Potential for the psychrophilic anaerobic treatment of swine manure using a sequencing batch reactor

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[1] Dairy and Swine Research and Development Centre, Agriculture and Agri Food Canada, Lennoxville, QC, Canada, J1M 1Z3; [2] Centre for Food and Animal Research, Research Branch, Agriculture and Agri-Food Canada, Ottawa, ON, Canada K1A 0C6; and [3] Department of Civil Engineering, Ottawa University, Ottawa, Ontario, Canada, K1N 6N5. *Received 22 September 1995; accepted 1 November 1996.*

Massé, D.I., R.L. Droste, Kennedy, K.J., Patni, N.K. and Munroe, J.A. 1997. **Potential for the psychrophilic anaerobic treatment of swine manure using a sequencing batch reactor**. Can. Agric. Eng. 39:025-034. The feasibility of psychrophilic anaerobic digestion (PAD) in intermittently fed sequencing batch reactors (SBR) was investigated during the start-up run of an ongoing laboratory study. The start-up run results indicated that PAD in SBRs was efficient in stabilizing and deodorizing swine manure slurry. The digester effluents had little odour when compared to the raw manure. Total chemical oxygen demand (COD) was reduced by 58 to 73% and soluble COD (SCOD) by 85 to 96%. Methane production varied from 0.30 to 0.66 L CH4/g volatile solids added and methane concentration in the biogas ranged from 50 to 80%. The biogas production rate continued to increase even when concentrations of acetic acid and ammonia nitrogen were as high as 5500 mg/L and 3700 mg/L, respectively. Keywords: anaerobic digestion, swine manure, biogas, manure treatment, psychrophilic process, anaerobic treatment.

Cet article présente les résultats préliminaires du projet d'étude sur la digestion anaérobie en condition psychrophile dans un bio-réacteur à opération séquentielle. Les résultats expérimentaux ont démontré que cette nouvelle technologie désodorise et stabilise le lisier de porc. Le lisier traité est presque inodore comparativement au lisier de porc brut. La demande chimique en oxygène totale a été réduite de 58 à 73%. La demande en oxygène chimique soluble à subit une forte diminution variant de 85 à 96%. La production de méthane était de 0.30 à 0.66 litre de CH_4 par gramme de solides volatiles alimentés aux bio-réacteurs. La concentration du méthane dans le biogaz variait entre 50 et 80%. Ce procédé est très stable, il n'est pas affecté par des concentrations élevées d'acide acétique (5500 mg/l) et ammoniac (3700 mg/l).

INTRODUCTION

Animal manures have produced a growing public concern in Canada and the U.S.A. because of their potential to produce strong odours, encourage fly breeding, introduce weed problems, and pollute air, soil and water. The Canadian Agricultural Services Coordination Committee (CASCC 1991) and Canadian Agricultural Research Council (CARC 1991) recommended further research that would allow farmers to adopt sustainable and environmentally sound agricultural practices where animal manure is integrated into the overall production system. A National Workshop on Land Application of Animal Manure in Canada, recommended that processes be developed to stabilize, deodorize, and add value to animal manure (Leger et al. 1991).

At the present time there is no economical, stable, and easy-to-operate process to stabilize, deodorize, and add value to, or recover energy from, animal liquid manure. Psychrophilic anaerobic digestion (PAD) at temperatures ranging between 5 and 25°C holds promise for success under Canada's cool climatic conditions compared to mesophilic and thermophilic anaerobic processes previously studied. The feasibility of using PAD at 20°C in intermittently fed sequencing batch reactors (SBRs) was examined as a possible treatment to: a) reduce the pollution potential; b) recover energy; and c) reduce odours of swine manure slurry on both small and large farm operations.

LITERATURE REVIEW

Feasibility of psychrophilic anaerobic digestion

Massé (1995) carried out an extensive literature search on PAD. A limited number of studies using municipal wastewater and animal manures (Balsari and Bozza 1988; Chandler et al. 1983; Cullimore et al. 1985; Kroeker et al. 1979; Lo and Liao 1986; Maly and Fadrus 1971; O'Rourke 1968; Sutter and Wellinger 1987; Wellinger and Kaufmann 1982; Zeeman et al. 1988) have demonstrated that PAD has the potential to be used successfully as a low cost process to produce methane from animal manure; but there was a large variation in PAD process performance for unexplained reasons. The energy or fibre content of the diet of the animals and the presence of antibiotics or food additives were not indicated. Also, several reports did not provide information on the age of the manure or its characteristics. Most of the studies concentrated on biogas production while little consideration was given to odour reduction, waste stabilization, or increase in availability of plant nutrients. Additional research is therefore necessary to evaluate precisely the feasibility of PAD in SBRs.

