
Volume 99, issue 6, April 2008
ISSN 0960-8524
ELSEVIER
BIORESOURCE TECHNOLOGY
• biomass • bioenergy • biowastes • conversion technologies •
• biotransformations • food • agriculture •
• production technologies •
Editor-in-Chief: S.C. Ricke
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Bioresource Technology 99 (2008) 1972–1980

BIORESOURCE TECHNOLOGY

Effects of cycle-frequency and temperature on the performance of anaerobic sequencing batch reactors (ASBRs) treating swine waste

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Received 29 September 2005; received in revised form 2 March 2007; accepted 14 March 2007
Available online 29 May 2007

Abstract

Anaerobic digestion of animal waste is a technically viable process for the abatement of adverse environmental impacts caused by animal wastes; however, widespread acceptance has been plagued by poor economics. This situation is dismal if the technology is adapted for treating low strength animal slurries because of large digester-volume requirements and a corresponding high energy input. A possible technology to address these constraints is the anaerobic sequencing batch reactor (ASBR). The ASBR technology has demonstrated remarkable potential to improve the economics of treating dilute animal waste effluents. This paper presents preliminary data on the effects of temperature and frequency-cycle on the operation of an ASBR at a fixed hydraulic retention time (HRT). The results suggest that within the parameter range under consideration, temperature did not affect the biogas yield significantly, however, higher cycle-frequency had a negative effect. The biogas quality (%CH_4) was not significantly affected by temperature nor by the cycle-frequency. The operating principle of the ASBR follows four phases: feed, react, settle, and decant in a cyclic mode. To improve the biogas production in an ASBR, one long react-phase was preferable compared to three shorter react-phases. Treatment of dilute manure slurries in an ASBR at 20 °C was more effective than at 35 °C; similarly more bio-stable effluents were obtained at low cycle-frequency. The treatment of dilute swine slurries in an ASBR at the lower temperature (20 °C) and lower cycle-frequency is, therefore, recommended for the bio-stabilization of dilute swine wastewaters. The results also indicate that significantly higher VFA degradation occurred at 20 °C than at 35 °C, suggesting that the treatment of dilute swine slurries in ASBRs for odor control might be more favorable at the lower than at the higher temperatures examined in this study. Volatile fatty acid reduction at the two reactor temperatures and cycle-frequencies, from a high of 639 ± 75 mg/L to a low of 92 ± 23 mg/L, greatly reduced the odor and the odor-generation potential in post-treatment storage. The nutrients (both N and P) in the waste influent were conserved in the effluents.
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Keywords: Anaerobic digestion; Swine waste; Odor; Bio-stabilization; ASBR

1. Introduction

In recent years the number of animal feeding operations in the United States has decreased considerably; however, the economic strategy is to implement larger and more concentrated feedlots. This trend has led into generation of large volumes of animal manures in small geographical locations; situations that seriously jeopardize environmental quality. Alongside these changes has emerged heightened environmental awareness pertaining to air, water, and soil pollutions from this modern livestock industry. In this respect, regulatory agencies are implementing more stringent regulations to protect the environment from damage caused by these larger operations. To protect and sustain this modern livestock industry, cost-effective technologies to deal with issues of odor nuisances and gaseous contaminants must continue to be developed. Anaerobic

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0960-8524/$ - see front matter Published by Elsevier Ltd.
doi:10.1016/j.biortech.2007.03.056

digestion is a viable technology to reduce pollution arising from livestock wastes while providing a return on the costs of pollution control in the form of biogas and simultaneously maintaining a high nutrient value for the recovered N and P compounds (Parsons, 1986; Taleghani and Kia, 2005; Batzias et al., 2005).

Anaerobic digestion has in particular been used for decades in the recovery of energy in form of biogas from animal and other types of organic waste-streams. However, widespread adoption of anaerobic digestion technology has not occurred in the animal industry essentially because of poor economics. Because of labor constraints, most of these modern livestock industry uses huge volumes of water to collect and convey manure as dilute slurries or liquids. This practice further adds to the economic challenges of anaerobic digestion of these low strength wastes because of the much larger digester volumes and higher energy input requirements compared to treatment of high-strength animal waste.

