length: diameter ratio in polyethylene biodigesters

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Effect of length: diameter ratio in polyethylene biodigesters on gas production and effluent composition

Do lengths of biodigesters influence gas production and retention time? (from Livestock Research for Rural Development)

Abstract

Introduction

Many factors influence gas production and the fertilizer value of the effluent in tubular plug-flow biodigesters. Studies have been made on the effect of retention time, temperature, types of manure and concentration of solids in the influent (Boodoo et al 1979; Bui Xuan An and Preston 1999; San Thy et al 2003). However, the configuration of tubular polyethylene biodigesters, namely the ratio of diameter to length has not been studied. Most biodigesters of this type have been between 8 and 10m in length with a diameter of 1 m (Duong Nguyen Khang personal communication), equivalent to a ratio of 10.1:1 and 12.7:1 between length and cross-sectional diameter. Smaller biodigesters (2m long by 0.63m diameter; ratio of 6.4:1 of length to cross-sectional area)) were used by San Thy et al (2003) and appeared to be very efficient with production rates exceeding 100% of the biodigester liquid volume. It was therefore hypothesized that different ratios of length to cross-sectional area in tubular polyethylene might influence the rate and efficiency of gas production.

Hypotheses

The hypothesis was that a length: ratio of 5: 1 (length: area ratio of 6.3:1) of of the biodigester would result in higher rate of gas production and more efficient use of substrate than narrower or wider ratios; and that a retention time of 10 days would give higher gas production than 20 days.

Materials and methods

Location

The experiment was conducted in the four countries participating in the MEKARN project (http://www.mekarn.org) : Cambodia (CelAgrid, Cambodia), Thailand (Chiang Mai University), Vietnam (Nong Lam University) and Lao (Livestock Research Centre). The activities in the different countries were initiated at different times: in Vietnam from September to November 2003, in Cambodia and Lao from February to April 2004; and Thailand from June to July 2004.

Experimental treatments and design

The treatments arranged as a 4*2 factorial were: Length: diameter ratio and hydraulic retention times. Each location was considered as a replicate.

Length: diameter ratios

These were as follows (length: cross-sectional area is in brackets):

Retention time

This was 10 or 20 days.

The design was a single changeover with experimental periods of 40 days on each retention time (Table 1).

Table 1. Changeover arrangement of retention times within fixed lengths of the biodigesters

	[illegible]	[illegible]	[illegible]	[illegible]
Period 1	10	20	10	20
Period 2	20	10	20	10

In each location, four experimental biodigesters were constructed according to the design developed by San Thy et al (2003). Tubular polyethylene film of 63 cm diameter was used to construct 4 biodigesters in each locaton(2, 3, 5 and 8m length).

Inoculation

At the beginning, the biodigesters were inoculated with effluent from a functioning biodigester. The ratios used were 60% of digester effluent and 40 % of water. A mixture of manure and water was added to give an initial solids concentration of 4% (Table 2). At the time of changeover, water was added at 50 % of biodigester liquid volume to facilitate the outflow of organic solid materials from the first period that might effect biogas yield in the next period.

Table 2: Inoculation influent and manure water mixture

Biodigester length, m	[illegible]	[illegible]	[illegible]	[illegible]
Biodigester volume, m3	0.64	0.96	1.59	2.55
Liquid volume, liters	477	716	1194	1910
Influent input				
Effluent from other biodigester	286	430	716	1146
Manure kg	38.2	57.3	95.5	153
Water, liters	153	229	382	611

Construction of biodigesters

The 16 plug-flow biodigesters (in each location there were 4 biodigesters) were made from tubular polyethylene film (internal diameter 0.63m), mounted in shallow trenches lined with bricks (to ensure the dimensions were exactly the same size of plastic biodigester), to provide a liquid volume in the proportion of 80% of the total biodigester capacity (Photo 1). The biodigesters were installed in an area with the same microclimate condition by shading them with corrugated iron roof at 3 m above the ground. During the subsequent adaptation and data collection periods, the fresh pig manure and water were added in the proportion indicated for each loading rate treatment (Table 3).

Manure

Pig manure was used in each location. The loading rate was 4 kg DM per m³ of liquid volume. The manure was collected daily in the early morning from the pig pen and stored in a polyethylene sack. The pigs were fed a mixed feed formulated according to each location (Vietnam and Thailand fed by commercial feed and Lao and Cambodia fed by formulation feed, or high fiber feed such as water spinach, cassava silage, distillery waste and brewery spentd grain mixed with commercial feed).

The biodigesters were charged daily at exactly the same time and with the amounts of fresh manure and water according to the treatments and the liquid volume of the biodigester (Table 3). The indicated amount of pig manure was fixed on a DM basis. The amount of water added was determined by retention time (Table 3).

