampton, N.H.). A handheld pH meter (Accumet 1003, Fisher Scientific, Hampton, N.H.) equipped with a temperature−compensating probe was used to monitor the pH and the temperature in each reactor on a daily basis just prior to daily sampling of manure.

Manure Collection

Swine manure from a nursery barn located at the Oklahoma State University Swine Research Facility was collected in plastic containers. The manure collection system on this facility is a pit−recharge system operated either once or twice a week. The eight−week old piglets were fed a corn−soybean diet. Pertinent characteristics of the raw manure obtained from this barn and used in this study are given in table 1.

Table 1. Characteristics of the raw manure used in this study.

Parameter	Quantity
Total solids of raw manure (TS) (g/L)	15.6 ±0.8[a]
Chemical oxygen demand (COD) (mg/L)	26,286 ±76
Total phosphorus (TP) (PO_4^{-3} mg/L)	493 ±10
Orthophosphate (PO_4^{-3} mg/L)	425 ±16
Total Kjeldahl nitrogen (TKN) (mg/L)	2,391 ±59
Total ammonium nitrogen (TAN) (mg/L)	1294 ±18
pH	5.5 ±0.0
Oxidation−reduction potential (ORP) (mV)	−264 ±8

[a] "±" refers to one standard deviation from the mean (*n* = 6).

Manure Treatments and Sampling

Four identical reactors (described earlier in the Equipment and Instrumentation section) were used for this study: two for the control and two for the treatment. Prior to filling the reactors, the manure slurry was thoroughly stirred to ensure uniformity of the feed to all the reactors. Two reactors labeled "control" and the other two reactors labeled "treatment" were filled with 14 and 15 L of this well mixed manure, respectively. To facilitate solids/liquid separation in the treatment reactors for the solids separation treatment, the manure was allowed to quiescently settle for 5 h. The liquid portion in the treatment reactors was then decanted into separate containers. The two empty treatment reactors were cleaned thoroughly of the solids before pouring back 14 L of the separated liquid manure. The separated solids fractions, which formed about 7% of the original raw manure slurry, were discarded.

Before starting the aeration in each case, the manure in each reactor was again thoroughly stirred using a re−circulation pump (model 2E−38N, Little Giant Pump Co., Oklahoma City, Okla.) for about 10 min, and an 80 mL sample for laboratory analysis was drawn from a sample port positioned approximately 30 cm from the bottom of each reactor. Similar size samples were taken once every day thereafter, from each reactor, from the same location for the entire nine days duration of the aeration treatment. To ensure that representative samples were obtained, the contents of each reactor were thoroughly mixed with a re−circulation pump for 10 min prior to sampling. To compensate for the volume of manure lost through sampling from these batch processes, airflow rates were adjusted accordingly immediately after each sampling schedule to ensure the same aeration rate throughout the test. By day nine, no more reduction in COD was observed in the treatment and, therefore, aeration treatment was discontinued. At the completion of aeration treatment and after an overnight sedimentation, a sample of supernatant was taken from each reactor for analysis of TP, TS, TKN, and COD. This sample represented the effluent that would be received by the lagoon in a full−sized unit. Analyses were done immediately after the sampling whenever possible and if not, all the samples were frozen until the time of analyses. The frozen samples were then thawed and allowed to reach the room temperature prior to analyses.

Laboratory Analyses

The following parameters were determined using standard laboratory methods (APHA/AWWA/WEF, 1998): total

Table 2. Changes in concentrations (conc.) of the major parameters of the swine manure before and after treatments.