Most of the conventional anaerobic reactors (for example, the continuously stirred reactors and the plug-flow reactors) have the same solids retention time (SRT) and hydraulic retention time (HRT). However, microbial degradation kinetics of organic substrates suggest high and low degradation rates because during degradation the anaerobic mixed population rapidly consumes the easily biodegradable components (hence, fast rate) before slowly (hence slow rate) consuming the more recalcitrant organic matter (Tremier et al., 2005; Liwarska-Bizukojc et al., 2002; Admon et al., 2001). In the case of animal manure wastes, the easily biodegradable substrate-component is soluble while the recalcitrant component is trapped in the solid fraction. It is thus essential to a have a phased removal of soluble and insoluble compounds because both require different SRT in the reactor. This observation has lead researchers to decouple the SRT from HRT by providing biomass and solids settling and retention while removing the treated liquid in the effluent. This approach provides longer SRTs in the reactor as well as increasing biomass retention ensuring stability of the subsequent react-phases.

There are several anaerobic digesters that today separate HRT and SRT (e.g. upflow anaerobic sludge blanket (UASB), anaerobic contact reactors, anaerobic biofilters, fixed-film reactors, etc.) with varying degrees of treatment success. A more recent version of anaerobic reactors separating SRT from HRT is the anaerobic sequencing batch reactor (ASBR). The ASBR popularity stems largely from (i) elimination of a secondary clarifier tank, (ii) good biomass retention, and (iii) simple operations (Rodriguez 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 stages: feed, react, settle, and decant in a cyclic mode. A sequencing batch reactor, therefore, separates the SRT and HRT in the same reaction chamber so that the solids have a longer retention time while the easily degradable liquid spend a much shorter time in the reactor (Dague et al., 1992; Zhang et al., 1997). The advantage of this design is that the ASBR can treat more substrate volume per unit time compared to conventional reactors thus reducing the volumes of the digesters needed. In addition the high food-to-microorganism (F/M) ratio after feeding ensures high initial substrate degradation rates and more biogas production. At the end of react-phase just before settling, the F/M ratio is much lower implying less biogas production; a factor that greatly improves settling (Dague et al., 1992, 1998; Zhang et al., 1997). These characteristics cause the ASBR technology especially suited for the treatment and recovery of biogas from dilute animal waste 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).

The potential to treat dilute animal slurries has been proven using the ASBR but additional research to optimize the operational parameters is necessary to enhance widespread adoption of the technology. This paper reports preliminary studies on the effect of cycle-frequency and reactor temperatures on the treatment of dilute swine wastes. The effect of these two operational parameters on: (i) biogas production, (ii) biogas quality, (iii) effluent bio-stabilization, (iv) balances of nutrients, and (v) potential of odor reduction in the effluents, were examined in this study.

2. Methods

2.1. The ASBR system design and operation

Two similar bench scale 12 L-capacity ASBR reactors (Fig. 1), built using translucent Plexiglas were used to conduct the studies reported in this paper. The substrate was held in a 20 L-feeds tank stored in a refrigerator at 4 °C to prevent biodegradation. Both reactors were completely automated with respect to feeding, mixing of the contents of the reactors, solid settling, and decanting. These functions were programmed using digital-timers to accomplish the cycle time. A temperature-controller connected to a heating tape wrapped round the reactors and a temperature-sensor positioned at the mid-point of the reactor side was used to maintain desired temperatures in each reactor. The lower and the higher temperatures reactors were maintained at 20 ± 1 °C and 35 ± 1 °C, respectively.

The biogas volume was measured using a wet-tip gas meter. The quality of the biogas was determined by daily sampling from a rubber septa placed on the outlet gas line ahead of the wet-tip gas meter. Representative samples of approximately 100 ml of the influent were removed from the feed tank each time a new feed-batch was prepared. Representative effluent sample volumes were removed from the decant buckets after each cycle. In general, intensive mixing of the ASBRs contents destroys granules resulting in poor settling and wash-out of the biomass. Therefore, intensive mixing of the entire content of the ASBRs were performed only when necessary to obtain representative

