Swine Wastewater Treatment in Anaerobic Digesters with Floating Medium

J. Cheng, B. Liu

Abstract. A *20–L attached–growth anaerobic system with floating plastic Ballast rings as a medium has been studied for swine wastewater [chemical oxygen demand (COD) = 1,925 to 2,033 mg/L; total suspended solids (TSS) = 1,051 to 1,184 mg/L] treatment at the mesophilic temperature of 35° C. The plastic Ballast rings had a specific surface area of 108* m^2/m^3 *and a density of 0.98* g/cm^3 *and filled the upper half of the anaerobic digesters. The porosity of the filled portion of the digesters was 0.86. Performance of the anaerobic digesters was evaluated for organics decomposition and methane production with two different hydraulic retention times (HRTs): 10 days and 5 days. When HRT was 10 days in the anaerobic digesters, removal of COD, total organic carbon (TOC), TSS, and volatile suspended solids (VSS) was 65%, 55%, 69%, and 70%, respectively. Methane yield was 0.23* m^3 CH_4 *per kg COD removed. As the HRT was reduced to 5 days, the removal of COD, TOC, TSS, and VSS decreased to 55%, 48%, 57%, and 60%, respectively. Methane yield was 0.24* m^3 CH_4*/kg* COD_{rem}*. Higher HRT in the anaerobic digester resulted in higher organics degradation efficiency. However, higher rates of methane production and organics decomposition were obtained in the digester with lower HRT.*

Keywords. *Anaerobic digestion, Attached growth, Mesophilic, Methane, Swine wastewater treatment.*

Swine production has become one of the key agricultural industries in the U.S. in recent years. Over one hundred million hogs were produced in this country in 1998 (USDA, 1999). These hogs generated almost two hundred million tons of solid waste a year. Large amounts of swine waste cause environmental concerns such as greenhouse gas and odor emission and potential nutrient contamination to surface and ground waters. Currently, the anaerobic lagoon is the most widely used technology for swine waste treatment in the southeastern region of the U.S. However, such lagoons are vulnerable to severe weather conditions. In North Carolina, Hurricane Floyd broke several swine waste treatment lagoons in 1999, resulting in waste contamination in receiving watercourses.

Anaerobic digestion has been widely used for the treatment of high–strength industrial wastewaters and municipal waste sludge (Colleran et al., 1998; Dinsdale et al., 1997; Fitzgerald, 1996; Hamdi, 1996; Han and Dague, 1997; Lu et al., 1995; Maloney et al., 1998; Ruiz et al., 1997). It has also been applied to swine waste treatment (Boopathy, 1998; Cseh et al., 1984; Hill and Bolte, 2000; Lo et al., 1994; Montalvo, 1995). The process converts organic waste into biogas (a gas mixture of approximately 70% CH_4 and 30% CO_2) that can be used to generate heat and/or power. Anaerobic digesters have several advantages over traditional lagoons. In open anaerobic lagoons, some odorous organic intermediates of anaerobic degradation (e.g., volatile fatty acids) volatilize through the surface, causing odor emission. In a completely closed anaerobic digester, more thorough digestion can be achieved with much less odorous biodegradation intermediates leaving the digester, which significantly reduces odor emission.

The closed anaerobic digester also greatly reduces ammonia emission to the atmosphere. Biogas produced from the digester can be collected and utilized as an energy source, and methane emission to the atmosphere can be prevented. Methane is one of the greenhouse gases that cause increased atmospheric heat retention because these gases act as a blanket that retains solar heat in the atmosphere, resulting in an increased global surface temperature (El–Fadel and Massoud, 2001; Pipatti et al., 1996). CH_4 is very effective in absorbing infrared radiation, and it has 21 times the warming potential of CO_2 (Calander, 1995). Anaerobic digesters also have advantages over aerobic activated sludge or aeration systems that are commonly used for municipal wastewater treatment. The former produces energy, while the latter consumes energy for aeration. A disadvantage of anaerobic digestion, compared to aeration, is that a longer hydraulic retention time (HRT) is required for the anaerobic process.

To improve the performance of anaerobic digestion, several types of attached–growth anaerobic digesters (AGADs) have been developed, such as the packed–bed anaerobic digester (PBAD) and the fluidized–bed anaerobic digester (FBAD). The common concept for these innovative anaerobic digesters is to use media for anaerobic bacteria to attach and grow on, resulting in a higher bacteria concentration and much longer biomass retention time in the digesters.