Description of SBR system

An SBR is a simple operating system (Fig. 1). It consists of a tank where the following five consecutive steps take place: 1) fill; 2) react; 3) settle; 4) draw; and 5) idle. During the fill period the organic waste is loaded into the SBR. When the SBR is full, the react period starts and its length should be

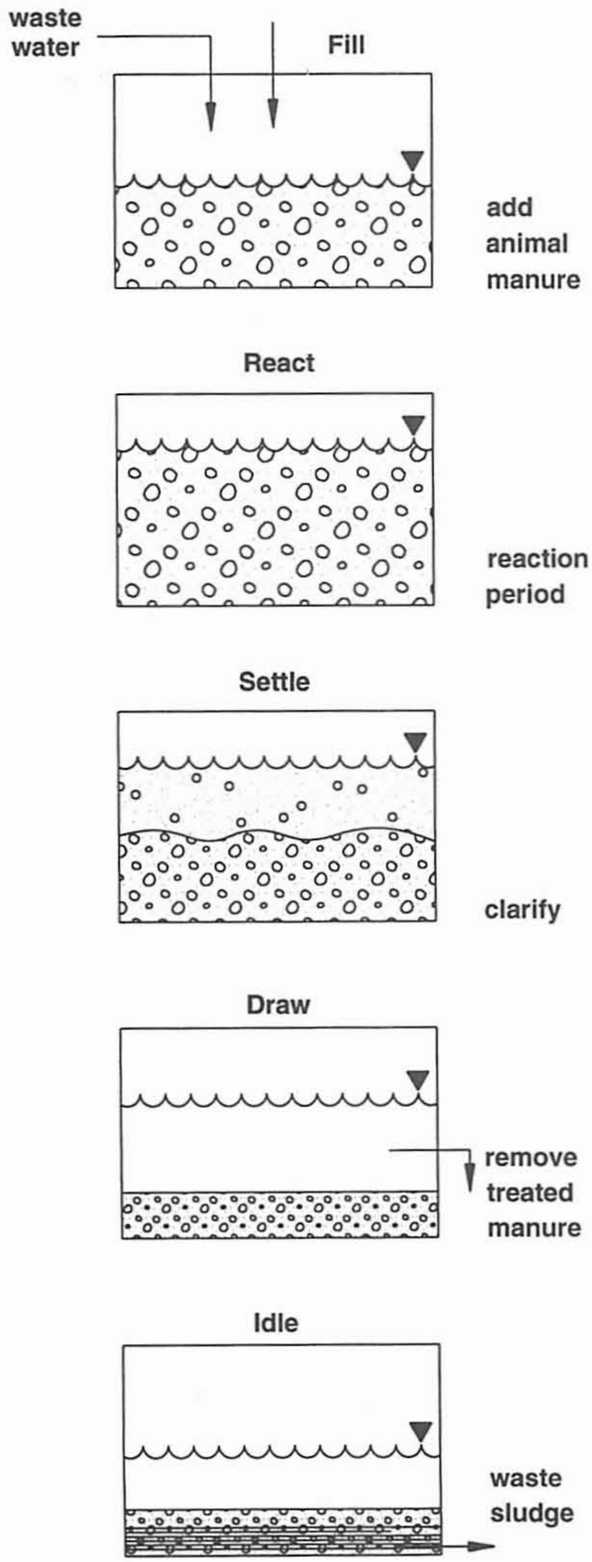

Fig. 1. Typical operation for a SBR during a complete cycle (Metcalf and Eddy 1991).

sufficient to meet the treatment objectives. During the settle period no mixing is provided and quiescent settling conditions prevail to allow treated liquid to be separated from the solids and to retain bacteria in the system. During the draw period the treated liquid is removed and finally the idle period offers the flexibility of coordinating simultaneous operation of two or more SBRs.

Potential benefits of an SBR to carry out PAD of animal manures

The microbial activities and ecosystem of anaerobic digestion are affected by digester design as well as by environmental and operational conditions (Harper and Suidan 1991). The SBR is highly suitable for treatment of animal manure at ambient temperatures because it offers optimum conditions to retain a high concentration of slow growing microorganisms in the tank. Dague et al. (1992) indicated that with an anaerobic SBR the food to microorganism (F/M) ratio is high after the filling period and low just prior to the settling period. These operating conditions resulted in efficient bioflocculation and solids separation. Dague et al. (1992) also indicated that with an SBR the partial pressure of CO_2 is maintained in the reactor during the settling period. As a result, no significant quantity of CO_2 is transferred to the head space. This reduces suspension or resuspension of particulates in the supernatant that can occur when CO_2 is transferred from the liquid to the gas phase. The long biomass retention time in the SBR may allow PAD to adapt to environmental changes such as temperature variations, changes in organic loading rate, and presence of inhibitory elements.

Another very important feature of an SBR is that it may not require continuous feeding. As a result, PAD in an SBR should not interfere with regular farm operations as previous systems did. It can be loaded during normal manure removal operations and the farmer will not have to deal with daily digester effluent. The SBR effluent will need to be handled once every one or two months, depending on operating conditions. Because intermittent feeding will make use of existing manure handling equipment at the farm and should not disrupt regular farm operations, the SBR has the potential to successfully treat animal manure on small and large operations.

The main disadvantage of an SBR is that its biogas-use strategy is more difficult to plan because the biogas production is not uniform during the fill and react periods. Other disadvantages are that no control strategies and experimental data are available for PAD of animal manure in an SBR.

EXPERIMENTAL PROCEDURE

Experiments were carried out in laboratory scale digesters located in a temperature-controlled room maintained at 20oC.

Experimental design

To apply results to the farm, laboratory tests should closely simulate the actual farm operations. On a typical farm, manure is generally removed from the barn once to three times a week. Therefore, the SBRs were intermittently fed once to three times per week. The fill period was limited to a month to limit the volume of the SBR. The react period was selected to produce almost odourless effluent with reduced pollution potential and increased fertilizer value. For PAD in an SBR to be cost effective, it is important that the operational cost is kept low. The operation should occur at ambient temperatures and mechanical mixing should be minimized.

