OPTIMIZATION OF ANAEROBIC SEQUENCING BATCH REACTORS TREATING DILUTE SWINE SLURRIES

P. M. Ndegwa, D. W. Hamilton, J. A. Lalman, H. J. Cumba

ABSTRACT. *Use of anaerobic digestion for the treatment and recovery of biogas from concentrated animal waste effluents is a technically viable approach, but widespread acceptance has been limited due to poor economics. This challenge is magnified several-fold when considering anaerobic digestion of low-strength or dilute animal slurries because of the larger digester volumes and the corresponding high energy input requirements. These constraints could be mitigated by using an anaerobic sequencing batch reactor (ASBR). This technology has shown tremendous potential to improve the economics for the treatment of dilute animal waste effluents. This article reports preliminary optimization (biogas production and organic strength reduction) of an ASBR treating dilute swine slurries from pit-recharge manure management systems commonly found in confined swine housing. Based on the results, optimum biogas yields from anaerobic digestion of low-strength swine waste (0.3% to 0.4% TS) were approximately 0.14 mL/mg COD and 0.16 mL/mg COD at 5.25 and 6 days HRT at digestion temperatures of 20°C and 35°C, respectively. Higher operational temperature improved the specific biogas yield, but the qualities of biogas produced at the two temperatures, although high (65% to 70%* CH_4 *and 17% to 20%* CO_2*), were not significantly different. Maximum COD reductions of approximately 90% and 84% would be achieved at 7.2 and 9.1 days HRT at digestion temperatures of 20°C and 35°C, respectively. Higher COD reduction (implying more bio-stabilization of slurry) in the lower-temperature digester was attributed to less biomass washout, which is likely due to more efficient solids settling. The volatile fatty acids at both reactor temperatures were reduced from a mean of 639 ±75 mg/L in the influent to mean values of 74 ±12 and 85 ±17 mg/L in the effluents at 20°C and 35°C, respectively, which significantly mitigated the potential of odor generation from the effluents. Additionally, it was observed that the nutrient (both N and P) levels in the effluents remained about the same as in the influent.*

Keywords. *Anaerobic digestion, ASBR, Biogas energy, Bio-stabilization, Low-strength swine slurries, Odor, Optimization.*

Recovery of biogas for energy from animal waste streams is not a relatively new technology by any measure. However, although its technical viability is not in dispute, widespread adoption of anaerobic digestion technology has not been forthcoming in the animal industry, largely because of unfavorable economics. This challenge is magnified several-fold when dealing with anaerobic digestion of low-strength or dilute animal slurries because of the much larger digester volumes and higher energy input requirements compared to treatment of high-strength animal slurries.

Conventional anaerobic reactors (for example, continuously stirred reactors and plug-flow reactors) have the same solids retention time (SRT) and hydraulic retention time (HRT). However, examination of microbial degradation kinetics models indicates that, in general, they have two degradation rates: a high rate, and a low rate. These two rates are explained by the faster initial degradation of the more easily biodegradable components of the substrate and the slower latter degradation of the more recalcitrant compounds (Tremier et al., 2005; Liwarska-Bizukojc et al., 2002; Admon et al., 2001). In the case of animal manure slurries, the more easily biodegradable carbon substrates are soluble, while the more recalcitrant components are obviously in the solids fraction. Based on microbial kinetic models, the removal of soluble and recalcitrant carbon compounds requires different solids residence times. This observation has led researchers to decouple SRT from HRT by providing biomass settling and recycling while at the same time removing an effluent with a lower carbon content compared to the influent. This approach not only provides longer solids digestion times in the reactor but also increases biomass retention. It has also been reported in past research that solids settling, and therefore solids retention, in anaerobic sequencing batch reactors (ASBR) increases with a decrease in temperature, thus increasing biomass concentration. Based on this observation and examining Stokes' law of particles falling in fluids, it appears that the viscosity of an ASBR's contents increases with temperature. This temperature-solids settling relationship allows ASBR operation at low temperatures without significantly compromising treatment efficiency (Dague and Pidaparti, 1992).

There are now several types of anaerobic digesters that separate HRT and SRT (e.g., upflow anaerobic sludge

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blanket (UASB), anaerobic contact reactors, anaerobic biofilters, fixed-film reactors, etc.) with varying degrees of treatment success. A relatively recent type of anaerobic reactor that separates SRT from HRT is the ASBR. The ASBR's popularity stems largely from: (1) elimination of a secondary clarifier tank, (2) good biomass retention, and (3) simple operation (Rodrigues et al., 2003; Dague and Pidaparti, 1992; Zhang et al., 1997; Zhang and Dugba, 2000; Ioannis and Bagley, 2002). The operating principle of the ASBR follows four steps in a cyclic mode: feed, react, settle, and decant. A sequencing batch reactor, therefore, separates the two retention times (SRT and HRT) in the same reactor chamber so that the solids have a much longer residence time in the reactor than the liquids (Dague et al., 1992, Zhang et al., 1997). The advantage of this design is that an ASBR can treat more volume of substrate per unit time compared to conventional reactors, thus reducing the required volume of the digester. In addition, the high food-to-microorganism (F/M) ratio immediately after the feeding phase ensures high initial rates of substrate removal and more biogas production. On the other hand, at the end of the react phase just before settling, the F/M ratio is much lower, implying a much lower biogas production, a factor that greatly improves settling (Dague et al., 1992; Zhang et al., 1997; Dague et al., 1998). These features make an ASBR especially suitable for the treatment and recovery of biogas from dilute animal slurries that would otherwise require extremely large volume digesters because of their high water content (Dague and Pidaparti, 1992; Zhang et al., 1997; Zhang and Dugba, 2000; Dague et al., 1998).