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The HRT can be significantly reduced, and a smaller volume digester can be used. AGADs have been successfully used for the treatment of chemical–pharmaceutical wastewater (Nacheva et al., 1997), propellant wastewater (Maloney et al., 1998), and brewery wastewater (Cronin and Lo, 1998). Considerable efforts have been made to investigate AGADs for livestock waste treatment (Bolte et al., 1986; Ranalli et al., 1995; Vartak et al., 1997; Yang et al., 1993). Each attached–growth digester has its advantages and disadvantages. PBADs are simple and easy to build, but they can be easily clogged by solids when treating high–solids wastewater. FBADs have high efficiency in treating wastewater, but they also have high operating costs because energy is required to keep the medium fluidized. Swine wastewater usually contains higher solids than most industrial wastewaters. To apply attached–growth anaerobic digestion to the treatment of swine wastewater, research is required in the following areas: (1) development of AGADs that can handle high–solids swine wastewater without clogging problems, and (2) identification of cost–effective media that can provide high–efficiency wastewater treatment.

Ballast rings are widely used in chemical and petroleum industries as a packing medium for packed–bed reactors. High surface area and porosity make Ballast rings an ideal medium in AGADs for swine wastewater treatment. In this study, floating plastic Ballast rings were tested as a medium in mesophilic AGADs for swine wastewater treatment. The performance of AGADs was studied, and organics decomposition and methane production in the digesters were monitored at two HRTs (10 and 5 days). Successful development of the AGAD system would provide a high–efficiency alternative technology for animal wastewater treatment.

Materials and Methods

Bacteria Attaching Medium

In this study, plastic Ballast rings (Koch–Glitsch, Dallas, Texas) were used as the medium for bacteria to attach in anaerobic digesters. The Ballast ring was selected because of its high surface area and porosity and low density. The characteristics of the plastic Ballast rings are shown in table 1. The density of the Ballast rings is slightly lower than that of water, so they do not sink. As shown in table 1, the Ballast rings have a large surface area on which bacteria can attach and grow. This can result in high concentrations of bacteria in the digesters. The high porosity of Ballast rings reduces interference with the flow in the digester and can diminish solid clogging problems.

Design of the Anaerobic Digester with Floating Medium

Two identical cylindrical Plexiglas anaerobic digesters were designed and built for swine wastewater treatment in this study (fig. 1). The inner diameter (ID) of the digesters was 19 cm. The total height of each digester was 85 cm, making the total volume 24 L. In actual operation, the vertical distance between the effluent outlet and the bottom of the digester was 76 cm, the upper half of which (38 cm) was filled with the medium because the medium density was lower than water. The top 9 cm of the digester (approximately 2.5 L) was a headspace without either medium or mixed liquor. Since the porosity of the medium in the digester was 0.86, the total working volume in the digester was 20 L. A Plexiglas water jacket was installed around the anaerobic digester to control the temperature.

Table 1. Characteristics of the plastic Ballast rings used as bacteria attaching medium in the anaerobic digesters treating swine wastewater.

Size: diameter × height (cm)	1.6 × 1.6
Density (g/cm^3)	0.98
Specific surface area (m^2/m^3)	108
Porosity (%)	86

Operation of the Attached–Growth Anaerobic Digester

Raw swine wastewater was obtained from the swine unit at the Lake Wheeler Road Field Laboratory (LWRFL) of North Carolina State University. The swine unit is a farrow–to–finish operation with 250 sows. A flushing system was used to remove swine manure from the barns. As shown in figure 1, the swine wastewater was stored in a 20–L storage tank in which continuous mixing was provided with a magnetic mixer to keep the solids suspended in the wastewater. To prevent biological activities in the storage tank, the temperature was kept at approximately 4° C with a refrigerating system consisting of a WK 230 chiller (Fisher Scientific, Pittsburgh, Pa.) and a stainless steel coil heat exchanger. The heat exchanger was installed in the storage tank, and low–temperature coolant from the chiller was pumped through it.