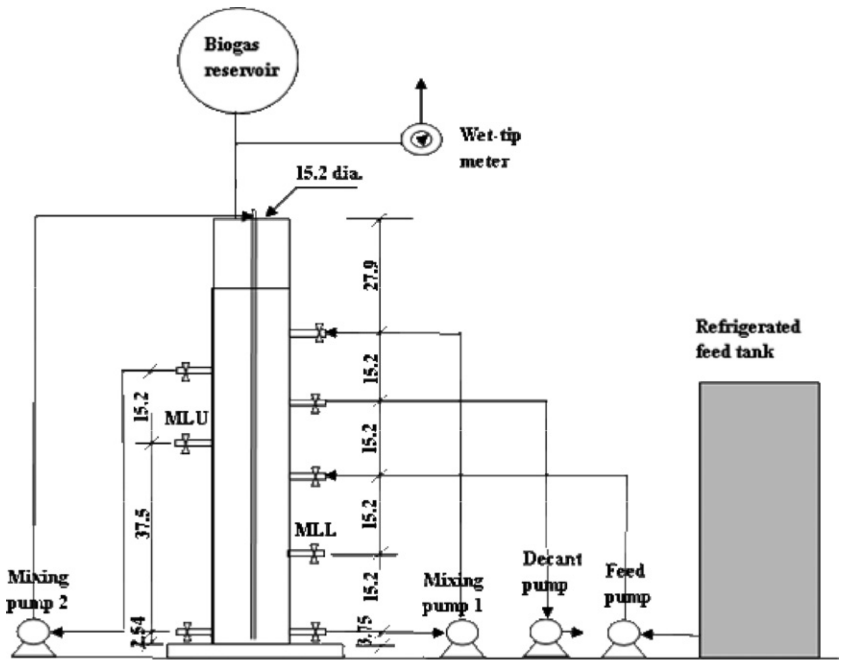

Fig. 1. Schematic of a bench scale ASBR unit (all dimensions in cm).

samples for the determination of mixed liquor solids and mixed liquor suspended solids; usually at the beginning and end of each test condition. This intensive mixing was accomplished using two pumps; a centrifugal pump (labeled as mixing pump 1; Little Giant Model 2E-38N, Granger, Oklahoma City, OK) and a peristaltic pump (labeled as mixing pump 2: L/S modular pump 77913-20, Cole Parmer, www.coleparmer.com). Two samples drawn from ports MLU and MLL after 15 min of intensive-mixing (at full pumps' throttle) were combined to form a composite sample. A continuous mixing of the reactors contents to improve mass transfer fluxes during the react-phase of a typical cycle was achieved using a peristaltic pump (mixing pump 2) that re-circulated the slurry at a rate of 500 ml/min; ensuring a turnover of the entire reactors contents approximately every 24 min. The feed and decant peristaltic pumps in each set delivered and removed 500 ml/min, respectively.

2.2. Experimental design and reaction seeding

The reactors were seeded with anaerobic sludge from the City of Stillwater (OK) Municipal wastewater treatment facility and allowed to acclimate to the feed over approximately 6 months, at the respective reactor-operational temperatures. During this seeding phase, the organic loading rate into each reactor was 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. In this study, steady-state was defined by a sustained biogas output (within ±15% deviation, see Fig. 2) for six continuous days; COD degradations of at least 70% were observed during this period. Since the preliminary test 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. A 1000 ml/day of influent corresponding to the 400 mg COD/day/L was fed after decanting a similar volume of effluent once every day; defining 1 cycle/day. This feeding schedule translated into a HRT of 12 days. The loading rates were then successively adjusted upward to 600, 800, and 1200 mg COD/day/L, which corresponded with HRTs of 8, 6, and 4 days, respectively.

Evaluation of the effect of cycle-frequency or cycles/day (both terminologies are used interchangeably in this paper) was conducted once an HRT of 4 days was attained. At this point, the organic loading rates were maintained at 1200 mg COD/day/L of liquid reactor volume. A 1 cycle/day and a 3 cycles/day operation mode were arbitrary selected for this preliminary evaluation based on practical range of possible operation cycles in a single day. Typical mesophilic-temperatures of 20 °C and 35 °C at which the reactors would be expected to operate were arbitrary selected. 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 solids levels remained within acceptable levels for effective settling. Total solids levels of between 1% and 2% were found to have optimal settle-ability in manure slurries (Moore et al., 1975; Martinez et al., 1995; Ndegwa et al., 2001). Throughout this study the total accumulating TS was within this range.