Research on the technical and economic viability of using an ASBR to treat various waste streams has been on-going over approximately the last one and a half decades. The potential of treating dilute animal slurries has been proven using ASBRs, but additional research to optimize the operational parameters is necessary before widespread dissemination of ASBR technology can be accomplished. This article reports preliminary optimization studies of an ASBR in treating dilute swine slurries. The specific objectives were to determine: (1) the HRT for optimum biogas production, (2) the HRT for maximum bio-stabilization of dilute swine slurries, (3) the nutrient balances (nitrogen and phosphorus), and (4) the effect of HRT on potential of odor reduction in the effluents.

METHODS AND MATERIALS

ASBR SYSTEM DESIGN AND OPERATION

Two similar, bench-scale, 12 L capacity ASBR reactors, built using transparent plexiglass, were used to conduct the studies reported in this article. Both reactors were completely automated. The substrate was held in a 20 L feed tank stored in a refrigerator at 4°C to prevent biodegradation. Periodic feeding during the feed cycle occurred at certain predetermined times, the recirculation of the contents of the reactors was started and stopped at certain specified times to mix or to start solids settling, and the decant pumps were similarly programmed to draw out effluents according to established schedules. These functions were programmed using digital timers to accomplish planned ASBR operations. A temperature controller, connected to a heating tape wrapped around the reactors and a temperature sensor positioned approximately half-way down the reactor, was used to maintain desired temperatures in each reactor. The lower- and higher-temperature reactors were maintained at 20 ±1°C and 35 ±1°C, respectively. A schematic of the bench-scale ASBR is presented in figure 1.

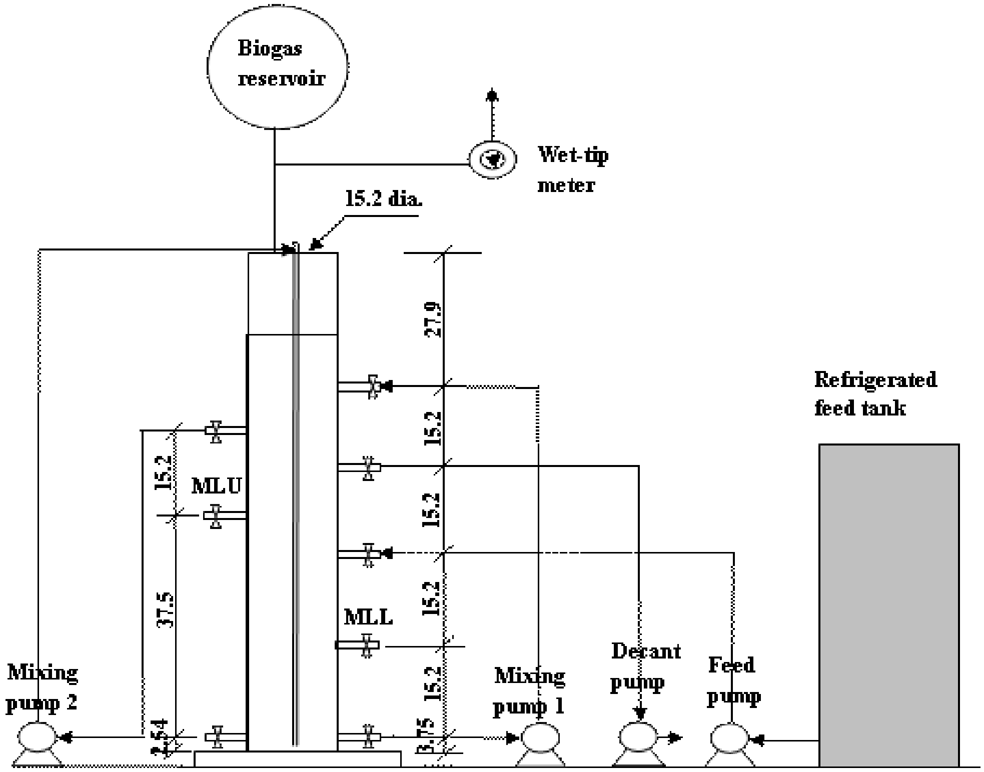

Figure 1. Schematic of the bench scale ASBR (all units are in cm).