The swine wastewater in the storage tank was semi–continuously pumped with a peristaltic pump system (Cole–Parmer, Vernon Hills, Ill.) to each anaerobic digester at a given flow rate (2 L/day for 10–day HRT or 4 L/day for 5–day HRT). The peristaltic pump system consisted of a 6–rpm Masterflex drive, a pump head (Model 7015–20), and a 4.8 mm ID L/S 15 high–performance precision pump tubing. The pump flow rate was precisely calibrated once every month. A ChronTrol timer (Fisher Scientific, Pittsburgh, Pa.) was used to control the on and off of the pump drive. A desired wastewater flow rate to an anaerobic digester was achieved by programming the timer to turn the pump drive on for a certain period of time every hour. No significant solid accumulation was observed in either the storage tank or the

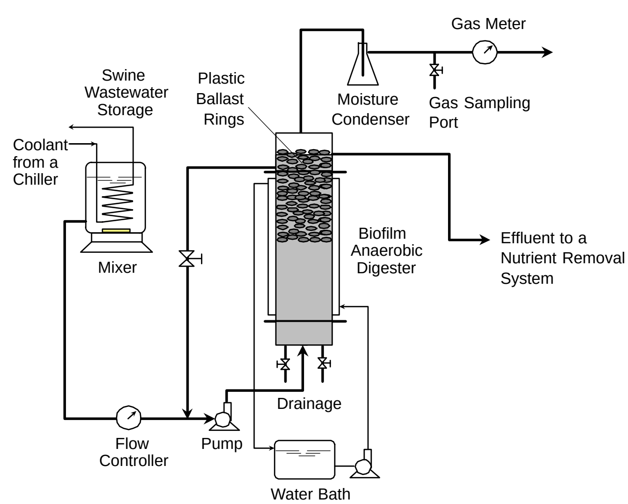

Figure 1. Schematic of an attached–growth anaerobic digestion system with floating medium for swine wastewater treatment.

tubing. The peristaltic pump system worked well without any clogging for the entire operation period of approximately sixteen months and transported both liquid and solids from the storage tank to the anaerobic digesters.

The temperature in each digester was maintained at 35° C by circulating hot water provided by an Isotemp 220 temperature–controlled water bath (Fisher Scientific, Pittsburgh, Pa.) in the water jacket. Continuous hydraulic mixing was provided for the anaerobic digesters with recirculation of mixed liquor (approximately 100 L/h) from the top to the bottom, as shown in figure 1. No sludge was withdrawn during the normal operation. Biogas produced in each anaerobic digester passed through a moisture condenser and was measured for volume with a gas meter (Speece Tip, Vanderbilt, Tenn.). Effluent of each anaerobic digester was further treated in an intermittent aeration nitrification/denitrification system for nitrogen removal (Cheng and Liu, 2001).

To start the anaerobic digesters, each was first purged with pre–purified nitrogen gas for ten minutes. One liter of anaerobic sludge obtained from the bottom of an anaerobic lagoon at LWRFL in which swine wastewater was treated was used as seed culture. The digester was then filled with liquid from the anaerobic lagoon to the working volume of 20 L. Raw swine wastewater from the storage tank was continuously pumped into the anaerobic digester after biogas production was observed. Methane production and effluent quality were monitored in order to determine the performance of the two anaerobic digesters.

Two phases of experimentation were conducted in the anaerobic digesters. In the first phase (9 April to 25 August 1998), the same raw swine wastewater flow rate of 2 L/day (HRT = 10 days) was applied to both digesters. In the second phase (26 August 1998 to 31 July 1999), the wastewater flow rate for digester A was kept at 2 L/day (HRT = 10 days), while the wastewater flow rate for digester B was doubled to 4 L/day (HRT = 5 days). Typical HRTs applied in suspended–growth and attached–growth mesophilic anaerobic digesters are 20 to 30 days and 2 to 5 days, respectively (Malina and Pohland, 1992). In the mesophilic anaerobic digester investigated in this study, approximately 46% of the working volume was filled with the plastic medium on which the predominant bacterial population attached and grew, and 54% of the volume was mixed liquor in which the bacteria were suspended and grew. Therefore, an HRT of 10 days, which was between the typical HRT values for suspended–growth and attached–growth digesters, was tested in the duplicate anaerobic digesters in the first phase of this study. To investigate the effect of a lower HRT on the performance of the anaerobic digester, an HRT of 5 days was tested in digester B and the performance was compared to that of digester A, for which a 10–day HRT was maintained in the second phase of the study.