For the start-up run, effects of inoculum type and loading rate on the process were investigated. Fill and react period lengths were kept constant and no mixing was provided to the SBRs. Operating conditions for the start-up run are given in Table I. Four pairs of bioreactors were used in this study. Each pair of bioreactors investigated a different operating condition. Therefore the experimental data represent the average response of two bioreactors.

Loading rates in Table I are calculated according to:

$$L = \frac{V_f C_f}{V_i t_f} \tag{1}$$

where:

L = loading rate (g COD•L^{-1}•d^{-1}),
V_f = volume of feed (L),
C_f = concentration of chemical oxygen demand (COD) in the feed (mg/L),
V_i = volume of sludge in the reactor at the beginning of the cycle (L), and
t_f = duration of the fill period (d).

Experimental equipment

The bench scale SBRs and feeding system used in this study are illustrated in Fig. 2. Eight 25-L nalgene bottles were used in the startup runs. Wet tip gas meters were used to measure biogas production.

Swine manure slurry collection and storage

Manure slurry that was up to 4 days old was obtained from gutters under a partially slatted floor in a growing-finishing barn at a commercial swine operation. It was screened to remove particles larger than 3.5 mm as these large particles tend to create operational problems with small scale laboratory digesters (eg. plugging of influent line). The raw manure was mixed to reduce experimental variation and feed samples were prepared and stored in a freezer at -15°C to prevent biological activity. Manure feed samples were warmed to the digester operating temperature (20°C) prior to feeding.

Start-up of the SBR

All eight digesters were initially started using 7.5 L of anaerobic granular sludge obtained from the Agropur Co-Operative anaerobic wastewater treatment plant at Notre-Dame du Bon Conseil, QC. Digesters 3, 4, 7, and 8 each received a mixture of sludge (5.9 L of Agropur Sludge and 1.6 L of anaerobic non-granulated sludge obtained from the Robert O. Pickard Environmental Centre, Ottawa, ON). The Agropur sludge substrate consisted mainly of fats and proteins. The anaerobic municipal sludge substrate came from both primary and secondary clarifiers. Municipal sludge that is already acclimatized to compounds such as cellulose, hemicellulose, and lignin should increase treatment efficiency.

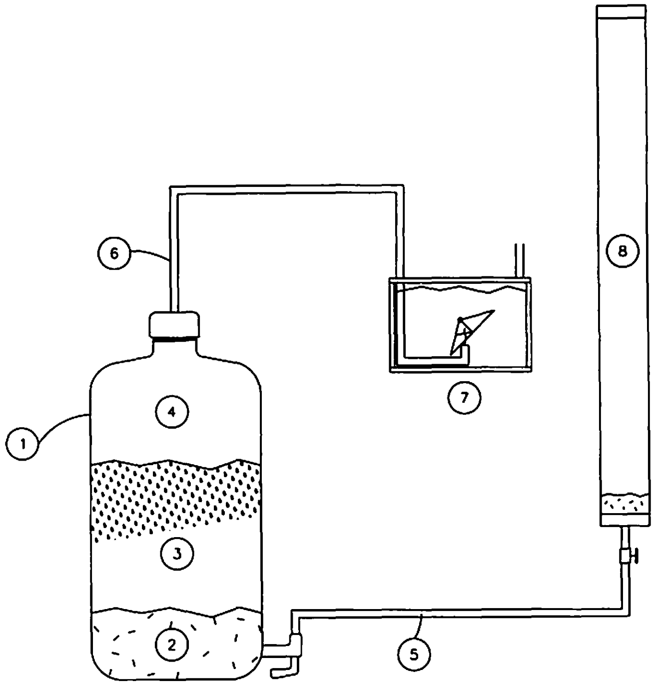

Fig. 2. Schematic of laboratory scale SBRs used for the start up run (test run no 4).

Table I: SBR operating conditions for the start-up run

SBR No.	Loading rate (g COD•L^{-1}•d^{-1})*	Fill period (week)	React period (week)	Inoculum** type
1 - 2	0.72	4	4	A
3 - 4	0.72	4	4	B
5 - 6	1.20	4	4	A
7 - 8	1.20	4	4	B

*Equivalent loading rate if the swine manure would have been fed continuously.
** A - Agropur Sludge
B - Mixture (79% Agropur and 21% Municipal Sludge)

The feeding procedure consisted of adding fresh swine manure slurry to the feeder tubes. Thereafter nitrogen gas was used to pressurize the individual feeder to transfer the manure slurry to the SBR. This feeding method worked very well and it took less than one minute to deliver the feed to an SBR. A mixed liquor sample of 100 mL was withdrawn from each SBR at the beginning of the experiment and at 7 day intervals after the start of the experiment. Additional 100 mL samples were withdrawn from the supernatant and settled sludge bed zones at the end of the experiment. Swine manure slurry was sampled immediately before it was fed to the SBRs.