The volume of biogas produced was measured using a wet-tip gas meter. The quality of the biogas was determined by daily sampling of the biogas from a rubber septum placed on the outlet gas line ahead of the wet-tip gas meter. Representative samples of approximately 100 mL of the influent were taken out of the feed tank each time a new feed batch was prepared. Representative effluent samples of similar volume were removed from the decant buckets after every cycle. In general, intensive mixing of an ASBR's contents destroys granules, resulting in poor settling and washout of biomass. Therefore, intensive mixing of the entire content of the ASBR was performed only when necessary to obtain representative samples for the determination of mixed liquor solids and mixed liquor suspended solids. This intensive mixing was accomplished using two pumps: a centrifugal pump (labeled mixing pump 1; Little Giantmodel 2E-38N, Granger, Oklahoma City, Okla.), and a peristaltic pump (labeled mixing pump 2; L/S modular pump 77913-20, Cole Parmer, Vernon Hills, Ill.). Two samples drawn from ports MLU and MLL after 15 min of intensive mixing (pumps at full speed) were combined to form a composite sample. Continuous mixing of the reactor's contents to improve mass transfer fluxes during the react phase of a typical cycle was achieved using a peristaltic pump (mixing pump 2), which recirculated the slurry at a rate of 500 mL/min, ensuring a turnover of the entire reactor's contents approximately every 24 min.

EXPERIMENTAL DESIGN AND REACTOR SEEDING

The key operational parameters to optimize and characterize anaerobic reactors for the digestion of a substrate include: organic loading rate, hydraulic retention time (HRT), solids retention time (SRT), and temperature. In our studies, the organic loading rates were set at 400, 600, 800, and 1200 mg COD/day/L of liquid reactor volume. At one cycle per day operation mode, these loading rates corresponded to 12, 8, 6, and 4 days HRT. Typical mesophilic temperatures at which the reactors are expected to operate were also selected: 20°C and 35°C for the non-heated and heated digesters, respectively. Solids retention time (SRT) in these studies was variable because solids were allowed to accumulate throughout the study period. Except for the solids wasted during the decant phase, no deliberate wasting of the solids was attempted because the solids levels remained within an acceptable levels for effective settling. In previous studies, total solids levels between 1% and 2% were found to have optimal settling ability in manure slurries (Moore et al., 1975; Martinez et al., 1995; Ndegwa et al., 2001). Throughout this study, the total accumulating TS fell within this range.

The reactors were seeded with anaerobic sludge from the City of Stillwater, Oklahoma, municipal wastewater treatment facility and allowed to acclimate for a six-month period. During this seeding phase, the organic loading rates into each reactor were approximately 400 mg COD/day/L of liquid reactor volume. Acclimatization was considered complete when the reactors achieved steady state at this organic loading rate. For the purpose of this study, steady state was defined by a sustained biogas output (within ±15% deviation) and a chemical oxygen demand (COD) destruction of at least 70% for six continuous days. Because preliminary tests on sedimentation did not indicate any improvement in solids settling beyond 45 min, the settling phase was set at 45 min during the entire study. Depending on the specific HRT setup, the four phases (feed, react, settle, and decant) were set at between 2 and 8 min, 23 h, 45 min, and between 2 and 8 min, respectively. The feed and decant pumps in each set delivered 500 mL/min. This effectively meant one cycle every 24 h. Approximately 99% of the cycle time was shared between the react and settle phases, while the remaining 1% was spent on the feed and decant phases.

The following parameters were measured for each experimental run: biogas production rate and quality; nutrient (N and P) concentrations in the influents, effluents, and sludge (mixed liquor); solids in the influents, effluents, and sludge; volatile fatty acids (VFAs) concentration in the influents and effluents; COD of the influents and effluents; and pH of the influents and effluents. At each steady-state condition, the parameters were determined for six consecutive days, defining six replicate data points for every measured parameter for the experimental condition under examination.

SWINE WASTE AND LOADING RATES

Swine waste was collected separately as feces and urine from pig-feeding cages from pigs fed a fortified corn-soybean meal. Characteristics of raw manure fed to the bioreactors are shown in table 1. Water was added to this raw manure to simulate swine manure slurries from pit-recharge manure management systems. The raw manure was diluted in a ratio of approximately 1:30 with reverse osmosis (RO) water to produce a feed concentration of approximately 0.3% to 0.4% TS and a COD of approximately 4,800 mg COD/L feed. For the four HRTs investigated in this study (12, 8, 6, and 4 days), the volumetric loading were 1000, 1500, 2000, and 3000 mL/day, respectively, which corresponded to a COD loading rate of 400, 600, 800, and 1200 mg COD/day/L of liquid reactor volume for one cycle per day operation.