Chemical Analysis

Biogas samples and liquid samples from the raw swine wastewater and the anaerobic effluents were taken for analysis every week. All chemical analyses were conducted in the Environmental Analysis Laboratory of the Biological and Agricultural Engineering Department at North Carolina State University. Biogas was analyzed for methane content with a Shimadzu 15A gas chromatograph (GC) with a thermal conductivity detector (TCD) (Shimadzu, Atlanta, Ga.). A 3.2 mm ID, 3 m stainless steel column packed with 100/120 Carbasieve SII (Shimadzu, Atlanta, Ga.) was used for the analysis of gas composition. Helium served as the carrier gas.

Liquid samples were analyzed for chemical oxygen demand (COD), total organic carbon (TOC), total Kjeldahl nitrogen (TKN), ammonium nitrogen (NH_4–N), total phosphorus (TP), ortho–phosphate phosphorus (o–PO_4–P), pH, total suspended solids (TSS), and volatile suspended solids (VSS). EPA methods (EPA, 1983) 410.4, 415.1, 351.2, and 350.2 were used for the analyses of COD, TOC, TKN, and NH_4–N, respectively. APHA standard methods (APHA/AWWA/WEF, 1995) 4500–P C, 4500–P F, 4500–H^+, 2540 D, and 2540 E were used for TP, o–PO_4–P, pH, TSS, and VSS analyses, respectively.

Results and Discussion

The floating medium in the anaerobic digesters was used to avoid clogging by solids in the wastewater because the swine wastewater contained relatively high solids. During the entire operation period of 16 months, no clogging problem was observed in either of the digesters. Solid accumulation in the tubing was negligible. A rapid start–up was observed with biogas production within 24 hrs, indicating that the anaerobic culture from the lagoon sludge quickly acclimated to the mesophilic conditions.

In the first phase of this study, an HRT of 10 days and an influent flow rate of 2 L/day had been maintained in both anaerobic digesters to investigate the reproducibility of the performance of the floating medium anaerobic digestion system for a 20–week period (9 April to 25 August 1998). COD and TOC reductions in both digesters during this period are shown in figures 2 and 3, respectively. The TOC data were not collected for the initial five weeks, until 25 May 1998. As shown in the figures, COD and TOC reductions in the two digesters were very close. The COD and TOC concentrations in the effluents of the anaerobic digesters were fairly stable, even though they fluctuated in the influent (COD: 1180 to 2930 mg/L; TOC: 344 to 708 mg/L). The fluctuation of the influent COD and TOC was due to the diversity of the animal sizes in the swine unit where the raw wastewater was obtained. In this swine unit, farrowing and gestating sows and nursery and finishing pigs are raised in separate houses. The characteristics of the wastewaters from the different pigs are different (Barker and Zublena, 1995). The raw wastewater for this study was drawn randomly from the flushed manure from the various swine houses.

TSS, VSS, N, P, and pH were monitored for the influent and effluents of both anaerobic digesters. The average and standard deviation of these parameters, as well as COD and TOC for both anaerobic digesters during the first phase, are listed in table 2. As shown in the table, the performance of swine wastewater treatment in both digesters was similar. Statistical analysis also showed a high fluctuation in organic loading to the anaerobic digesters. The standard deviation/average ratios in the influent were 25% and 22% for COD and TOC concentrations, respectively. The corresponding ratios in the effluents of the anaerobic digesters were only about 12%. This indicates that the attached–growth anaerobic digesters were capable of handling the fluctuation and shocks of the organic loading in the wastewater.