The following parameters were measured for each experimental run: biogas production rate and quality; nutrients (N and P) concentrations in the sludge (mixed liquor), in

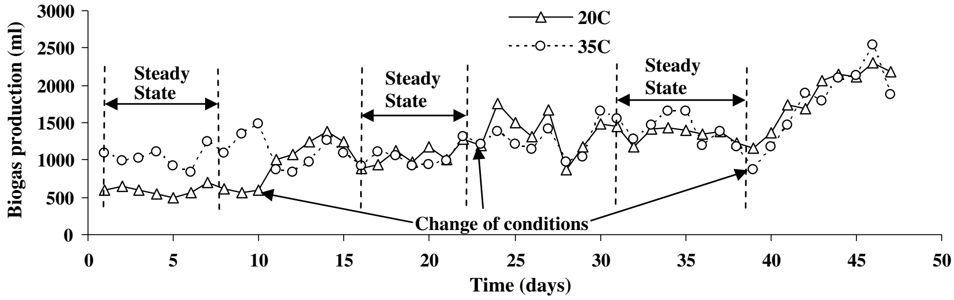

Fig. 2. Typical steady-state conditions based on ±15% biogas production in six consecutive days.

the influents, and effluents; solids in the influents, effluents, and in the sludge; volatile fatty acids (VFAs) concentration in the influents and effluents, chemical oxygen demand (COD) of the influents and effluents, and pH of the influents and effluents. At steady state conditions, these parameters were determined for six consecutive days defining six replicates data points for every measured parameter for the experimental condition under examination.

2.3. Swine waste and loading rates

Swine waste was collected separately as feces and urine from feeding cages from animals fed a fortified corn-soybean meal. Characteristics of raw manure fed to the reactors 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 0.3–0.4% TS and a chemical oxygen demand (COD) of approximately 4800 mg COD/L feed. For the 4-day HRT under which the effect of cycle-frequency was investigated, the volumetric loading was 3000 ml/day, which corresponded to a COD loading rate of 1200 mg COD/day/L of liquid reactor volume. At a 1 cycle/day operational mode, the entire 3000 ml/day was fed and decanted once a day. At a 3 cycles/day operational mode, 3000 ml/day was added and removed in 1000 ml/cycle. At 1 cycle/day, the cycle length was 24 h; implying the effective react-time was 23 h/day after allowing for 45 min settle-time and 15 min of feeding, decanting, and transitions. At 3 cycles/day, the cycle-length was 8 h; implying the effective react-time was 21 h/day after allowing 60 min after each react phase for settling, feeding, decanting, and transitions.

Table 1
Manure characteristics

TS (mg/L)	3560 ± 297[a]
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] "±" refers to one standard deviation from the mean ($n = 6$).

2.4. Laboratory analyses

The following parameters were determined using standard laboratory methods (APHA, 1998): total solids (TS), total volatile solids (TVS), total suspended solids (TSS), and total volatile suspended solids (TVSS), orthophosphates (*ortho*-P), total phosphorus (TP), total ammonia-nitrogen (TAN), and Total Kjeldahl nitrogen (TKN). To determine *ortho*-P, volatile fatty acids, and TAN, a representative sample was centrifuged at 4000*g* for 15 min and then filtered using GF/A Whatman filter papers (Cole-Parmer Instrument Co., Vernon Hills, IL). The *ortho*-P in the filtrate was determined colorimetrically as the phosphomolybdate complex after reaction with ascorbic acid (APHA, 1998). The TP 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 report, therefore, both *ortho*-P and TP are reported in terms of PO_4^{3-}. The VFA 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 Company Inc., 1993). The chemical oxygen demand (COD) was measured using the standard ampule method (Adams, 1990).

To analyze the biogas composition, biogas samples were drawn ahead of the wet tip gas meters using a standard gas lock sampling syringe and immediately injected into in a gas chromatograph (model 8610 C, SRI Instruments, Torrance, CA) configured with a thermal conductivity detector (TCD) and a helium ionization detector (HID). The column was a 0.53 mm diameter, 3 m long packed Heyesep Q, (Alltech, Deerfield, IL). 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 detectors 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 influent and effluent samples immediately after each sampling event. Analyses were conducted immediately after the samplings whenever possible and if not the samples were frozen for future analyses. Before conducting the analyses, frozen samples were allowed to thaw and equilibrate with the room temperature.

2.5. Data analyses

The mean percent reductions in concentrations of COD (Fig. 4a) were calculated based on the differences between influent and effluent mass concentrations. The two statistics used in the data comparisons are the mean and the standard deviation. In all cases, significant difference when mentioned implies a difference of more than one standard deviation from the respective mean value.

3. Results and discussion

3.1. Biogas yield and quality

Within the two temperatures (20 and 35 °C) investigated in this study, temperature demonstrated no significant effect on the biogas yield (Fig. 3a). A plausible explanation is that a large fraction of the soluble substrate was removed at 20 °C but at 35 °C, the insoluble fraction of the waste was not solubilized and hence, the biogas yield did not increase. However, increasing the number of cylces per day from one to three significantly decreased the biogas production rate for the same volume of waste treated, i.e. higher cycle-frequency decreased biogas yield (Fig. 3b). In contrast, it is evident from Fig. 3b that the quality of the biogas produced was not significantly affected either by temperature or by the cycle-frequency.