Parameter[a]	Test[b]	Conc. after Solids Separation	Conc. after Aeration	Conc. after an Overnight Sedimentation	Mean Conc. Reduction (%) Achieved (**O:** A, B, C)[d]
TCOD (mg/L)	Control	26,286 ±76[c]	17,135 ±3,027	15,744 ±4,238	**40:** 0, 35, 5
	Treatment	21,042 ±76	6,968 ±454	6,219 ±1,817	**76:** 20, 53, 3
TKN (mg/L)	Control	2,176 ±47	2,096 ±58	1,963 ±70	**10**: 0, 4, 6
	Treatment	1,791 ±2	1,537 ±33	1,462 ±2	**33:** 18, 12, 3
TAN (mg/L)	Control	1,294 ±18	1,309 ±50	1,309 ±50	**−1:** 0, −1, 0
	Treatment	1,288 ±4	1,219 ±34	1,219 ±34	**5:** 0, 5, 0
TP (mg/L)	Control	493 ±10	493 ±10	168 ±1	**66:** 0, 0, 66
	Treatment	427 ±9	427 ±9	149 ±15	**70:** 14, 0, 56
TS (g/L)	Control	16.0 ±1.1	16.3 ±0.5	11.6 ±0.4	**27:** 0, −2, 29
	Treatment	13.4 ±0.0	9.9 ±0.5	8.7 ±1.5	**46:** 16, 22, 8

[a] TCOD = total chemical oxygen demand, TKN = total Kjeldahl nitrogen, TAN = total ammonium nitrogen, TP = total phosphorus, and TS = total solids.
[b] "Treatment" refers to pre−aeration solids/liquid separation of manure.
[c] "±" refers to one standard deviation from the mean (*n* = 2).
[d] "**O:** A, B, C" refers to overall reductions: reductions due to solids separation prior to aeration, reductions due to aeration, reductions due to solids separation after aeration, respectively.

solids (TS), total volatile solids (TVS), soluble ortho−P, total phosphorus (TP), ammonium nitrogen, and total Kjeldahl nitrogen (TKN). To determine the soluble ortho−P and ammonium nitrogen, a well−mixed sample was diluted and vigorously shaken for 5 min. The diluted sample was then filtered using GF/A Whatman filter papers. The soluble ortho−P in the filtrate was determined colorimetrically as the phosphomolybdate complex after reaction with ascorbic acid (Hach, 1993). The TP was determined using the persulfate digestion method, by which all the species of P in a sample are first converted to soluble ortho−P. The samples are then filtered and the TP measured calorimetrically using the ascorbic acid method. The chemical oxygen demand (COD) was measured using the standard ampule method (Adams, 1990).

The mean percent reduction in concentrations of TCOD, TKN, TAN, TP, and TS (table 2) were calculated based on the initial concentration of the parameter in question and the final concentration of the same parameter between any two points in the overall process. For example, the percent reduction of TCOD due to solids separation is the percentage of the difference in the concentrations of TCOD before and after solids separations and the TCOD concentration before solids separation.

Results and Discussion

Solids Removal Prior, During, and After Aeration Treatment

The removal of TS prior to aeration and during the aeration process is shown in figure 1, while the TS in the effluent after an overnight sedimentation process is presented in table 2. Solids separation by 5 h of gravity sedimentation prior to aeration treatment removed approximately 16% of the TS. During the following nine days of aeration treatment, a further 22% reduction in TS was observed in the separated liquid manure, while a build−up of approximately 2% was observed in the control experiment. This 2% build−up of TS in the control is believed to be due to sampling and analysis errors. At the conclusion of the study and after allowing for an overnight quiescent sedimentation, very definite layers of sludge and supernatant were observed. Analysis of TS in the liquid supernatant revealed that an additional 8% and 29% of TS were removed from effluents of the treatment and the control, leading to net TS removals of 46% and 27%, respectively.