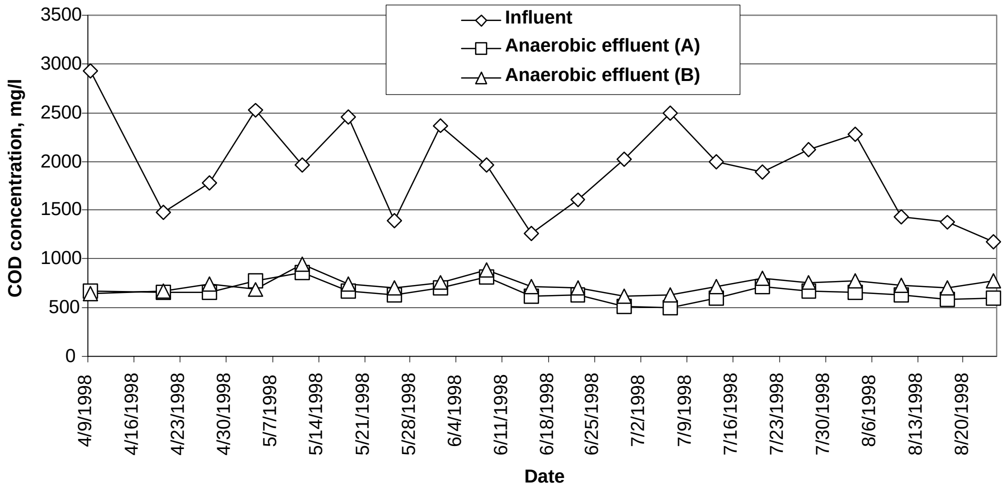

Figure 2. Chemical oxygen demand (COD) in the influent and effluents of the anaerobic digesters with floating medium for swine wastewater treatment under mesophilic conditions (HRT = 10 days; T = 35° C).

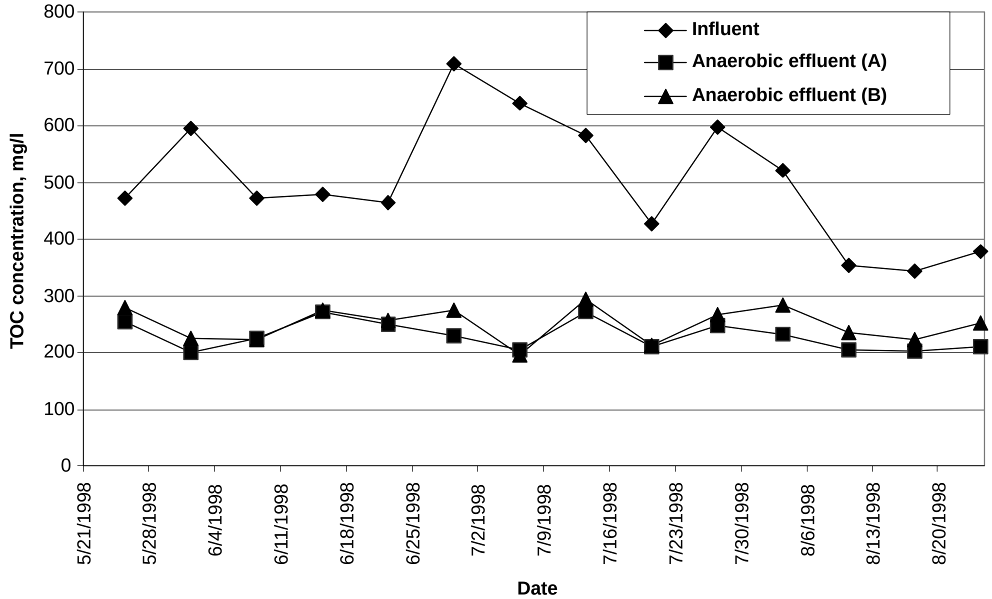

Figure 3. Total organic carbon (TOC) in the influent and effluents of the anaerobic digesters with floating medium for swine wastewater treatment under mesophilic conditions (HRT = 10 days; T = 35° C).

Table 2. Performance of the mesophilic anaerobic digesters with floating medium for swine wastewater treatment during the first phase (16 April to 25 August 1998) with the same HRT of 10 days.

Parameter	Unit	Influent	Effluent		Removal Efficiency (%)	
			Digester A	Digester B	Digester A	Digester B
COD	mg/L	1,925[a] ±487[b]	661 ±87.9	737 ±80.1	66	62
TOC	mg/L	502 ±111	230 ±25.2	249 ±30.7	54	50
TSS	mg/L	1,051 ±331	307 ±60.0	361 ±72.7	71	66
VSS	mg/L	916 ±308	264 ±53.4	304 ±78.2	71	67
TKN	mg/L	317 ±38.2	289 ±29.5	292 ±26.7	8.8	7.9
NH_4–N	mg/L	184 ±25.0	224 ±21.9	223 ±20.3	–22	–21
TP	mg/L	87.2 ±21.3	69.7 ±4.3	68.5 ±4.4	20	21
o–PO_4–P	mg/L	44.0 ±14.4	49.6 ±7.1	47.8 ±7.3	–13	–8.6
pH	—	7.81 ±0.24	7.62 ±0.20	7.59 ±0.22	–	–

[a] Average of 20 observations and the same for the other parameters in the influent and effluents.
[b] Standard deviation of 20 observations and the same for the other parameters in the influent and effluents.