Table 3: Details of inputs of manure and water for the two hydraulic retention times in periods 1 and 2

	1.2	1.3	1.5	1.8
Biodigester volume, m^3	0.637	0.955	1.59	2.54
Liquid volume, liters	477	716	1194	1910
Period 1 (1-40 days)				
Retention time, days	10	20	10	20
Daily slurry input, liters	47.7	35.8	119.4	95.5
Fresh manure, kg	9.5	14.3	23.9	38.2
Water, liters	38.2	21.5	95.5	57.3
Solids concentration, %	4	8	4	8
Period 2 (41-80 days)				
Retention time, days	20	10	20	10
Daily slurry input, liters	24	72	60	191
Manure, kg	9.5	14.3	23.9	38.2
Water, liters	14.3	57.3	35.8	152.8
Solids concentration, %	8	4	8	4

Data collection and analyses

The experimental data were recorded daily during the last 20 days of each experimental period. Samples of fresh pig manure and effluent were taken daily on days 21 to 40, immediately before (manure) and after (effluent) charging the biodigester.

The samples of fresh manure were bulked and mixed every 10 days, and effluent every 7 days, prior to taking representative samples for analysis of total N and ammonia-N using a Foss-Tecator Kjeldahl apparatus and for organic matter by ashing the samples in a furnace oven (AOAC 1990). DM content was determined by microwave radiation (Undersander et al 1993).

Gas production was measured daily using the system of water displacement developed by San Thy et al (2003) (Photo 2). The change in volume was recorded 2 to 3 times a day to determine daily gas production.

Statistical analyses

The data were subjected to analysis of variance (ANOVA) using the General Linear Model (GLM) of the MINITAB software Release 13.31 (2000). The model was:

Yij k = μ + Ti +Pj + Ak+ eijk

Where:

Results and discussion

Manure at different locations

There were no differences in the DM, OM and total N concentration of the manure between locations (Table 4). Ammonia-N as a proportion of total N was highest in he pig manure in Lao and Vietnam and lowest in Cambodia and Thailand.

Table 4: Pig manure characteristics from different countries

	Cambodia	Lao	Vietnam	Thailand	SE/P
DM, %	33.1	35.2	29.1	26.8	2.13/0.356
OM, %	69.7	70.3	76.3	75.7	2.46/0.18
Total N, mg/kg	4221	7481	4390	7856	662.7/0.000
NH_3-N, mg/kg	381	1114	656	803	77.6/0.000
NH_3-N as proportion of total N, %	9.54	15.02	15.03	10.2	0.97/0.01

Influent

Ammonia-N as percentage of total N was higher for the more diluted influent (10 day retention time (Table 5).

Table 5: Effect of water added to pig manure according to retention times on slurry input

	Retention times, days			
	10[a]	20[b]	SE	Prob
DM, %	4.78	7.38	0.286	0.001
OM, %	67.5	71.6	1.039	0.022
N, mg/litre	994	2156	161.7	0.001
NH_3-N, mg/litre	297	442	22.3	0.003
NH_3-N in Total N, %	32.2	20.8	1.88	0.001

[a] Manure/water ratio 1:4 for 10 days retention time and solid concentration with 4%
[b] Manure/water ratio 1:1.5 for 20 days retention time and solid concentration with 8%

OM content of the DM of the manure was lower in Lao and Cambodia than in Thailand and Vietnam (Table 6). Correspondingly, NH3-N as proportion of total N was higher in Cambodia and Lao.

Table 6: Influent characteristics from different countries

	Cambodia	Lao	Thailand	Vietnam	SE/P
OM, % in DM	61.1	59.6	76.2	76.7	1.47/0.001
N, mg/litre	1308	1802	1925	1308	29.7/0.001
NH_3-N, mg/litre	340	411	291	286	11.6/0.001
NH_3-N as N of total					
%	31.1	30.7	23.4	20.7	1.87/0.002

Ammonia-N as proportion of total N was higher in the influent than in manure , presumably reflecting microbial action between the time taken to sample raw manure, and the adding of water and stirring activities to make the influent slurry (Figure 1).

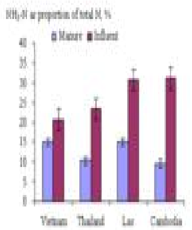


Figure 1 Effect of adding water to pig manure on the proportion of NH_3-N in total N

Biodigester effluent

There was no effect of the length of the biodigester on the DM, OM, total N and ammonia N (total ammonia as well as percent of total N) in the effluent (Table 7).

Table 7: Effect of biodigester length and retention times on effluent composition

	Biodigester length, m				
HRT, days	2	[illegible]	[illegible]	8	SE/P
	DM, %				
10	3.11	5.09	3.98	5.7	0.559/0.009
20	6.72	6.24	5.07	5.53	
Mean	4.91	5.67	4.53	5.62	0.49/0.113
	OM, %				
10	62.8	57.5	62.2	62.0	2.99/0.938
20	71.6	67.6	68.8	69.9	
Mean	67.2	62.6	65.5	66.0	2.09/0.423
	N, mg/litre				
10	1237	1214	1349	1248	246/0.088
20	1773	2266	1237	2063	
Mean	1505	1740	1293	1656	172/0.256
	Ammonia-N, mg/litre				
10	615	536	746	582	191/0.136
20	1017	886	555	1270	
Mean	816	711	650	926	137/0.479
	NH_3-N as proportion of total N, %				
10	50.3	44.7	60.0	49.9	5.81/0.236
20	49.0	39.0	49.9	62.3	
Mean	49.6	41.8	54.9	56.1	4.17/0.106

There was no effect of the manure dilution rate (retention time) on the proportion of total N in effluent in the form of ammonia (Table 8), nor of the biodigester length (Figure 2).