Analytical methods

Samples were analysed for pH, alkalinity, solids, volatile acids (VA), total Kjeldahl nitrogen (TKN), ammonia nitrogen, total COD, and soluble COD (SCOD). Some samples were also analysed to determine concentration of C, H, and N. Biogas production was monitored daily and its composition analysed weekly. Gas samples were withdrawn with 10 mL syringes through septums located in digester gas lines. SCOD was determined by analysing the supernatant of centrifuged slurry according to the method developed by Knechtel (1978). Alkalinity, pH, TS, TSS, VS, VSS, and TKN were determined using standard methods (APHA 1992). TKN and ammonia nitrogen were determined using a Kjeltec auto-analyzer model TECATOR 1030 (Tecator AB, Hoganas, Sweden). VA concentrations were determined by a Perkin Elmer gas chromatograph model 8310, that had a DB-FFAP high resolution column. Biogas composition was determined by using a Carle 400 AGC gas chromatograph. C, H, and N were determined using LECO CHN 600 analyzer.

Table II: Inocula Characteristics

Constituent	Agropur Sludge	Municipal Sludge
Total solids (%)	11.0	2.6
Total suspended solids (%)	10.7	2.3
Volatile solids (%)	5.6	1.3
Volatile suspended solids (%)	5.4	1.2
Carbon (% VS)	48.41	55.9
Nitrogen (% VS)	9.64	8.4
Hydrogen (% VS)	7.54	10.6
Oxygen (% VS)	34.41*	25.1*
Soluble COD (g/L)	10.0	3.0
Total COD (g/L)	73.0	8.2
NH4-N (g/L)	1.3	1.0
TKN (g/L)	7.9	1.8
Cellulose (% TS)	0.70	0.84
Hemicellulose (% TS)	0.73	3.98
Lignin (% TS)	1.56	2.9
pH	7.6	7.3
Alkalinity (g $CaCO_3$/L)	16.0	6.0
Operating temperature (°C)	35.0	35.0
Sludge residence time (week)	26.0	2.0

*% Oxygen = 100% - (% Carbon + % Nitrogen + % Hydrogen)

EXPERIMENTAL RESULTS

Composition of swine manure slurry and inoculum

The manure had a neutral pH and high concentrations of TCOD, SCOD, TKN, NH_3-N, VA, and alkalinity. Based on the concentrations of C, N, and H given in Table III, the composition of the insoluble organic fraction of the fresh swine manure slurry was $C_{1.0}H_{1.9}O_{1.0}N_{0.1}$. This composition is similar to the formula for carbohydrates $[CH_2O]_n$.

The main characteristics of the Agropur granulated sludge were that it had very high solids, TCOD, SCOD, and TKN (Table II). The municipal sludge was less concentrated than the granulated Agropur sludge, but it had a higher fibre content on a dry weight basis and also had a lower alkalinity. Both sludges came from digesters operated at 35°C. The concentrations of C, H, and N of the organic fraction of Agropur and municipal sludges yield the following stoichiometric formulations for the volatile solids (VS) composition:

Municipal sludge: $C_5H_{11.5}N_{0.66}O_{1.8}$
Agropur sludge: $C_5H_{9.25}N_{0.84}O_{2.7}$

Table III: Composition of Swine Manure

Constituent	Concentration Mean ± S.D.
Total solids (%)	4.8 ± 0.12
Total suspended solids (%)	3.6 ± 0.20
Volatile solids (%)	3.0 ± 0.16
Volatile suspended solids (%)	2.6 ± 0.30
Soluble COD (g/L)	39 ± 9.00
Total COD (g/L)	84 ± 10.00
TKN (g/L)	7.5 ± 0.35
NH4-N (g/L)	5.8 ± 0.40
pH	7.4 ± 0.30
Alkalinity (g $CaCO_3$/L)	19.0 ± 2.70
Acetic acid (g/L)	6.3 ± 0.40
Propionic acid (g/L)	1.9 ± 0.15
Butyric acid (g/L)	2.5
Cellulose (% TS)	2.43
Hemicellulose (% TS)	4.15
Lignin (% TS)	1.31
Carbon (% VS)	38.18
Nitrogen (% VS)	4.69
Hydrogen (% VS)	6.10
Oxygen (% VS)	51.00*

*% Oxygen = 100% - (% Carbon + % Nitrogen + % Hydrogen)

Biogas production

Gas production at 20°C occurred without any breakdown or sign of process instability for a 2.5 months period from June 14 to September 1 (Figs. 3 and 4). Shapes of cumulative biogas production curves are similar for the four treatments. The rate of gas production was low during the fill period and it increased during the react period. The 30 day lag phase in biogas production probably resulted from acclimatization of microorganisms to a lower temperature and a new substrate (swine manure). During the react period the biogas production rate increased exponentially until the end of the period when it started to decrease as the availability of substrate became the limiting factor. Substantial amounts of biogas were produced beyond the react period. This indicates that treatment was not complete at the end of the react period. Therefore, during startup the organic loading rate (OLR) should be reduced or the react period should be extended beyond the 77 days used here.