From these observations, it can be inferred that, for an ASBR operating on a 4 day HRT; when maximizing the biogas production is the goal, one long react-phase is preferable rather than three short react-phases. These observations can be explained using two interrelated events (i) one long react-phase results in a longer effective react-time of 23 h/day for 1 cycle compared to a shorter react-time of 21 h/day using 3 cycles (2 h are gained by decreasing the settle time by three in the one long react-phase), and (ii) a greater gas yield resulting from a more complete degradation of the organic matter in the former compared to the latter operation. A similar study conducted by Siman et al. (2004) using an anaerobic sequencing biofilm batch reactor (ASBBR) showed that a 12 h-cycle was more efficient than an 8 h-cycle for removing organic matter. Siman et al.'s (2004) work, therefore, supports the results from this study assuming the removal of organics translates into biogas production. For shorter HRT than the four days examined in this work, because of the practical implication of removing too much effluent at one time, which may be prone to wasting of vital biomass, the 1 cycle/day may not, nevertheless, be suitable. It is, therefore, recommended that, future studies should also focus on appropriate operation-cycle(s) for shorter HRTs than the 4-day HRT examined in this study.

The methane yield estimated at 0.12 L/g COD observed in this study was much lower than the stoichiometric methane production of 0.35 L/g COD. However, the reduction of the organic strength by between 73% and 88% was significantly high. Similar studies (Hawkins et al., 2001) suggested that the observed COD reduction was caused by settling of organic matter in the sludge. The study by Hawkins et al. (2001) reported the COD of the settled sludge being as high as 10 times that of the influent feed after one month of mass balance and reported zero biogas production at the 0.5-day operational HRT. In this study further reductions of between 25% and 39% in the effluent COD was reported. In contrast to this study, the study reported here observed only a slight increase in the sludge COD in the range of 6600–8700 mg/L compared to a concentration of 4800 mg COD/L in the influent. A mass balance over the two months that these experiment were conducted indicate that, the settled sludge accounted for only 9–12% of total COD into the system, which is in-line with the 73–88% COD reduction observed in the effluent.

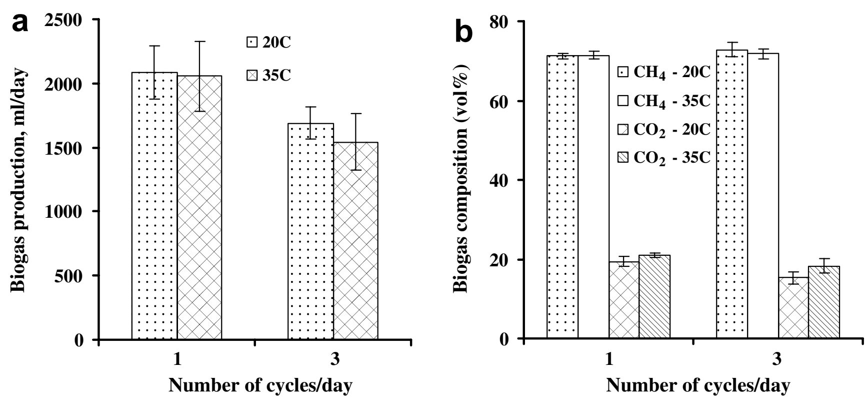

Fig. 3. Effect of cycle-frequency and temperature on the biogas production and quality.

Obviously, the two studies have some fundamental differences that would explain the observed differences; such as short HRT and dairy versus swine wastewater. Further discussion on the wastewater treatment is provided in more details in the next section.

3.2. Waste bio-stabilization

The effects of cycle-frequency and temperature on COD degradation are presented in Fig. 4a. Based on the data from the 2 cycles (1 and 3 cycles/day) and the two reactor-temperatures (20 and 35 °C), both temperature and cycle-frequency significantly affected the COD degradation.