Effect of Solids Removal on COD During Treatment

Bio−stabilization refers to the degradation of organic materials during biological processes and is usually defined

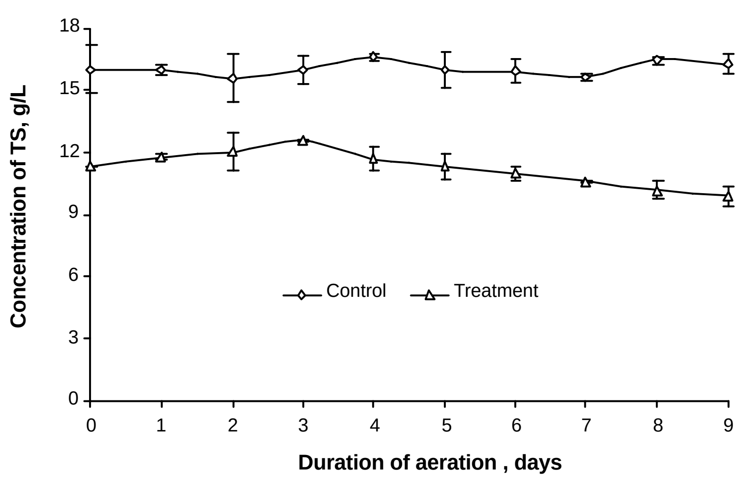

Figure 1. Changes in total solids (TS) in the control and treatment with time of batch aeration.

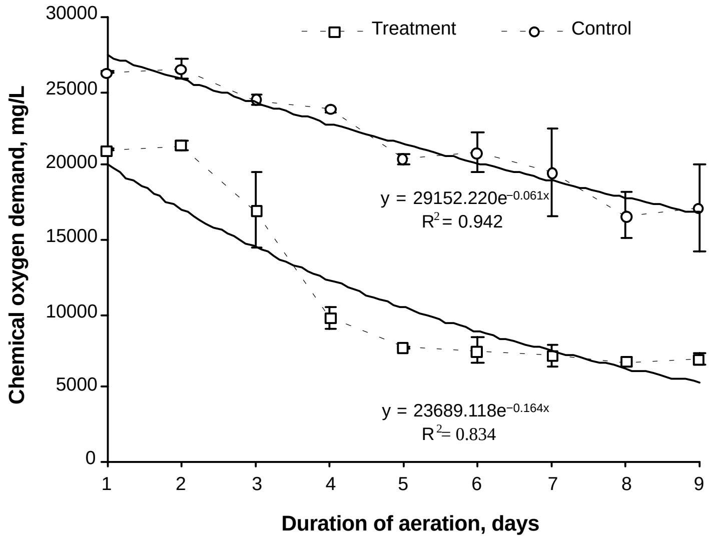

Figure 2. Changes in chemical oxygen (COD) in the control and treatment with time of batch aeration.

by a bio−stabilization constant, which basically indicates the rate at which the organic material is degraded (Metcalf and Eddy, 1991; Adani et al., 2002). Assuming a first−order kinetics model to describe organic matter degradation, the following expression can be used to estimate decay of the volatile solids, the biochemical oxygen demand (BOD), or the COD:

$$S = S_0 \times e^{-kt} \qquad (1)$$

where S is the mass concentration of substrate at time t (mg/L), S_0 is the initial mass concentration of substrate (mg/L), k is the bio−stabilization constant (day^{-1}), and t is the time (days). In our case, COD is the substrate.

The changes in the COD of the manure in the treatment and the control are shown in figure 2 and table 2. Based on the first−order regression equations for degradation of COD in both the treatment and the control, the bio−stabilization rate in the treatment (k = 0.164 day^{-1}) was significantly higher than in the control (k = 0.061 day^{-1}). By using the reductions rates of COD from the fitted regression models, the rate of COD reduction due to the treatment compared to the control was approximately 2.7 fold higher. In addition, using the respective models, it was estimated that 50% bio−stabilization (also known as the half−life decay period) is achievable in 4.2 days and 11.4 days of aerobic treatment in the separated liquid manure and in the control (unseparated) manure, respectively. By day nine, the actual reductions in COD achieved were 40% and 76% in the control and in the treatment, while the model estimated 42% and 77% reductions, respectively. These numbers indicate good fit as also confirmed by the correlation coefficients of 0.91 and 0.97 of the first−order regression equations of the treatment and the control, respectively.

