

length: diameter ratio in polyethylene biodigesters

length: diameter ratio in polyethylene biodigesters

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 each length of the biogasifiers

	10d	20d	10d	20d
Period 1	10	20	10	20
Period 2	20	10	20	10

In each location, four experimental biogasifiers 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 biogasifiers in each location (2, 3, 5 and 8m length).

Inoculation

At the beginning, the biogasifiers were inoculated with effluent from a functioning biogasifier. 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 biogasifier liquid volume to facilitate the outflow of organic solid materials from the first period that might affect biogas yield in the next period.

Table 2. Inoculation volume and manure water ratios

Biogasifier length (m)	2	3	5	8
Biogasifier volume (m ³)	0.64	0.96	1.59	2.55
Liquid volume (liters)	47	70	119	190
Inoculum type				
Effluent from other biogasifier	28	42	70	116
Manure (kg)	3.2	3.7	6.3	10.3
Water (liters)	19	28	49	74

Construction of biogasifiers

The 16 plug-flow biogasifiers (in each location there were 4 biogasifiers) 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 biogasifier), to provide a liquid volume in the proportion of 80% of the total biogasifier capacity (Photo 1). The biogasifiers 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 spent 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

	T2	T3	T8	T9
Biodigester volume, m ³	0.677	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	6	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:

$$Y_{ijk} = \mu + T_i + P_j + A_k + e_{ijk}$$

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 the pig manure in Lao and Vietnam and lowest in Cambodia and Thailand.

Table 4 Pig manure characteristics from different countries

	Cambodia	Lao	Vietnam	Thailand	SEF
DM %	31	32	21	29	23(0.76)
OM %	67	70	75	71	24(0.11)
Total N, mg/kg	421	503	406	706	402(0.06)
NH ₃ -N, mg/kg	30	114	44	40	77(0.06)
NH ₃ -N as proportion of total N, %	6.5	10.0	10	5.2	19(0.1)

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 manure added to pig manure according to retention time on effluent composition

	Retention time, days			
	10	20	SE	Prob.
DM %	47.8	7.8	0.20	0.001
OM %	67.5	71.0	1.09	0.02
N, mg/litre	94	216	11.7	0.001
NH ₃ -N, mg/litre	27	42	2.1	0.001
NH ₃ -N as Total N, %	12.1	20.1	1.0	0.001

SE = standard error; Prob = probability of difference between two and all concentrations with P.

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 Manure characteristics from different countries

	Cambodia	Lao	Thailand	Vietnam	SEF
DM % (DM)	31	30	29	21	23(0.01)
N, mg/kg	100	102	107	106	23(0.06)
NH ₃ -N, mg/kg	14	11	21	26	1.0(0.01)
NH ₃ -N as Total N, %	11	8.7	21	27	13(0.02)

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).

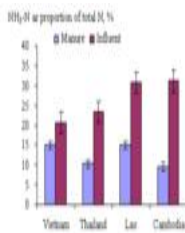


Figure 1 Effect of adding water to pig manure on the proportion of NH₃-N as total N

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

RET. days	Biodigester length, m				
	2	3	SE	Prob.	
DM %					
10	3.11	3.06	3.08	3.7	0.35(0.009)
20	6.32	6.26	6.07	6.33	
Mean	4.71	5.67	4.57	5.62	0.005(11)
OM %					
10	62.8	57.5	62.2	62.0	2.9(0.038)
20	74.0	67.6	68.0	69.9	
Mean	67.5	62.6	65.5	66.0	2.0(0.023)
N, mg/litre					
10	1237	1214	1189	1260	24(0.018)
20	1773	1260	1237	2063	24(0.018)
Mean	1503	1740	1263	1676	172(0.256)
NH₃-N, mg/litre					
10	417	376	362	362	19(0.136)
20	1017	886	555	1270	
Mean	810	711	450	920	137(0.479)
NH₃-N as proportion of total N, %					
10	30.3	44.7	60.0	49.9	5.9(0.202)
20	49.0	39.0	49.9	62.3	
Mean	49.6	41.8	54.9	56.1	4.17(0.016)

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 %	57.6	7.36	0.70	0.001
OM %	61.67	70.83	1.08	0.001
N, mg/litre	1334	2186	131.3	0.003
NH ₃ -N, mg/litre	747	1095	128.8	0.001
NH ₃ -N as Total N, %	49.4	46.9	3.82	0.638

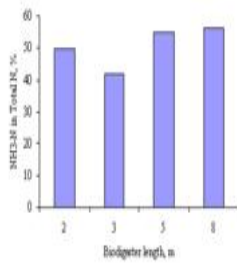
San Thy et al (2003), using pig manure with different loading rates of 2.93, 1.46 and 0.92 kg DM/day/m³ liquid volume and hydraulic retention times of 10, 20, and 30 days, observed that the proportion of

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 20.7-31.1% 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.