The digesters with combined sludge produced the highest amount of biogas, perhaps because of an increased hydrolysis rate. Cumulative biogas production was 30 and 70% higher in these digesters compared to the digesters seeded with Agropur sludge at OLRs of 0.72 and 1.20 g $COD \cdot L^{-1} \cdot d^{-1}$, respectively. This combined sludge was already acclimatized

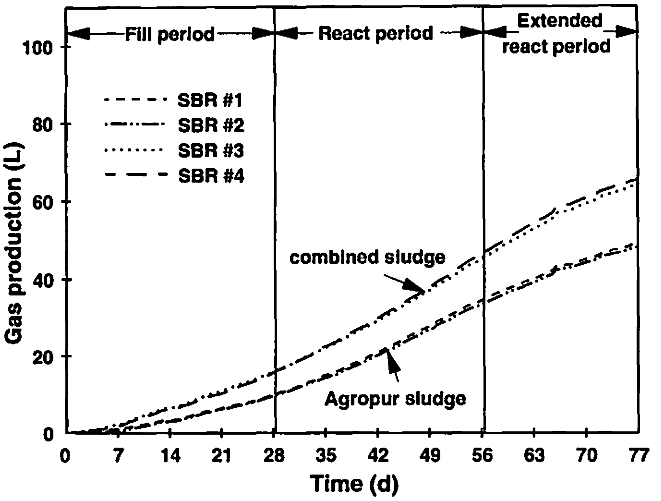

Fig. 3. Cumulative biogas production as a function of time for SBRs with organic loading rate of 0.72 g COD•L^{-1}•d^{-1}.

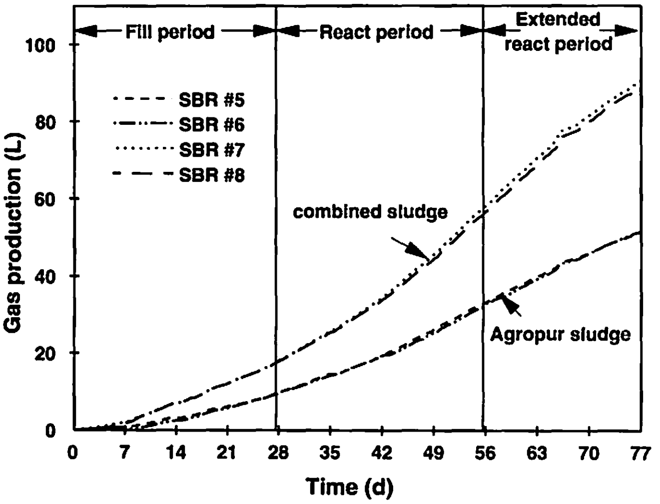

Fig. 4. Cumulative biogas production as a function of time for SBRs with organic loading rate of 1.2 g COD•L^{-1}•d^{-1}

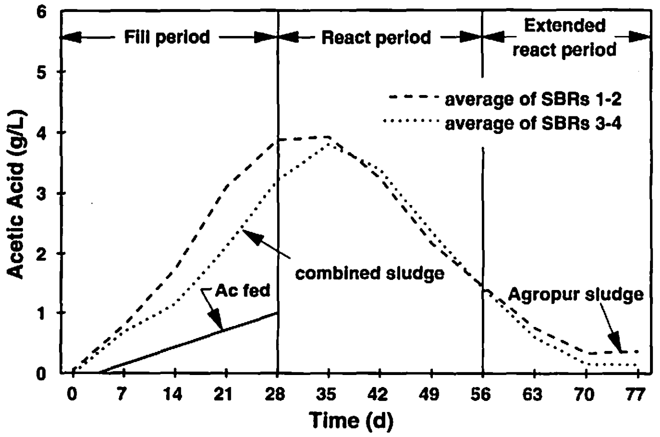

Fig. 5. Average acetic acid concentration as a function of time for SBRs with a loading rate of 0.7 g COD•L^{-1}•d^{-1}.

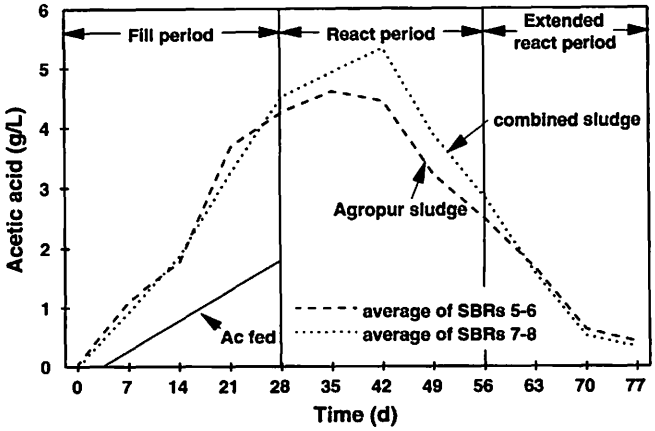

Fig. 6. Average acetic acid concentration as a function of time for SBRs with a loading rate of 1.2 g COD•L^{-1}•d^{-1}.

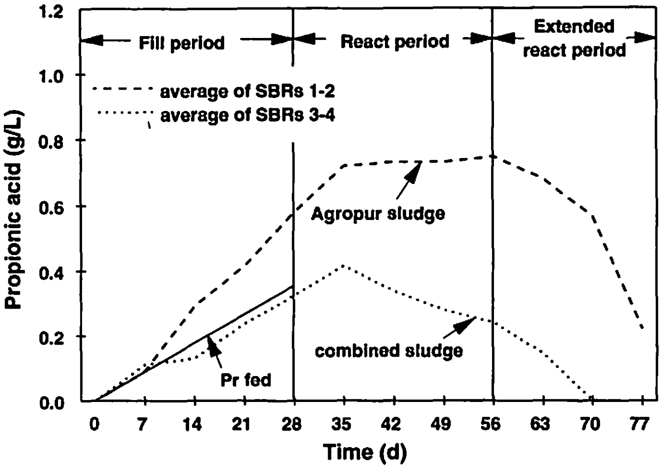

Fig. 7. Average propionic acid concentration as a function of time for SBRs with a loading rate of 0.7 g COD•L^{-1}•d^{-1}.