A slight reduction in TKN (7.9% to 8.8%) was observed in the anaerobic digesters, which was probably the result of nitrogen assimilation for the synthesis of bacterial biomass. An increase in NH_4–N in the anaerobic effluents compared to the influent should be the result of conversion of organic nitrogen to ammonium by the bacteria. Total phosphorus was reduced by about 20%, most likely because of metal phosphate precipitation in the anaerobic sludge and bacterial assimilation. Inorganic phosphorus ($o–PO_4–P$) in the effluent increased by about 10%, a result of conversion of organic phosphorus to phosphate by the bacteria. The values of pH in both influent and effluents of the digesters were very close and stable, indicating a strong buffer capacity of the swine wastewater. Average removal of COD, TOC, TSS, and VSS from the swine wastewater in the anaerobic digesters was 64%, 52%, 68%, and 69%, respectively.

Biogas production in both anaerobic digesters during the first phase was similar, and the data are shown in figure 4. Methane content in the biogas was fairly consistent, 70.5 ±4.6% for digester A and 69.4 ±6.2% for digester B (the averages and standard deviations are based on 20 observations throughout the first phase of the experiment). During the first week of the operation, biogas production in both digesters increased, reached a peak value at day 5, and then decreased to a relatively stable level. A high biogas production during start–up of the digesters in the first week was a result of anaerobic biodegradation of the swine wastewater and the organic residues in the lagoon liquid that was used to initiate the digesters. Biogas production in both digesters was fairly stable from 16 April to 25 August 1998. Methane production was calculated with the biogas production and the average methane content. The average methane production and standard deviation for digesters A and B during this period were 27.6 ±8.3 and 28.0 ±8.9 mL per liter of digester working volume per day, respectively. The difference between the two digesters in methane production was within 2.0%. Specific methane productivity or methane yield in digesters A and B was found to be 0.22 and 0.24 m^3 CH_4 per kg COD removed, respectively.

In the second phase of this study (26 August 1998 to 31 July 1999), the effect of HRT on the performance of the anaerobic digestion system for swine wastewater treatment was investigated. The HRT for digester B was reduced to 5 days and the influent flow rate was increased to 4 L/day, while the HRT for digester A remained the same (10 days). The performance data for both digesters during the second phase are listed in table 3. As shown in the table, the organics degradation efficiency was obviously lower in digester B with a 5–day HRT than in digester A with a 10–day HRT. The reduction of COD, TOC, TSS, and VSS was 68%, 62%, 69%, and 73%, respectively, in digester A, but only 55%, 48%, 57%, and 60% in digester B. Vartak et al. (1997) studied the performance of an attached–growth anaerobic system for dairy cattle wastewater treatment with a high HRT of 33 days. They found that COD was reduced by 94% in an anaerobic reactor with a polyester medium at 37°C. These results indicate that higher organics decomposition efficiency has been achieved with a higher HRT in the anaerobic digesters.