LABORATORY ANALYSES

The following parameters were determined using standard laboratory methods (APHA, 1998): total solids (TS), total volatile solids (TVS), total suspended solids (TSS), total volatile suspended solids (TVSS), orthophosphates (ortho-P), total phosphorus (TP), total ammoniacal-nitrogen (TAN), and total Kjeldahl nitrogen (TKN). To determine ortho-P, volatile fatty acids, and TAN, a representative sample was centrifuged at 3200 rpm for 15 min and then filtered using GF/A Whatman filter papers. The ortho-P in the filtrate was determined colorimetrically as the phosphomolybdate complex after reaction with ascorbic acid (APHA, 1998). The TP

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

Parameter	Value[a]
TS (mg/L)	3560 ±297
VS (mg/L)	2752 ±365
pH	7.72 ±0.09
COD (g/L)	4816 ±309
TKN (mg/L)	778 ±52
TAN (mg/L)	330 ±27
TP (mg/L)	74 ±3
Orthophosphates (mg/L)	35 ±7
Volatile fatty acids (mg/L)	639 ±75

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

was determined using the persulfate digestion method, by which all the species of P in a sample were first converted to ortho-P or PO_4^{-3}. The samples were then filtered, and the P content was measured colorimetrically using the ascorbic acid method. Throughout this article, therefore, both ortho-P and TP are reported in terms of PO_4^{-3}. The VFAs in the filtrates were determined using an esterification method. This method is based on esterification of the carboxylic acids present in the sample, followed by colorimetric determination of the esters produced by the ferric hydroxamate reaction. All VFAs are reported as their equivalent mg/L acetic acid (Hach, 1993). The COD was measured using the standard ampule method (Adams, 1990).

To analyze biogas composition, biogas samples were drawn ahead of the wet-tip gas meters using a standard locking sampling glass syringe and immediately transferred and injected into in a gas chromatograph (model 8610 C, SRI Instruments, Torrance, Cal.) fitted with a thermal conductivity detector (TCD) and a helium ionization detector (HID). The column was a 0.53 mm diameter, 3 m long, and packed Heyesep Q (Alltech, Deerfield, Ill.). During the analyses, the oven temperature was held at 20°C for 1 min, ramped at 40°C/min to 150°C, and held at this temperature for another 0.5 min. The detector's temperatures were also set at 150°C. A pH meter (Accumet 1003, Fisher Scientific) equipped with a temperature-compensating probe was used to measure the pH of the influents and effluents samples immediately after each sampling event. Analyses were done immediately after the sampling whenever possible; if not, the samples were frozen for future analyses.

DATA ANALYSES

To determine the respective general trends, statistical regression equations were fitted consecutively until the best fit and the simplest regression equation describing the trend was obtained. Ultimately, the criteria used to select the best fit were the coefficient of determination (R^2) and the simplicity of the regression equation. The other criterion used was adherence of the fitted regression equation to well-established theoretical biodegradation kinetics. The percentage reductions of COD and VFA were calculated based on the influent and effluent concentrations of the respective parameter.

Optimization studies usually involve establishing conditions that utilize the most economical combination of resources or factors to produce the best results. In other words, even if increasing one factor leads to an increased production of the product, the increase may be so marginal that the increased cost does not warranty the extra cost. Mathematically, when the rate of the increase is zero, no more additional input is justifiable. Differential calculus was used to determine where these points occurred in the regression equations by examining their first and second derivatives.

The two statistics used in the comparisons of data in this study were the mean and the standard deviation. Therefore, when mentioned in this article, significant difference implies a difference of more than one standard deviation from the mean in question.

RESULTS AND DISCUSSION

BIOGAS PRODUCTION

The results of the biogas production at various HRTs are shown in figures 2, 3, and 4. An exponential rise in the daily volume of biogas production with a decrease in HRT is shown in figure 2. This increase in gas production is expected, as shorter HRTs result in an increase in the loading rate and hence more supply of degradable substrate. The exponential increase is likely attributable to the more improved contact between the substrate and the microbial population, an observation supported by Monod kinetics. However, the exponential rise is somewhat misleading because it suggests that we could infinitely raise the production of biogas by further shortening of the HRT. The fact that we may not practically continue reducing the HRT is illustrated in figure 3. The specific biogas yield, which is the amount of gas produced per unit of the degraded substrate, shows a decline below an HRT of approximately 6 days. In practice, if we progressively reduced the HRT using higher daily volumetric loading and unloading, a point would be reached where there might be an imbalance of microbial populations (i.e., acid-producing bacteria outnumbering the methane-producing microorganisms), resulting in failure or "souring" of the digester.

For the low-strength swine waste typical of pit-recharge manure management systems (like the one used in this study), optimum biogas yields (fig. 3) were approximately 0.14 mL biogas/mg COD at 5.25 days HRT at a temperature of 20°C, and 0.16 mL biogas/mg COD at 6 days HRT at

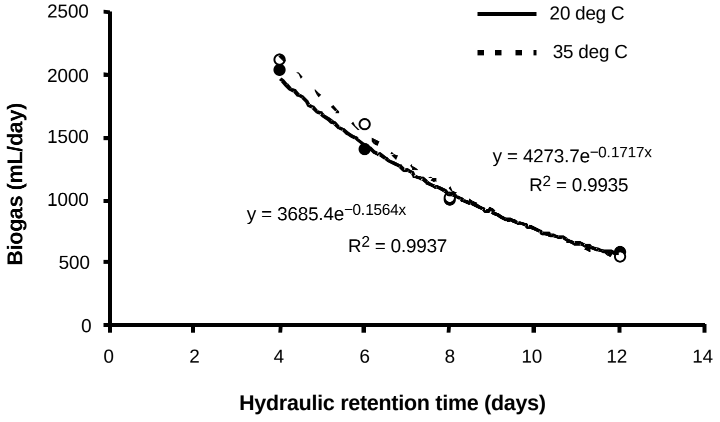

Figure 2. Total daily biogas production with changes in HRT at the two temperature conditions.