From the preceding paragraph, it can be inferred that solids/liquid separation prior to aerobic treatment of swine manure enhances bio−stabilization of the separated liquid manure. This faster stabilization can be explained in part by the removal of the most of larger particulate matter, which is more recalcitrant to microbial degradation, and in part by the improved efficiency of oxygen transfer in the separated liquid manure as opposed to the whole swine manure (Martin and Loehr, 1976; Westerman and Zhang, 1997). The latter factor is discussed in more detail in a later section of this article.

Effect of Solids Removal on Nutrient Dynamics

Nitrogen

The changes in total Kjeldahl nitrogen (TKN) and total ammonium nitrogen (TAN) in the control and the treatment during the aerobic treatment of swine manure are shown in

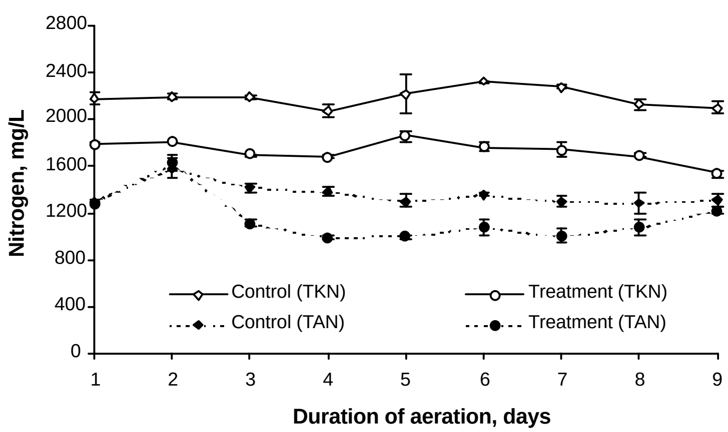

Figure 3. Changes in total Kjeldahl nitrogen (TKN) and total ammonium−nitrogen (TAN) in the control and treatment with time of batch aeration.

figure 3 and table 2. Removal of solids by 5 h of quiescent sedimentation prior to aeration treatment removed 18% of the TKN, implying that most of the TKN is in solution and in the very fine suspended solids. Aeration treatment during the entire nine days of this study only removed a further 12% and 4% of TKN in the treatment and the control, respectively. The overnight quiescent sedimentation process removed an additional 3% and 6% of TKN from the treatment and the control, respectively, to give net reductions of 33% and 10%.

A slight rise in TAN was observed in both the control and the treatment during the first day of aerobic treatment. This trend reversed immediately on day two, after which declines were observed in both the control and the treatment. However, similar to changes in the COD discussed in the preceding section, a faster reduction was observed in the treatment compared to the control. This is consistent with general microbial degradations, whereby consumption of nutrients follows consumption of COD. The TAN taken up by the microbes is part of the TKN and, therefore, does not explain changes observed in the TKN. The author believes that more nitrification and possibly more loss of free ammonia (higher pH conditions) may explain the higher loss of ammonia and TKN in the separated liquid manure compared to the unseparated manure.

Phosphorus

It is evident from the data presented in table 1 that soluble ortho−P was the largest component of TP in the raw manure, comprising approximately 86%, while combined organic P and insoluble ortho−P comprise only 14% of TP. This observation suggests that a solids/liquid separation process on manure from a nursery pull−plug operated once or twice a week will not significantly reduce P loading in the lagoons because the effluent liquid manure holds most of the P in solution already. To alleviate P loading into the lagoons, some form of treatment is necessary to reduce soluble ortho−P in the manure.