The lower temperature treatment in the ASBR was more effective than the higher temperature for COD removal irrespective of cycle-frequency. In particular, the difference in the COD removed at the lower reaction temperature was less pronounced than at the higher temperature with a change in cycle-frequency, i.e. the change from 1 cycle/day to 3 cycles/day did not significantly compromise the COD removal at the lower temperature compared to the higher temperature. The greater reaction temperature and the same change in operational cycle-frequency resulted in a large difference in the COD removed. These observations are contradictory because the degradation rate would be expected to increase as the temperature increases. The TSS data presented in Fig. 4b offers an explanation to this apparent contradiction. Evidently, solids-settling was more efficient at the lower reaction temperature digester than at the higher temperature digester as indicated by lower TSS content in the effluent from the two temperature conditions examined. Evidence by Dague and Pidaparti (1992) demonstrated that the solid retention appear to adjust automatically in parallel with the temperature i.e. at lower temperatures, improved solid settling increased the biomass accumulation which compensated for the lower temperature and vice versa. In another ASBR study, the researchers observed that while removal of the soluble COD is fairly high and consistent, the total COD levels varied widely (Masse et al., 2003). Changes in the total COD removed was attributed to variations in settling of the solids which depend on operation of the bioreactor.

Likewise, a longer react-time resulting from 1 cycle/day was more effective at removing COD at either temperature than the shorter effective react-time resulting from 3 cycles/day. Supporting data (Siman et al., 2004) showed that an anaerobic sequencing biofilm batch reactor (ASBBR) operating at a 12 h-cycle (2 cycles/day) was more efficient than a 8 h-cycle (3 cycles/day) in removing organic matter. As previously described, the 2 h gain obtained by decreasing the settle time by 3 h probably caused a larger fraction of organic matter to be removed in the react phase. Another plausible explanation to this inconsistency is shown by carefully considering the differences in the settling effectiveness caused by the operational cycle-frequency (Fig. 4b). Clearly, the degree of settling was impaired by operating a larger number of cycles/day at a given HRT and temperature. In addition, the impairment in solid-settling was more severe at the higher compared to the lower temperature. Using the data from this work, the treatment of dilute swine slurries in ASBR is more effective at the lower temperature and at lower cycle-frequency for more effective bio-stabilization of the swine wastewater.

3.3. Odor abatement

The effects of cycle-frequency and temperature on the effluents odor generation potential are presented in Fig. 5. The difference in the degradation of the VFAs is more pronounced at the two different digestion temperatures than at the two different cycle-frequencies examined in this study. Temperature significantly affected the degradation of the VFA with higher degradation of VFAs occurring at lower reactor temperature than at higher reactor temperature. However, this significantly higher removal of VFAs at the lower temperature does not seem to have resulted in significantly higher production of methane. This obvious imbalance may be attributed to less conversion efficiency of VFAs to methane at the lower temperature than at the higher temperature. Physically, higher removal of VFA implies reduced levels of odorous compounds and

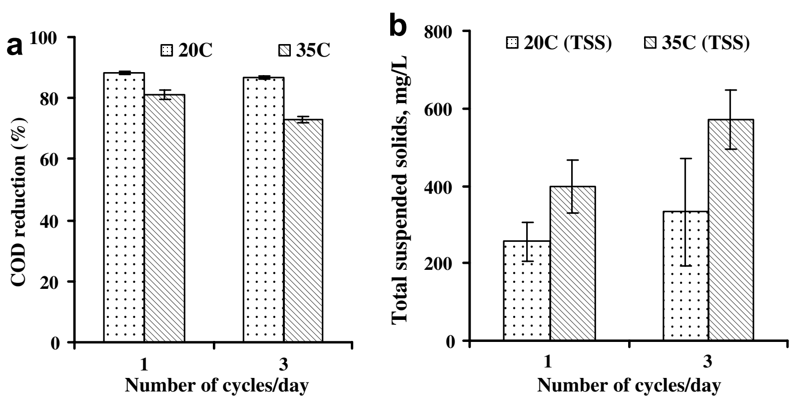

Fig. 4. Effect of cycle-frequency and temperature on bio-stabilization and solids settling.

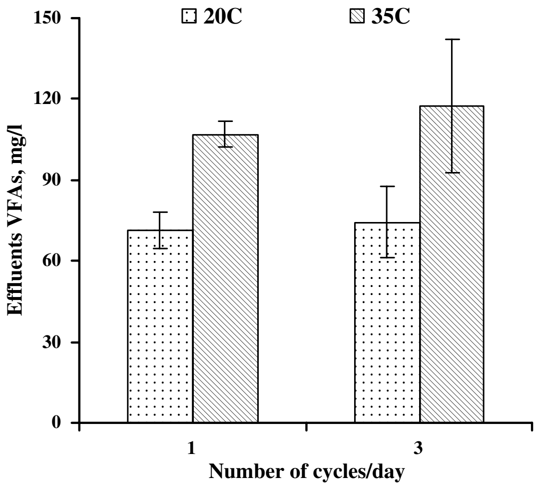

Fig. 5. Effect of cycle-frequency and temperature on effluent odor potential (VFAs are reported as acetate equivalents).