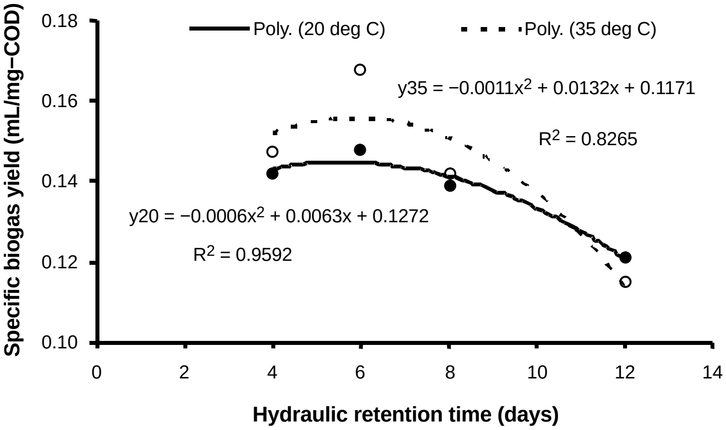

Figure 3. Specific biogas production with changes in HRT at the two temperature conditions.

35°C. Evidently, the higher temperature improved specific biogas yield as expected because of higher microbial metabolic activity and, therefore, higher organic removals. The increase in specific biogas production described in this work is similar to that reported in previous studies (Banik and Dague, 1997; Dague et al., 1998). In contrast, however, although the quality of biogas produced at the two temperatures was high (65% to 70% methane), no significant difference in the biogas quality was observed at the two temperatures (fig. 4). Temperature, therefore, seems to have an effect on biogas yield but not on the composition of the biogas.

Swine Waste Stabilization

Reduction of COD, TSS removal, and VFA reduction as a function of HRT are shown in figures 5, 6, and 7. For the HRT range evaluated in this study, an ASBR operated at the two temperatures reduced COD by at least 80%. The performance of the ASBR in reducing COD seemed better at the lower temperature than at the higher temperature. This observation is contradictory from a theoretical standpoint, as higher degradation is expected with a rise in temperature because of higher microbial metabolic activity. However, other factors must also be considered that could account for this contradiction. In our studies, solids settling during the settling phase was observed to be much better in the lower-temperature digester than in the higher-temperature digester. An analysis of TSS (fig. 6) illustrates this observation. The TSS content of the effluent from the lower-temperature digester was less than that of higher-temperature digester. Conversely, the TSS of the sludge (mixed liquor) in the lower-temperature digester was generally higher than that in the higher-temperature digester, with the former showing a higher accumulation of TSS than the latter. Previous work by Dague and Pidaparti (1992) reported a similar observation, noting that solids retention seems to adjust automatically in parallel with the temperature, i.e., at a lower temperature, improved solids settling in the ASBR increases biomass accumulation, which compensates for the lower temperature, and vice versa. The two regression equations fitted using the COD data of the effluents at the two temperatures (fig. 5) both indicate a maximum reduction occurring within the HRT range investigated in this study. The maximum COD reductions in this study were found to be approximately 90% and 84% at 7.2 and 9.1 days HRT at 20°C and 35°C, respectively. Similar COD reductions have been reported by Dague et al. (1998) for dilute synthetic wastewaters with comparable initial COD levels and at similar operating temperatures but within even lower operating HRTs.

The reductions of VFA at the two temperatures were also significantly large, from a mean of 639 ±75 mg/L to means of 74 ±12 and 85 ±17 mg/L at reactor temperatures of 20°C and 35°C, respectively (fig. 7). Noticeably, the VFA contents

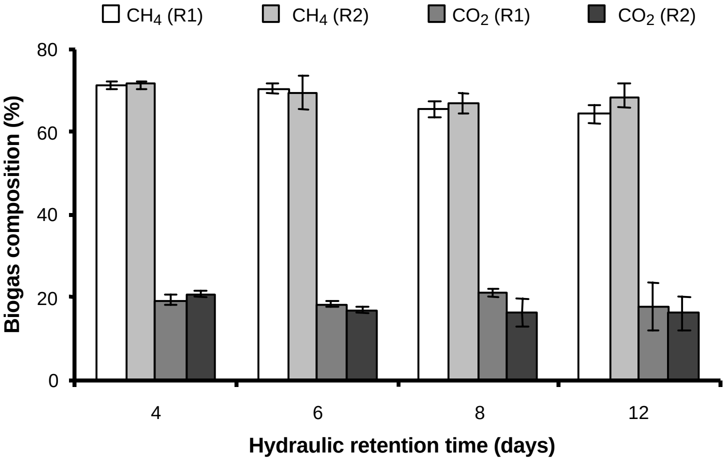

Figure 4. Effect of HRT and reactor temperature on biogas quality.