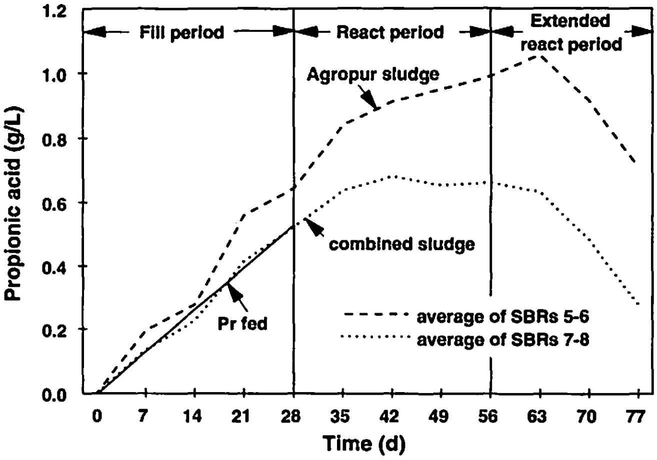

Fig. 8. Average propionic acid concentration as a function of time for SBRs with a loading rate of 1.2 g COD•L^{-1}•d^{-1}.

to compounds such as cellulose, hemicellulose, and lignin while the Agropur sludge was only acclimatized to proteins and fats which are the major constituents of cheese plant wastewater. Also, the activity of the municipal sludge may have been higher than that of the Agropur sludge. Actual sludge activities of inoculum were not measured in this study.

During the first 60 days, increased OLR had no significant effect on biogas production for the digesters with the Agropur sludge. However, for the digesters with combined sludge there was an increase in biogas production of 40% when the OLR increased from 0.72 to 1.20 g $COD{\bullet}L^{-1}{\bullet}d^{-1}$.

For the four treatments tested, the methane fraction in the biogas was not constant. It continuously increased with time. At the start of the fill period the methane concentration ranged from 47 to 63% while at the end of the react period it ranged from 77 to 80% for all treatments.

Volatile acids accumulation

Acetic acid accumulated rapidly from 0 to 5500 mg/L during the fill period in the SBRs fed 1.2 g $COD{\bullet}L^{-1}{\bullet}d^{-1}$ (Figs. 5 and 6). This accumulation is about five times larger than the amount of acetic acid fed to the digesters. Propionic acid was accumulating faster in digesters with the Agropur sludge than in digesters with combined sludge during the fill period (Figs. 7 and 8). For digesters with combined sludge, the propionic acid accumulations were equal to the cumulative concentration fed. Butyric acid was not accumulating during the fill period, but rather was consumed because its concentrations were substantially lower than the cumulative concentration fed (Figs. 9 and 10).

The rapid increase in acetic acid concentration during the fill period indicates that hydrolysis and acidification were occurring and that the utilization of acetic acid by the methane formers was the rate limiting step. The rapid increase in acetic acid is usually due to the faster growth rate of acid formers or inhibition of methane formers by an increase in concentration of VA or other compounds. Comparing Figs. 3 and 4 with Figs. 5 to 10 demonstrates that methane formers were not inhibited by the increase in VA concentrations because during the period of increased VA concentration the methane production rate also increased. Therefore the increase in VA is more probably due to the faster growth rate of acid formers. The large increase in VA did not affect the process stability because: 1) alkalinity in the SBRs was very high (16000 mg $CaCO_3$/L) (the large increase in VAs caused only a small drop in pH); and 2) pH was maintained between 7.5 and 7.8 (unionized VA concentration was always low at 6 mg/L). Several existing models assume that the growth rate of methane formers is affected by the VA concentration whereas preliminary results from this work show that this theory does not apply for acetic acid concentrations up to 6000 mg/L in SBR anaerobic digestion of swine manure at 20°C.

During the react period there was rapid utilization of acetic and butyric acids (Figs. 5, 6, 9, and 10) indicating that hydrolysis and acidification were the rate limiting processes during the react period. When the OLR increased from 0.72 to 1.20 g $COD{\bullet}L^{-1}{\bullet}d^{-1}$, the maximum acetic, propionic, and butyric acid concentrations in the SBR increased by 25, 13, and 33%, respectively (Figs. 5 to 10).

Inoculum type did not have much effect on acetic acid concentrations although the SBRs with the combined sludge inoculum had higher CH_4 production and lower propionic and butyric acid concentrations at all times. Thus SBRs were more stable with combined sludge than with Agropur sludge and for this reason all subsequent experimental runs were carried out with the combined sludge inoculum.

Propionic acid is the only VA that substantially increased during the react period (Figs. 7 and 8). A mass balance on propionic acid shows that it was being utilized during the fill period, but at a rate lower than the feed and production rate. The increase in propionic acid might be due to an increase in dissolved hydrogen concentration (Mosey 1983). Fukazaki et al. (1990) stated that fermentation of propionic acid to CH_4 and CO_2 is inhibited by dissolved hydrogen and acetic acid. Results for SBRs 3-4 (Fig. 7) indicate that propionic acid was utilized even when the concentration of acetic acid was high. Therefore the propionic acid accumulation in this study may be attributed to the effect of dissolved hydrogen in the SBRs. Inhibition of hydrogenotrophic methanogens may be another factor for the increase of propionic acid.