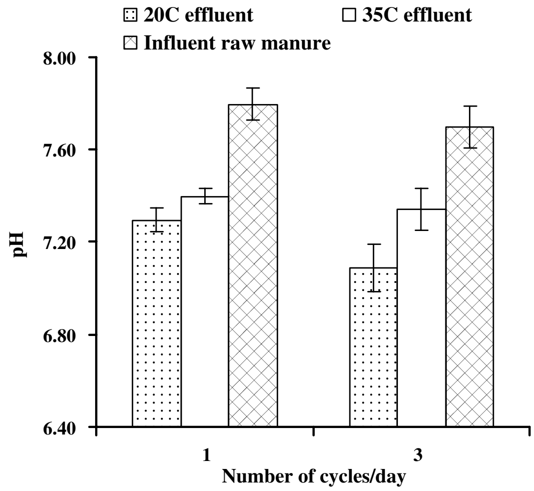

Fig. 7. Effect of the number of cycle-frequency and temperature on effluents pH.

simultaneous reduction of potential of odor generation from the resulting effluents. Significantly higher removals of the VFAs were observed at the lower temperature at either cycle-frequency. However, the cycle-frequency did not significantly affect the removals of VFAs at either of the temperatures examined in this study. It can, therefore, be inferred from the preceding two observations that, treatment of dilute swine slurries in ASBRs for the purpose of odor control is more favorable at the lower temperature than at higher temperature examined in this study. In addition, it can also be concluded that, changing the cycle-frequency from one to three does not significantly affect the odor generation potential of the effluents.

The reductions of volatile fatty acids at the two reactor temperatures and react-cycle times were also significantly high from a mean of 639 ± 75 mg/L to means lower than 92 ± 23 mg/L for all experimental conditions and operational modes examined in this study. Evidently, the VFA contents of the effluents decreased to below 230 mg/L; the level of VFA below which odor problem is not expected, and certainly less than the 520 mg/L threshold of unacceptability. In other words, manure slurries stored and with VFA concentration below 230 mg/L should not cause any problems, while those containing VFA levels above 520 mg/L should release offensive odors (Sneath et al., 1992).

3.4. Nutrient balances

The dynamics of nutrients (N and P) speciation at the two operational cycle-frequencies (1 and 3 cycles/day) and two reactor-temperatures examined in this study are presented in Figs. 6–8. Although there were some observable slight differences in the *ortho*-P content in the influents and effluents from the two bioreactors, these differences were statistically insignificant (see the standard-deviation error-bars in Fig. 6a). As illustrated in Fig. 7, these small differences might have been caused by variations in the pH of the influent and effluent streams. The pH level in swine manures is well-established to be a major influence in the partitioning of the inorganic-P species; with higher pH situations resulting in lower dissolved *ortho*-P and vice versa. The *ortho*-P contents in the influents and effluents display this dependency on pH but incidentally, although the pH-values were statistically different (Fig. 7), their influences on *ortho*-P contents were not significantly different. As expected, the total phosphorus in the effluent remained approximately the same as in the influent

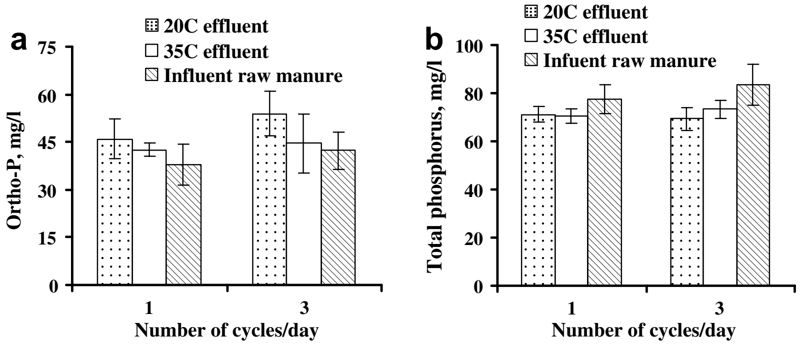

Fig. 6. Dynamics of *ortho*-P and total-P with cycle-frequency and temperature during treatment.