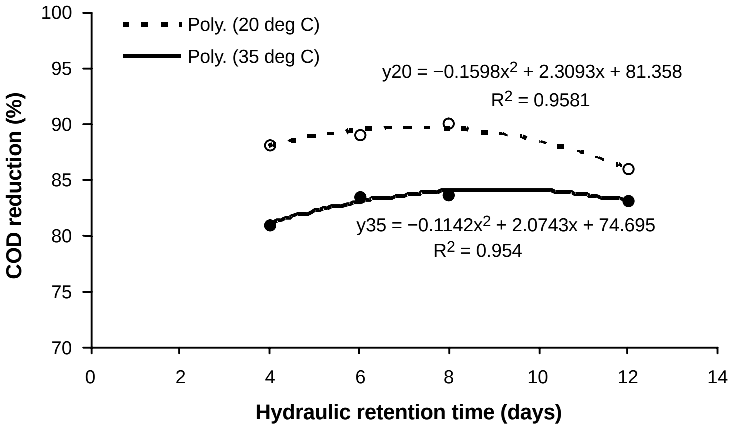

Figure 5. Percentage reduction of COD with change in HRT at the two temperatures conditions.

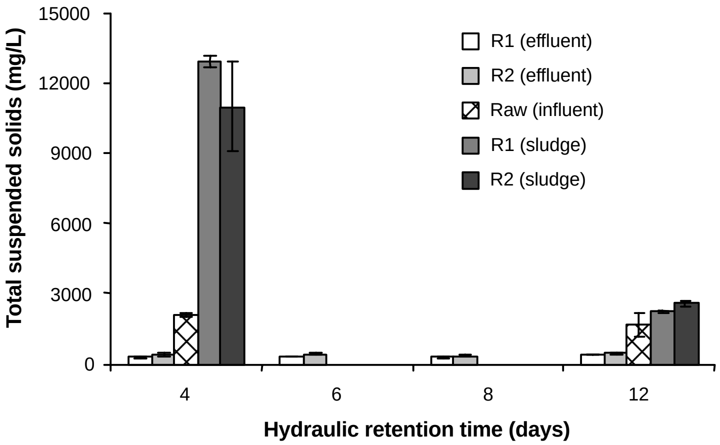

Figure 6. TSS contents in the influent, effluent, and mixed liquor at the two temperatures conditions (R1 = 20˚C, R2 = 35˚C).

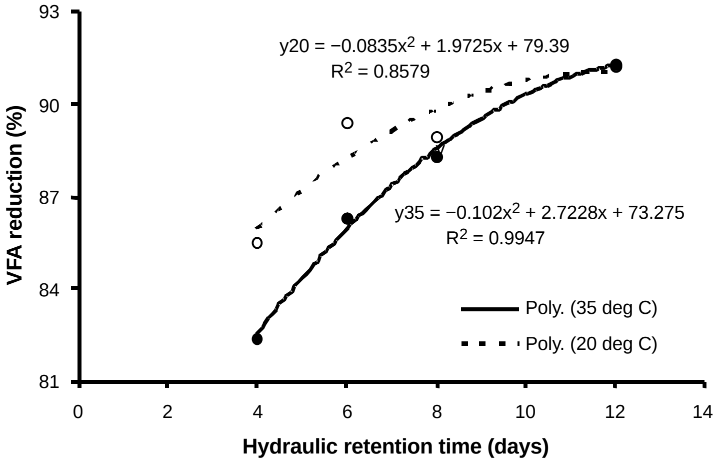

Figure 7. Percentage reduction of VFA in the reactors effluents with change in HRT at the two temperature conditions.

of the effluents from both digesters decreased to below 230 mg/L, the level of VFA below which an odor problem is not expected, and certainly less than the 520 mg/L threshold of unacceptability. In other words, manure slurries stored with VFA concentrations below 230 mg/L are not prone to odor problems, while those containing VFA levels above 520 mg/L could potentially release offensive odors (Sneath et al., 1992). From the regression equations using VFA in the reactors' effluents (fig. 7), the lower-temperature digester is expected to achieve a maximum reduction of VFA of 91% at 11.8 days HRT, while the higher-temperature digester would attain the same maximum at 13.8 days HRT. The VFA results shown in figure 7 again demonstrate why reducing the HRT eventually causes failure of the digesters, i.e., the reduction in the efficiency of the microbial biomass to degrade VFA usually leads to inhibition of the acetogenic and methanogenic populations, a situation that is synonymous with failure of most anaerobic digesters.