Process stability

The pH level, alkalinity, and ammonia concentrations as a function of time for the SBRs with an OLR of 1.2 g $COD{\bullet}L^{-1}{\bullet}d^{-1}$ were similar to curves obtained at the lower OLR of 0.7 g $COD{\bullet}L^{-1}{\bullet}d^{-1}$ (Fig. 11). The pH ranged from 7.4 to 7.8. The higher concentration of VA during the react period did not affect the microorganisms because of the high initial alkalinity. The increase in VA slightly reduced the pH and alkalinity during the fill periods. During the react period both the alkalinity and pH started to increase mainly due to VA utilization. The contribution of ammonia-N to the pH and alkalinity during the react period was negligible because there was no increase of ammonia-N during this period (Fig. 11). The high concentration of ammonia-N did not inhibit methane formers because both the methane production and the ammonia-N concentration increased simultaneously. Kroecker et al. (1979) found that ammonia is inhibitory to the methanogenic bacteria when its concentration exceeds 2000 mg/L. Melbinger and Donnellon (1971) found that ammonia is toxic only when its concentration exceeds the threshold limit of 1700 to 1800 mg/L and is increasing faster than the acclimatization of the methanogenic bacteria. McCarty (1964) indicated that an ammonia-N concentration exceeding 3000 mg/L is toxic to the anaerobic bacteria regardless of pH. Henze and Harremoes (1983) indicated that dissolved ammonia is substantially more toxic than ammonium ions to anaerobic bacteria. They indicated that a dissolved ammonia gas concentration ranging between 100 and 200 mg/L should have an inhibitory effect on the anaerobic process. In this test, the total ammonia-N concentration (3700 mg/L) represents the sum of ammonium ions (3550 mg NH_4^+N/L) and dissolved ammonia (150 mg NH_3-N/L). Inhibition by ammonia-N was not observed in this study. It is likely that the long hydraulic and solids residence times provided in this study allowed the microorganisms to increase their tolerance to high concentrations of ammonia-N. PAD in SBRs appears to be suitable to treat wastewater with a high nitrogen content.

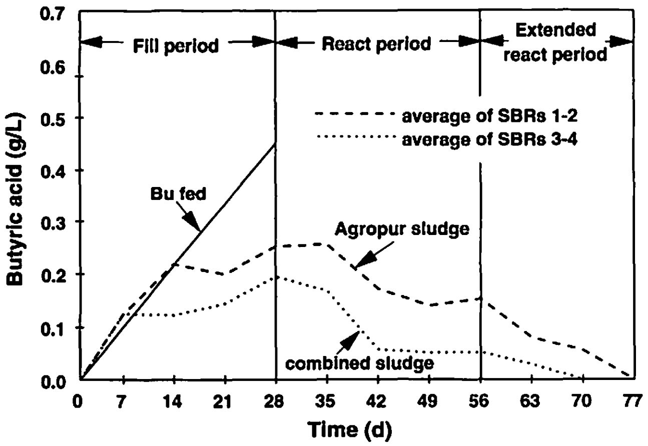

Fig. 9. Average butyric acid concentration as a function of time for SBRs with a loading rate of 0.7 g COD•L^{-1}•d^{-1}.

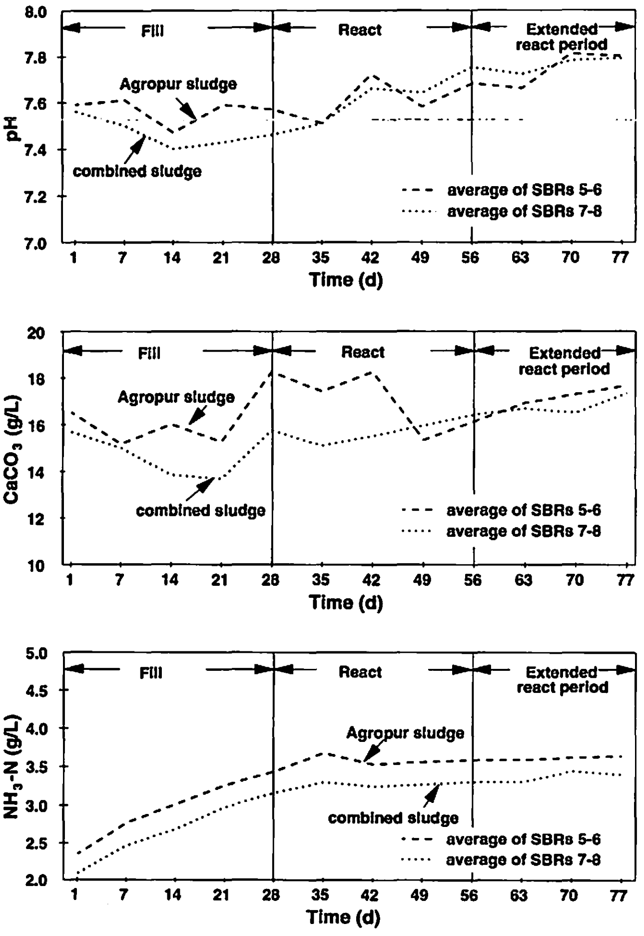

Fig. 11. PH, alkalinity (g $CaCO_3$/L) and NH_3-N concentration as a function of time for SBRs with a loading rate of 1.2 g COD•L^{-1}•d^{-1}.