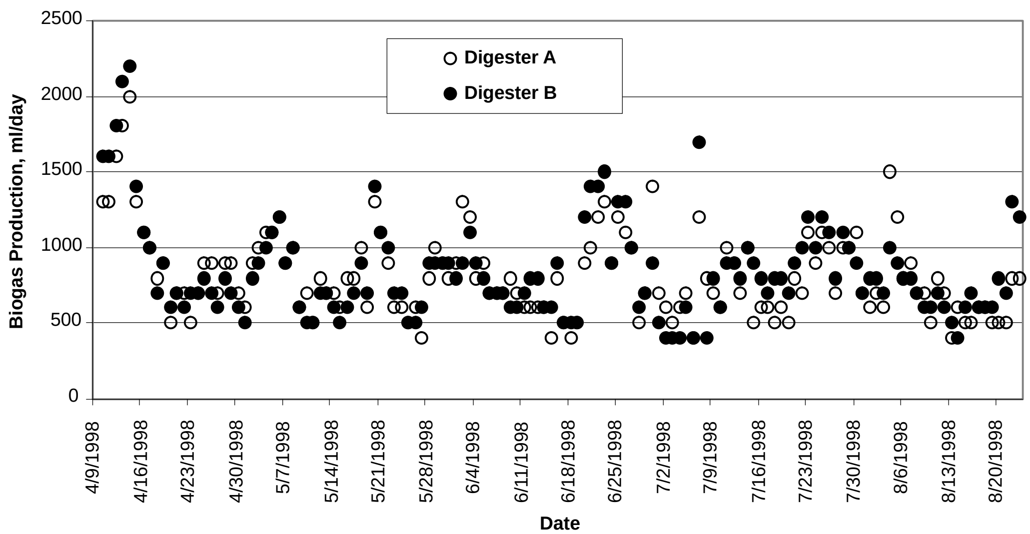

Figure 4. Biogas production in the duplicate floating–medium anaerobic digesters treating swine wastewater under mesophilic conditions (phase I: HRT = 10 days; T = 35° C).

Table 3. Performance of the mesophilic anaerobic digesters with floating medium for swine wastewater treatment during the second phase (26 August 1998 to 31 July 1999) with different HRTs (10 days for digester A and 5 days for digester B).

			Effluent		Removal Efficiency, %	
Parameter	Unit	Influent	Digester A	Digester B	Digester A	Digester B
COD	mg/L	2,033[a] ±505[b]	660 ±154	910 ±187	68	55
TOC	mg/L	653 ±123	245 ±65.8	339 ±79.7	62	48
TSS	mg/L	1,184 ±390	364 ±65.5	511 ±85.5	69	57
VSS	mg/L	1,099 ±351	302 ±97.1	435 ±117	73	60
TKN	mg/L	324 ±50.8	285 ±46.4	295 ±53.2	12	9.0
NH_4–N	mg/L	183 ±44.5	221 ±42.0	213 ±46.4	–21	–16
TP	mg/L	87.0 ±20.1	67.0 ±12.2	65.0 ±11.6	23	25
$o–PO_4–P$	mg/L	48.1 ±14.7	49.2 ±13.6	50.3 ±12.7	–2.3	–4.6
pH	—	7.55 ±0.22	7.34 ±0.27	7.34 ±0.27	–	–

[a] Average of 45 observations and the same for the other parameters in the influent and effluents.
[b] Standard deviation of 45 observations and the same for the other parameters in the influent and effluents.

Biogas production in the anaerobic digesters during the second phase is shown in figure 5. The averages and standard deviations in digesters A and B were 923 ±281 and 1,576 ±447 mL/day, respectively. The methane content in the biogas was 69.3 ±4.6% for digester A and 69.1 ±7.1% for digester B. With these data, methane production was calculated and was determined to be 32.0 ±9.7 and 54.4 ±15.4 mL per liter of digester working volume per day in digesters A and B, respectively. Methane production was obviously higher in digester B than in digester A. This is because the organic (COD and TOC) loading in digester B was twice of that in digester A, and a larger amount of organic compounds were degraded in digester B. However, a lower degradation efficiency (percentages of COD and TOC removal) was observed in digester B (table 3).

A slightly higher methane production was observed during the second phase in digester A (32.0 mL L^{-1} day^{-1}) than in the first phase (27.6 mL L^{-1} day^{-1}). In the second phase, the average organic loading to the digester was significantly higher, 2,033 mg COD/L and 653 mg TOC/L compared to 1,925 mg COD/L and 502 mg TOC/L in the first phase. The COD and TOC removal efficiency increased by 2% and 8%, respectively (tables 2 and 3). This phenomenon was most likely due to the maturation of the bacterial biofilm development on the plastic medium, which normally would take more than three times the HRT, or 30 days in this case. The well–developed bacterial biofilm in the second phase of the study resulted in a higher bacteria concentration in the digester and therefore higher organics degradation capacity. The specific methane productivity in this phase was 0.23 m^3 CH_4/kg COD_{rem} in digester A and 0.24 m^3 CH_4/kg COD_{rem} in digester B, which were almost the same as in the first phase. Ranalli et al. (1995) reported that a specific methane productivity of 0.2 m^3 CH_4/kg COD_{rem} was achieved in an anaerobic expanded–bed laboratory digester treating swine slurries with a 5–day HRT. Hill and Bolte (2000) found that specific methane productivity in a conventional anaerobic fermenter treating liquid swine waste with 5–day HRT was 0.27 m^3 CH_4/kg COD_{rem}. Our observation was quite close to these previous studies.