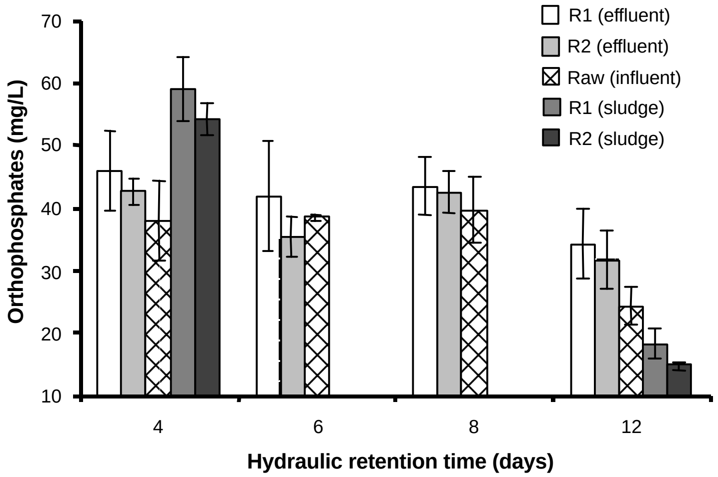

Figure 8. Effect of HRT and reactor temperatures on orthophosphates (R1 = 20˚C, R2 = 35˚C).

NUTRIENT BALANCES

The balances of nutrients (nitrogen and phosphorus) at the different HRTs examined in this study are presented in figures 8 through 12. Although there were some slight, observable differences in the ortho-P content in the influents and effluents from the two digesters, these differences were certainly not statistically significant. As illustrated in figures 8 and 9, these small differences might be caused by variations in the pH of the influent and effluent streams. The pH of swine manure is confirmed to be a major influence in the fractionation of the inorganic phosphorus, with higher pH levels resulting in lower dissolved orthophosphates, and vice versa. Just as expected, the total phosphorus in the effluents remained approximately the same as in the influents (fig. 10). Accumulation of TP was observed in the sludge, which seems like a contradiction of the previous statement. However, given the low volume of the sludge compared to the liquid effluent, the total mass of TP concentrated in the sludge was not significant. In general, there seemed to be no change in phosphorus during the ASBR process, a typical conservation of nutrients (N and P) observed in most other anaerobic digestion processes (Field et al., 1985; Prior et al., 1986; Salminen and Rintala, 1986, 1999).

Nitrogen (both TAN and TKN) seemed to follow the same trend as phosphorus during the ASBR manure treatment process (figs. 11 and 12). The effects of temperature and HRT on the balances of N were not significant in this study. The nitrogen content entering the ASBR seemed to come out unchanged in the effluents, notwithstanding the accumulation observed in the respective sludge or mixed liquor from each digester. The same comments can be made as in the case of phosphorus. Within the nine months these studies were conducted, the total masses of TKN accumulating in the sludge in the digester were only 12% and 9% of the total TKN going into the system in the lower-temperature and higher-temperature digesters, respectively.

In general, the nutrients (both N and P) levels in the effluents remained approximately the same as in the influents. This conservation of the nutrients, the substantial bio-stabilization of the effluents (high reduction in COD or organic strength), the production of effluents free of large clogging particles, and the reduction of the potential for odor generation from the effluents all add value to the effluents in the sense that the effluents are not only still rich in nutrients but also their utilization is enhanced. Storage, holding, or further treatment of such effluents in lagoons will have greatly reduced potential to generate odor. In addition, land

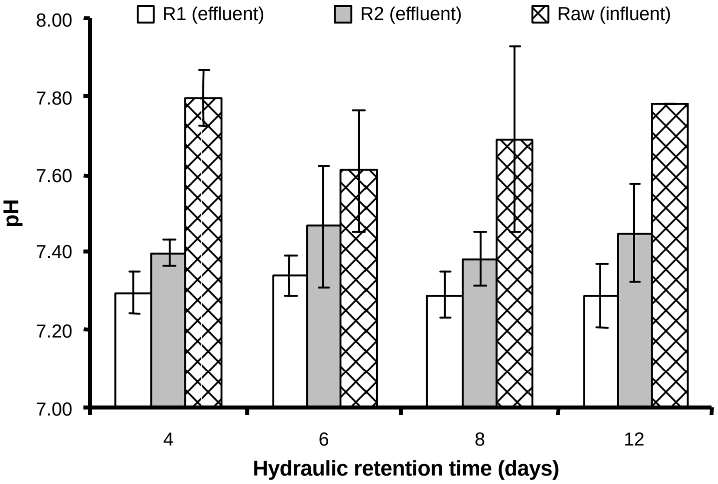

Figure 9. Variation of pH with HRT and temperature during anaerobic digestion of dilute swine slurry (R1 = 20˚C, R2 = 35˚C).

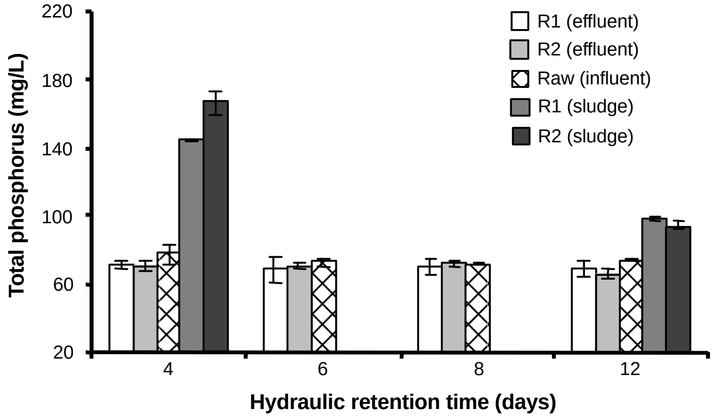

Figure 10. Effect of HRT on total phosphorus during the ASBR process (R1 = 20˚C, R2 = 35˚C).