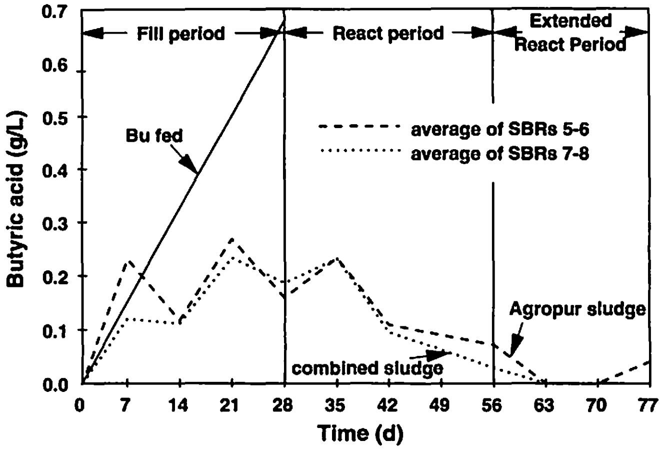

Fig. 10. Average butyric acid concentration as a function of time for SBRs with a loading rate of 1.2 g COD•L^{-1}•d^{-1}.

Energy recovery

The CH_4 production ranged from 0.30 to 0.66 L/g VS for most of the experiment runs (Table IV). Methane production obtained in this study was substantially higher than methane production from swine manure obtained by digestion at 35°C in continuous flow digesters by Kroecker et al. (1979), who reported methane production of 0.45 L CH_4/g VS added for a loading rate of 2.5 kg VS•m^{-3}•d^{-1} and by Hashimoto (1983), who reported 0.42 L CH_4/g VS added for a loading rate of 2.5 kg VS•m^{-3}•d^{-1}. The higher methane production per gram of VS fed to the SBRs obtained in this study could be due to: 1) the lower OLR (0.45 kg VS•m^{-3}•d^{-1}) and longer hydraulic retention time; 2) the fact that the measured VS in the influent is lower than the actual VS concentration because some VA and other soluble organics are volatilized during the VS determination; and 3) the fact that the measured methane flow rate includes the methane produced from microorganism decay. Another possible reason could be that the lower operating temperature and absence of mixing maintain higher concentrations of hydrogen and carbon dioxide in the liquid phase. As a result more carbon dioxide can be converted to methane by the hydrogen utilizing methanogens. Also, with the continuous flow anaerobic processes previously tried, some CO_2, H_2, and CH_4 were lost in the digester effluent. A high rate of methane production was not the main objective of this work but these data are useful in assessing system performance and stability. Steady production of methane per unit mass of VS fed indicates that PAD of swine manure at 20°C in the laboratory scale SBR digesters was a stable process.

Treatment efficiency

Total COD removal ranged from 58 to 73% and the VS removal ranged from 27 to 74% (Table IV). Results for VS and total COD were highly variable due to rapid settling of heavy particulates which affected VS and total COD determinations as well as the calculated methane production per gram of VS. The SCOD test results were consistent. High SCOD removal ranging between 85-96% was achieved.

Reduction in swine manure slurry odours was one of the

Table IV: Average Methane Production per Unit of VS Fed to the SBR and Reduction in Total COD, soluble COD and VS.

SBR number	Loading Rate		Sludge* type	CH_4 production L CH_4/g VS after 56 days	Removal(%) after 56 days		
	(g COD/feed)	g COD•L^{-1}•d^{-1}			TCOD	SCOD	VS
1-2	12.6	0.72	A	0.50	60.0	90.0	29.0
3-4	12.6	0.72	B	0.66	70.0	96.0	74.0
5-6	21.0	1.20	A	0.30	58.0	85.0	27.0
7-8	21.0	1.20	B	0.52	73.0	91.0	56.0

* Inoculum Type
A - 100% Agropur Sludge
B - Combined Sludge (79% Agropur and 21% Municipal)

objectives of this study. The major volatile compounds that produce odours in animal manure slurries are VA, amines, carbonyls, esters, hydrogen sulphide, and ammonia. Laboratory staff observed that test runs that achieved complete removal of VA and more than 85% removal of soluble COD produced treated manure that was relatively odourless compared to raw manure. A large reduction in soluble COD may result in complete utilization of amines, carbonyls, and esters. The actual degree of reduction in odour intensity was not determined because the techniques recommended to measure odour intensity are complex, subjective, time consuming, and could not feasibly be used within the time frame of this study. Quantification of odours will be addressed in future studies.

CONCLUSION

Anaerobic digestion of swine manure slurry at psychrophilic temperature (20°C), in non-mixed sequencing batch reactors, at loading rates of 0.7 and 1.2 g COD•L^{-1}•d^{-1}, stabilized and deodorized the swine manure slurry. The digester effluent was almost odourless when compared to the raw manure. The SBRs were efficient in retaining the biomass. Up to 73% removal of total COD was attained by the process operated at a cycle time and conditions that are suitable for typical farm operations. Methane production up to 0.66 L CH_4/g VS was obtained, with a methane content varying from 50 to 80%. This high biogas production and quality were not affected by high concentrations of volatile acids (6000 mg/L or higher) and ammonia-nitrogen (3700 mg/L) in the digester mixed liquor.

PAD at 20°C in intermittently fed SBRs is technically feasible, stable and easy to operate.

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