The changes in soluble ortho−P in the manure for the control and the treatment during the aerobic treatment are shown in figure 4. Low−level aeration of previously separated liquid manure obviously has an advantage over the aeration of unseparated manure (control). Solids/liquid separation treatment leads to more soluble ortho−P being converted to non−soluble species, which is removed by subsequent solids/liquid separation (87% compared to 84% removal in the control). This is evident in the data presented in table 2, which show a 4% higher overall removal of TP by subsequent removal of the sludge at levels of 70% for separated liquid manure compared to 66% for the control, respectively.

An increase in pH followed by a concomitant decrease in ortho−P, as evident in figure 4, exhibits the inverse relationship between pH and the content of soluble ortho−P in the liquid manure. This phenomenon, in which soluble ortho−P precipitates into insoluble phosphates (iron phosphate, calcium phosphate, and aluminum phosphate) when pH increases, has recently been acknowledged as a major route in the removal of ortho−P from liquid manure (Zhu et al., 2001; Ndegwa et al., 2001; Luo et al., 2001). Moore and Miller (1994) also observed that the reactions between ortho−P and iron or calcium are highly dependent on pH. Between a pH range of 4.7 and 7.1, the reaction between iron and ortho−P predominates, while at the pH range of 7.2 to 12, the reaction between calcium and ortho−P predominates. On average, manure contains substantially more calcium than iron ions (Zhu et al., 2001); therefore, more ortho−P will be precipitated if pH moves towards the range favoring formation of calcium phosphate. This may explain the higher removals of ortho−P in the separated liquid manure than in the control because the pH increased the same way.

Effect of Solids Removal on Aeration

The variations of ORP during aeration in both the separated liquid manure and the control are presented in figure 5. During the first three days of aeration, the oxidation level remained higher in the control than in the separated liquid manure. A possible explanation for the preceding observation is that microbial action was enhanced more in the separated manure than in the unseparated manure because of the improved contact between the microbial mass, the fine particles, and the dissolved substrate. The kinetic rates of degradation for the fine and dissolved solids are higher than for the coarse particles, and this increased substrate degradation kinetics require more oxidation power. These postulations are confirmed by examining figures 6 and 7. These two figures indirectly quantify microbial activities because the change in volatile solids closely follows microbial biomass

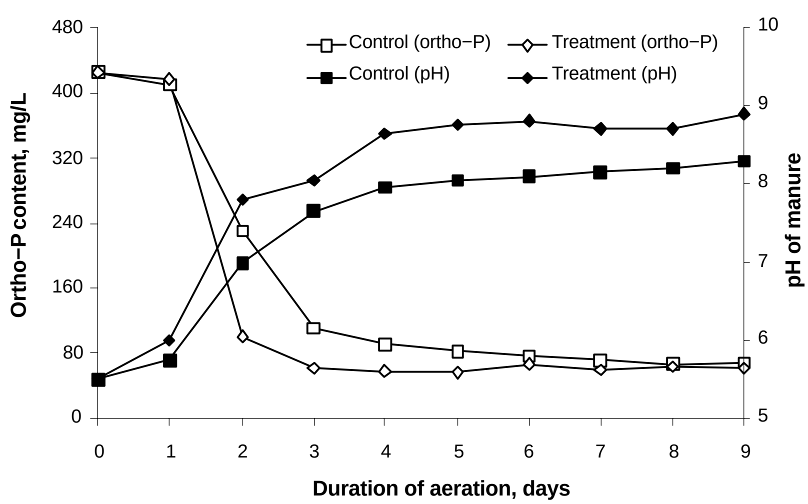

Figure 4. Changes in ortho−P and pH in the manure with time of batch aeration.