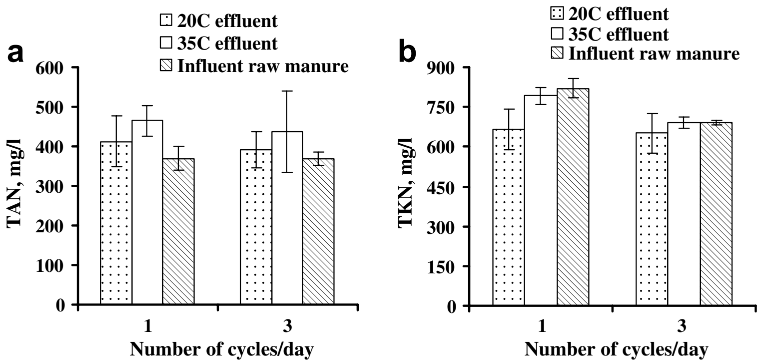

Fig. 8. Effect of cycle-frequency and temperature on TAN and TKN during treatment.

wastewater (Fig. 6b). In general, there appeared to be no change in phosphorus during operation of the ASBR. This observation is validated by previous studies which demonstrated a typical conservation of nutrients (N and P) in most anaerobic digestion processes (Field et al., 1985; Prior et al., 1986; Salminen and Rintala, 1986, 1999).

Nitrogen (both TAN and TKN) also appear to follow the same trend as phosphorus during operation of the ASBR (Fig. 8). Neither changing the ASBR operation from 1 cycle/day to 3 cycles/day or the temperature from 20 to 35 °C significantly affected the TAN levels in the influent and effluent. The effects of temperature and cycle-frequency on the balances of TKN appeared slightly significant during the 1 cycle operation mode and not significant during the 3 cycles/day operational mode. The TKN levels in the effluent from the ASBR operating at 20 °C were significantly less than in the influent. It is possible that the significant difference observed for the TKN levels at 20 °C during the 1 cycle/day operation could be due to experimental errors. In general, the species of nitrogen entering the ASBR did not change significantly.

4. Summary and conclusions

The effects of temperature and cycle-frequency on the operation of an ASBR treating dilute swine waste at a fixed HRT were investigated. Temperature displayed no significant effect on the biogas yield. Higher cycle-frequency decreased the biogas yield. In contrast, the quality of the biogas produced was not significantly affected either by temperature or by the cycle-frequency. Effectively therefore, one long react-phase is more preferable than three short react-phases.

Treatment of low-strength manure slurries was more effective in the removal of COD at the lower temperature treatment than at the higher temperature. Data for the suspended solids in the effluents indicate that the settling effectiveness was impaired by operating more cycles/day and that this impairment was more severe at the higher rather than at the lower operational temperature. Based on these results, treatment of dilute swine slurries in an ASBR at a lower temperature is recommended for the bio-stabilization of dilute swine wastewater.

Temperature significantly affected the VFA degradation with higher VFA degradation occurring at a lower reaction temperature than at a higher temperature. The cycle-frequency had no significant effect on the removal of VFAs. Higher removal of VFAs implies reduced levels of odorous compounds and simultaneous reduction of potential for odor generation from the resulting effluents. These results thus suggest that treatment of dilute swine slurries in ASBRs for odor control may be more favorable at the lower than at the higher temperatures examined in this study. The reductions of VFAs at the two reactor temperatures and cycle-frequencies were significantly high from a mean of 639 ± 75 mg/L to a mean value of 92 ± 23 mg/L and much lower than 230 mg/L; the threshold level of VFA defining "no odor nuisance" situations. Effluents from ASBR operating at the two temperature-conditions and cycle-frequencies examined in this study at a HRT of 4 days should be free of odor and will likely have a greatly reduced potential to generate odor in post-treatment storage or during field application of effluents.

The treatment of low-strength manure slurries in the ASBR system did not change the nutrients (both N and P) levels in the influent or effluent. In summary, nutrients were conserved during the treatment process thus conserving the fertilizer-value of the treated effluents.

Acknowledgements

This research was conducted using funds granted by the Food Research Initiative Program (FRIP) of Oklahoma State University and the Oklahoma Water Resources Research Institute for Water Research (OK). Dr. Scott Carter of the Animal Science Department at Oklahoma State University provided the swine manure used in this study. The authors also appreciate the invaluable contributions of Zath Marable (research assistant) to the success of this project.

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