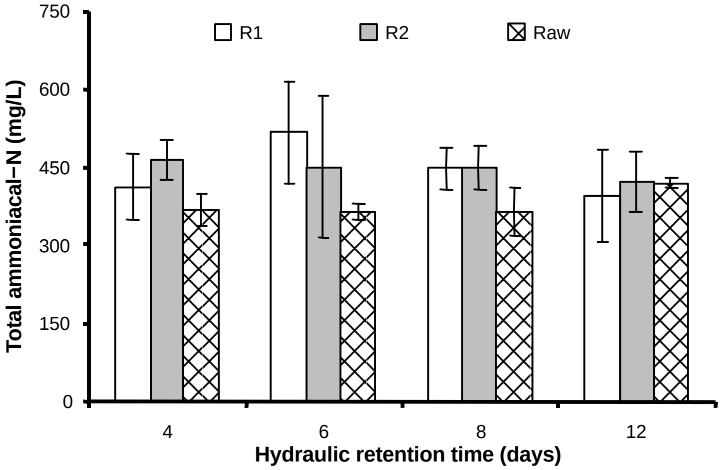

Figure 11. Changes in total ammoniacal-N in the influent and effluent due to the ASBR process at the two temperature conditions (R1 = 20˚C, R2 = 35˚C).

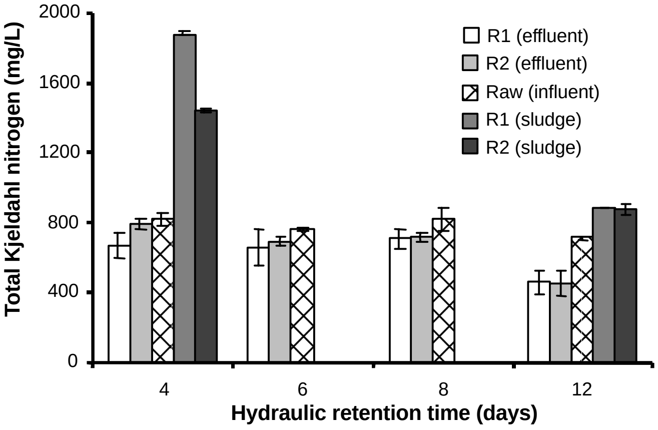

Figure 12. Changes in total Kjeldahl nitrogen during the ASBR process at the two temperature conditions (R1 = 20˚C, R2 = 35˚C).

application using the usual spray guns or other irrigation equipment will not likely create unacceptable odors or clog the irrigation equipment.

SUMMARY AND CONCLUSIONS

Several bioreactor design and operational parameters were examined to optimize the operation of ASBRs treating a dilute swine waste. The conclusions of this study are as follows:

- For the low-strength swine waste typical of pit-recharge swine manure management systems (0.3% to 0.4% TS), optimum biogas yields of approximately 0.14 mg biogas/mg COD at 5.25 days HRT and 0.16 mg biogas/mg COD at 6 days HRT were obtained in the lower (20˚C) and higher (35˚C) temperature digesters, respectively. The higher temperature improved the specific biogas yield, but the qualities of the biogas produced at the two temperatures, although high (65% to 70% methane and 17% to 20% carbon dioxide), were not significantly different between the two temperatures.

- For the range of HRT examined in this study (4 to 12 days), the ASBRs operated at the two temperatures (20°C and 35°C) reduced the COD by at least 80%, but the performance was higher at the lower temperature than at the higher temperature. The maximum COD reductions in this study were approximately 90% and 84% at 7.2 and 9.1 days HRT at 20°C and 35°C, respectively. The results of suspended solids of the effluents revealed improved solids settling in the lower-temperature digester than in the higher-temperature digester during the settling phase. This observation explains the higher reduction of COD at the lower temperature than at the higher temperature as would normally be expected. For better bio-stabilization of the effluents, digester operation at lower temperature seems better. Further and more rigorous test of this result is recommended.
- A relatively large removal of VFAs was achieved, from a mean value of 639 ±75 mg/L in the influent to means of 74 ±12 and 85 ±17 mg/L in effluents at 20°C and 35°C, respectively. The ASBR treatment, therefore, significantly reduced the potential for odor production from the effluents when weighed against the empirical 230 mg VFA/L threshold for potential nuisance odor conditions.
- The nutrients (both N and P) levels in the effluents remained approximately the same as in the influents. This conservation of nutrients, the high bio-stabilization of the effluents (high reduction in COD or organic strength), the production of effluents free of large clogging particles, and the reduction of the potential for odor generation from the effluents all add value to the effluents in the sense that the effluents are still rich in nutrients and are less prone to odor. Storage, holding, or further treatment of these liquid effluents in lagoons will have greatly reduced odor concerns. In addition, land application using the usual spray guns or other irrigation equipment will not likely generate unacceptable odors or clog the irrigation equipment.

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