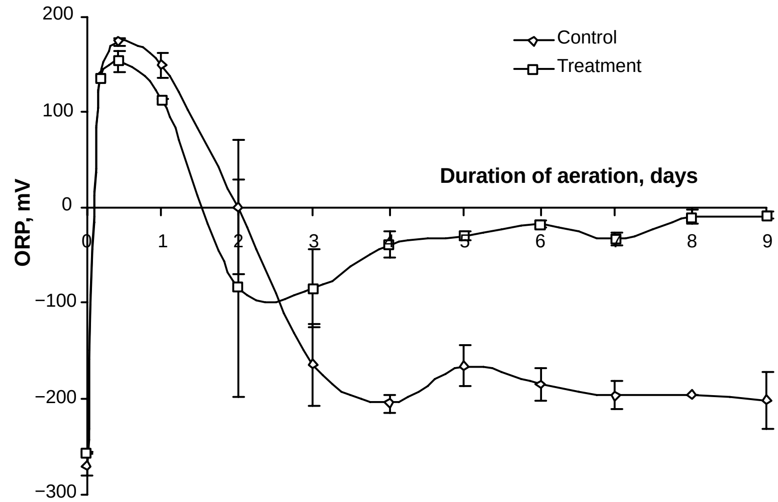

Figure 5. Changes in oxidation−reduction potential (ORP) in the control and treatment with time of batch aeration.

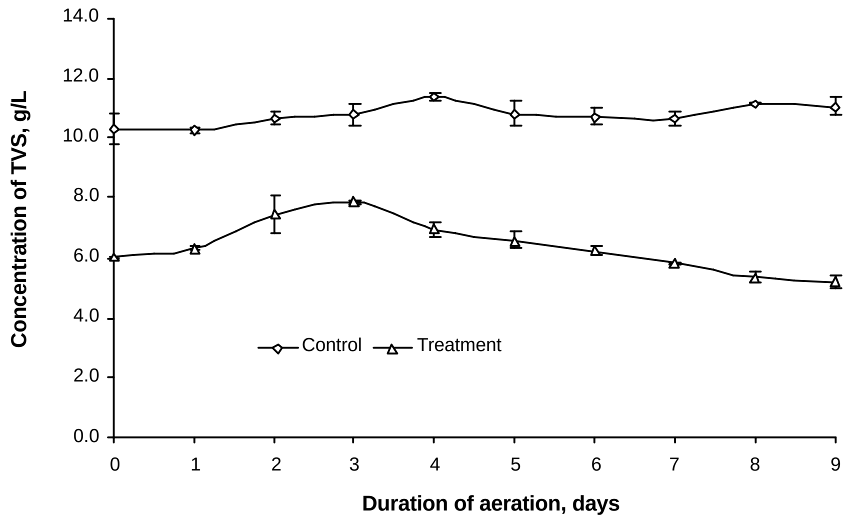

Figure 6. Changes in total volatile solids (TVS) in the control and treatment with time of batch aeration.

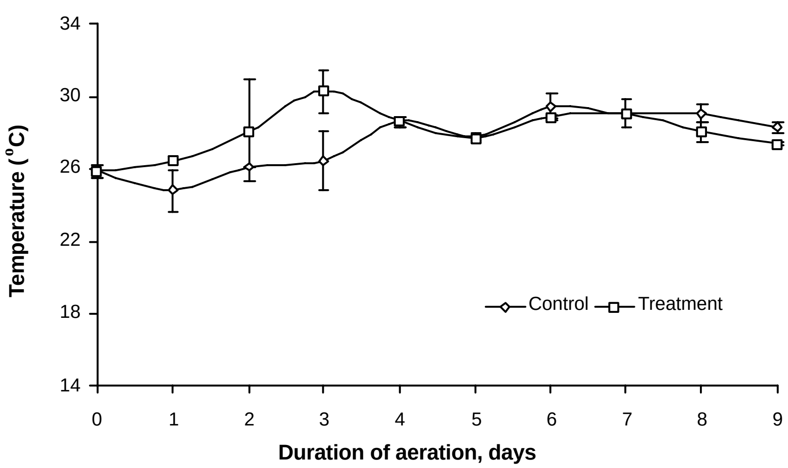

Figure 7. Temperature profiles of the treatment and the control during batch aeration treatment of swine manure.

growth, while temperatures of the reactor contents indicate microbial activity level from metabolic respiration. The temperatures in the control reactors remained lower than the temperatures in the reactors with separated liquid manure from the first day till the fourth day of aeration treatment. On the other hand, only a little change in microbial biomass was recorded during this time in the control, while considerable growth of microbial biomass was observed in the separated liquid manure in the same time. Both temperature and microbial biomass growth gradually declined after this point in the separated liquid manure. In the control, both temperature and microbial growth continued to rise marginally, indicating late degradation of the coarse particles.