SUMMARY

An attached–growth anaerobic digester with floating plastic Ballast rings as the medium has been successfully developed for swine wastewater treatment. Clogging problems can be avoided by using a high–porosity, low–density floating plastic medium. At a 10–day HRT, COD, TOC, TSS, and VSS in the swine wastewater were reduced in the anaerobic digester by 65%, 55%, 69%, and 70% (average of the data from digesters A and B in phase I and digester A in phase II), respectively. The corresponding methane production was 29.2 mL L^{-1} day^{-1}, and specific methane productivity was 0.23 m^3 CH_4/kg COD_{rem}. It was found that a higher HRT in the digester resulted in a higher organics removal efficiency. The removal of COD, TOC, TSS, and VSS decreased to 55%, 48%, 57%, and 60%, respectively, when the HRT in the anaerobic digester was reduced to 5 days. However, higher rates of organics degradation and methane production were achieved in the attached–growth anaerobic digester at 5–day HRT.

The floating–medium anaerobic digester is a promising system for swine wastewater treatment. Hydraulic retention time is an important parameter to be determined in real application, depending on the goal of the wastewater treatment. A higher HRT would be favored when the goal of the wastewater treatment is to achieve a high organics removal efficiency and low level of organics in the effluent. A lower HRT can be applied when high methane production and high organics destruction per unit volume of the digester are desired. In such a case, a polishing system following the anaerobic digester is usually necessary for further treatment.

When an anaerobic lagoon is used for swine wastewater treatment and temporary storage, it should have a minimal total capacity for appropriate waste treatment, additional storage for sludge accumulation, temporary storage for wastewater inputs and rainfalls, surface storage for a 25–year 24–hour rainfall event, and a freeboard (*ASAE Standards*, 1993). The attached–growth anaerobic digester tested in this study has a great potential to replace the waste treatment capacity of an anaerobic lagoon, greatly reducing the volume, odor emission, and methane emission of the lagoon.

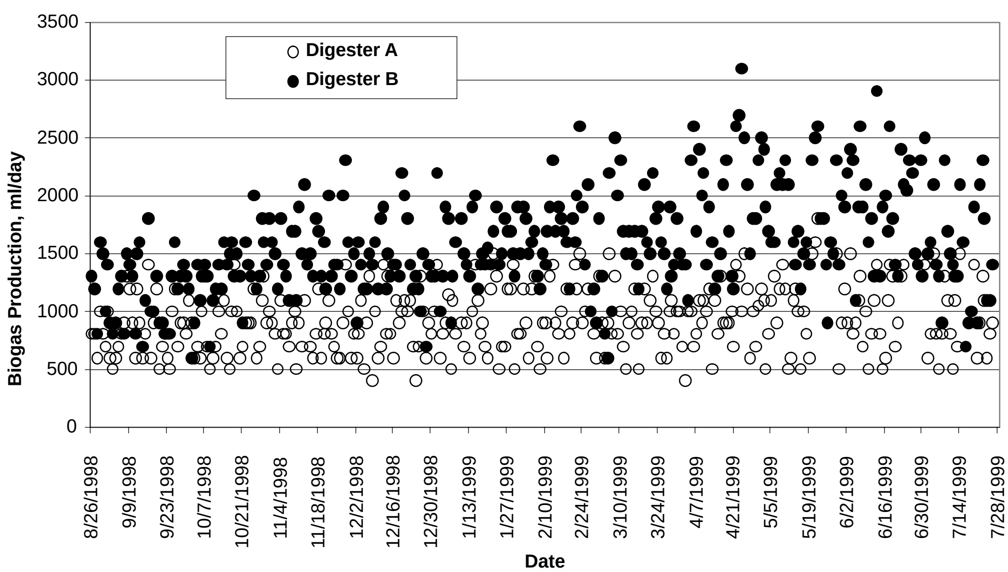

Figure 5. Biogas production in the floating–medium anaerobic digesters treating swine wastewater under mesophilic conditions (phase II: HRT = 10 days for digester A and 5 days for digester B; T = 35°C).

The effluent from the digester can be used for cropland irrigation or go through an advanced nitrification/denitrification system for nitrogen removal, as mentioned earlier in this article. In the latter case, ammonia emission from the swine waste management system can be substantially diminished. Biogas produced in the anaerobic digester can be used for energy (electricity and/or heat) generation, which would offset the cost of the digester installation. Detailed economic analysis of the attached–growth anaerobic digestion system needs to be conducted on a pilot– or full–scale system.

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