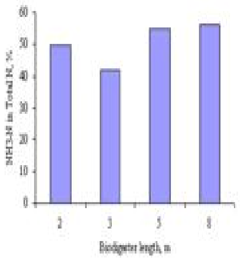
Table 8: Effect of retention times or water/manure on effluent composition

	Manure/water ratio			
	1:4	1:1.5	SE	Prob
DM, %	5.76	7.36	0.30	0.001
OM, %	61.67	70.83	1.88	0.001
N, mg/litre	1534	2186	151.3	0.003
NH_3-N, mg/litre	747	1095	128.8	0.061
NH_3-N in Total N, %	49.4	46.9	3.82	0.638

San Thy et al (2003), using pig manure with different loading rates of 2.93, 1.46 and 0.92 kg DM/day/m3 liquid volume and hydraulic retention times of 10, 20, and 30 days, observed that the proportion of ammonia N to total N increased with longer retention time but when pig manure loading rate was fixed, it was not affected by retention time.

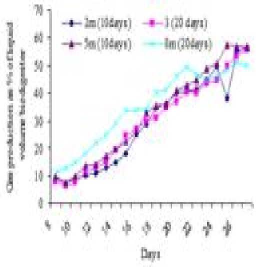
These experimental data do not support the original hypothesis that shorter biodigesters and retention time would support a greater degree of conversion of organic-N in the influent to ammonia-N in the effluent. However, the substantial improvement in ammonia-N as proportion of total N in the transition from manure to influent (diluted manure) from 9.54-15.03% to 20.7-31.% to 41.8-56.1%) is in accordance with the findings of Pedroza et al (2001) who reported increases from 20 in the influent to 60 in the effluent and San Thy et al (2003) who reported increases from 20 to 50-60 % of ammonia-N in total N in influent and effluent.

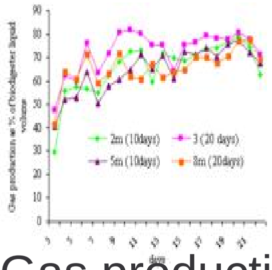
Biogas production



Adaptation period

After inoculation of the biodigester and an adaptation period of about 8 days, the biodigesters were charged daily with manure and water according to treatment. The trend in rate of gas production during this phase (Figure 3) was similar to that reported by San Thy et al (2003).





Gas production (during collection period)

There were no differences between biodigester dimensions for gas production as litres per kg DM (and OM) of manure, or as proportion biodigester liquid volume (Table 9).

Table 9. The interaction of length and hydraulic retention times on gas production

HRT, day	Biodigester length, m: 2	3	5	8	SE/P
	Liters/day				
10	233	404	670	962	40.2/0.43
20	272	437	633	1090	
Mean	253	420	652	1026	31.6/0.001
	Liters/kg DM				
10	73.4	86.9	85.1	78.3	3.54/0.27
20	88.8	91.7	83.5	86.4	
Mean	81.1	89.2	84.3	82.4	2.78/0.18
	Liters/kg OM				
10	102	124	118	112	4.97/0.21
20	127	127	119	120	
Mean	114	125	118	115	3.91/0.16
	Biogas production per liquid volume, m^3/m^3				
10	0.49	0.56	0.56	0.5	0.03/0.27
20	0.57	0.61	0.53	0.57	
Mean	0.53	0.59	0.55	0.54	0.02/0.17
	% of liquid volume				
10	49.0	56.4	56.2	50.4	3.31/0.17
20	57.1	61.1	53.0	57.1	
Mean	53.0	58.7	54.6	53.7	1.96/0.17

Gas production in different countries

The biogas production differed among the countries with highest values for Cambodia, followed by Lao, Vietnam and Thailand (Table10). We have no obvious explanation for these differences.

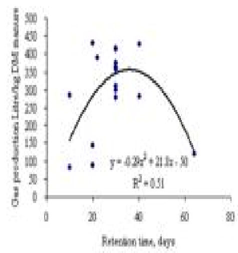
Table 10. [illegible]

	Cambodia	Lao	Vietnam	Thailand	SE/P
Litres/day	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Litres/kg DM	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Litres/kg OM	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
% of liquid volume	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

All measures of gas production showed increases for the longer retention time of 20 days (Table 11). This is in agreement with data in the literature (Figure 5) which showed a peak in production at around 20 day retention times and then a decline.

Table 11. [illegible]

[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]



Conclusions

Acknowledgement

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