Prolonged aeration treatments, however, seemed to be in favor of separated liquid manure in terms of maintaining higher oxidation status at the same level of aeration. This is quite evident in figure 5 after the third day of aeration, where ORP in the separated liquid manure stabilized at a much higher level (−15 mV) than in the unseparated manure (−200 mV). These observations suggest that solids separation prior to aeration treatment boosts maintenance of aerobic conditions in prolonged aeration of separated liquid manure, most probably through a combination of improved oxygen transfer efficiency effected by removal of coarse solids (leading to removal of some COD) and faster bio−stabilization (from the resulting higher fraction of more easily biodegradable COD) of the manure resulting in reduced oxygen demand. The consequence of this postulation is that it is possible to use lower aeration rates (or less energy) to maintain an adequate ORP level, especially in the latter period of the treatment. This gives solids/liquid separation an economic edge over unseparated manure in aeration treatments for control of odor generation when prolonged aeration treatments are desired.

Summary and Conclusions

Solids/liquid separation prior to aerobic treatment of swine manure enhances bio−stabilization of the separated liquid manure. In this study, 0.164 day^{-1} and 0.061 day^{-1} bio−stabilization rates were observed in the separated liquid manure and in the control (unseparated) manure, respectively: a difference of 2.7 fold. By day nine, 40% and 76% reductions in COD were achieved in the control and the treatment, respectively, i.e., the strength of the influent into the anaerobic lagoons can be reduced by as much as 76% using this combined treatment approach within nine days.

Removal of solids from the liquid manure effectively removed approximately 18% of the TKN. An additional 12% of the TKN was removed during the following eight days of aerobic treatment of the separated liquid manure compared to only 4% removal in the control manure during the same duration of treatment. Overnight quiescent sedimentation removed an additional 3% and 6% of the TKN. Liquid supernatant from the unprocessed manure, therefore, retained approximately 90% of the TKN, while liquid supernatant from the treatment retained approximately 67% of TKN.

Low−level aeration of separated liquid manure has an advantage over the aeration of unseparated manure (control) in the removal of ortho−P. The prior aeration solids/liquid separation treatment leads to slightly more soluble ortho−P being converted to non−soluble species, which are removed by subsequent solids/liquid separation (87% compared to 84% removal in the control). This is further evident in the 4% higher overall removal of TP by subsequent removal of the sludge at levels of 70% for the treatment compared to 66% for the control, respectively.

Solids/liquid separation effectively enhances bio−stabilization (reduced COD) without greatly reducing the TKN in the manure destined for lagoons from the aerobic reactors. In addition, TP in the effluent was substantially (70%) reduced, which is an advantage during later land application of effluents because plant requirements for P are much less compared to N requirements.

From the data obtained in this study, it is more economical in prolonged aeration treatment to treat separated liquid manure than unseparated manure. After only three days of aeration, separated liquid manure stabilized at a much higher ORP level (−15 mV), while the unseparated manure stabilized at a much lower level (−200 mV). These observations suggest that solids separation prior to aeration treatment enhances aeration of the liquid manure, probably through a combination of improved oxygen transfer efficiency and faster bio−stabilization of the manure. The importance of this postulation is that it is possible to use less energy to maintain an adequate ORP level in separated liquid manure than in unseparated manure, especially if prolonged aeration is desired.

Acknowledgement

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