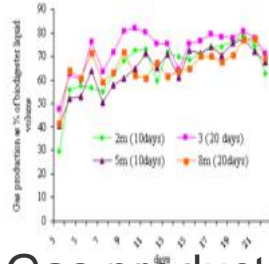
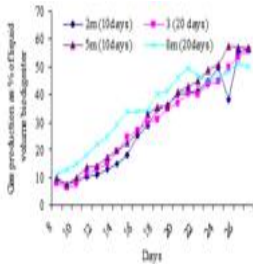
Biogas production

Adaptation period



After inoculation of the biogas digester and an adaptation period of about 8 days, the biogas digesters 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 biogas digester dimensions for gas production as litres per kg DM (and OM) of manure, or as proportion biogas digester liquid volume (Table 9).

Gas production in different countries

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

HRT, day	Biogas digester length, m				SEEP
	2	3	5	8	
Literally DM					
10	233	404	870	962	40,290.43
20	272	437	823	1090	
Mean	253	420	847	1026	31,690.003
Literally OM					
10	73.4	86.9	83.1	78.3	3,540.27
20	88.8	91.7	83.5	86.4	
Mean	81.1	89.2	84.3	82.4	2,780.18
Literally CH4					
10	192	124	134	112	4,970.21
20	127	127	119	120	
Mean	114	126	126	115	3,910.16
Biogas production per liquid volume, m³/m³					
10	8.49	8.56	8.56	8.3	0.030.27
20	8.57	8.61	8.53	8.57	
Mean	8.53	8.58	8.55	8.54	0.030.17
% of liquid volume					
10	49.0	56.4	56.2	50.4	3,710.17
20	57.1	61.1	53.0	57.1	
Mean	53.0	58.7	54.6	53.7	1,960.17

The biogas production differed among the countries with highest values for Cambodia, followed by Lao, Vietnam and Thailand (Table 10). We have no obvious explanation for these differences.

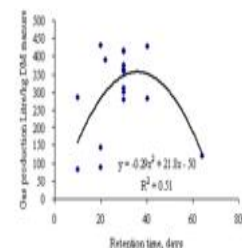
Table 10: Gas production in different countries using the literature of biogas

	Cambodia	Lao	Vietnam	Thailand	SE
Literally DM	122	74	87	11	3,010.17
Literally OM	38	82	53.6	21	2,040.17
Literally CH4	24	18	17	12.4	7,000.17
% of liquid volume	64	71	57	11.8	1,960.17

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: The interaction of retention time and digester length on gas production

HRT, day	Biogas digester length, m				SEEP
	2	3	5	8	
Literally DM					
10	233	404	870	962	40,290.43
20	272	437	823	1090	
Mean	253	420	847	1026	31,690.003
Literally OM					
10	73.4	86.9	83.1	78.3	3,540.27
20	88.8	91.7	83.5	86.4	
Mean	81.1	89.2	84.3	82.4	2,780.18
Literally CH4					
10	192	124	134	112	4,970.21
20	127	127	119	120	
Mean	114	126	126	115	3,910.16
Biogas production per liquid volume, m³/m³					
10	8.49	8.56	8.56	8.3	0.030.27
20	8.57	8.61	8.53	8.57	
Mean	8.53	8.58	8.55	8.54	0.030.17
% of liquid volume					
10	49.0	56.4	56.2	50.4	3,710.17
20	57.1	61.1	53.0	57.1	
Mean	53.0	58.7	54.6	53.7	1,960.17



Conclusions

Acknowledgement

The authors would like to thank the Swedish Agency for Research Cooperation with Developing Countries (SAREC) for funding this study through the regional MEKARN project, and all friends and research teams in riparian countries for their cooperation during the experiment.

References

1. AOAC 1990 Official Methods of Analysis. Association of Official Analytical Chemists. 15th edition (K elrick editor) Arlington pp 1230
2. Boodoo A, Delaitre C and Preston T R 1979 Effect of retention time on biogas production from slurry produced by cattle fed sugar cane. *Tropical Animal Production* 4:21
3. Bui Xuan An and Preston T R 1995 Low-cost polyethylene tube biodigesters on small-scale farms in Vietnam. *Electronic Proceedings, Second Int. Conf. on Increasing Animal Production with Local Resources*, p.11. Zhanjiang, China
4. Bui Xuan An and Preston T R 1999 Gas production from pig manure fed at different loading rates to polyethylene tubular biodigesters. *Livestock Research for Rural Development* (11) 1: <http://www.cipav.org.co/lrrd/lrrd10/3/an111.htm>
5. Bui Xuan An, Preston T R and Dolberg F 1997 The introduction of low-cost polyethylene tube biodigesters on small scale farms in Vietnam, *Livestock Research for Rural Development*, 9:2 <http://www.cipav.org.co/lrrd/lrrd9/2/an92.htm>
6. Duong Nguyen Khang, Le Minh Tuan and Preston T R 2002 The effect of fibre level in feedstock, loading rate and retention time on the rate of biogas production in plug-flow and liquid displacement biodigesters. *Proceeding biodigester workshop March 2002*. <http://www.mekarn.org/procbiod/khang.htm>
7. Hamilton D W, Sharp P R and Smith R J 1984 The Operation Characteristics of a manure digester for 60 beef cattle. Agriculture Engineering Department, Iowa state University, Ames. Journal paper No. J-11879 of the Iowa Agriculture and Home economic experimental station.
8. Hayes T D, Jewell W J, Dell, Orto S, Fanfoni K J, Leuschner A P and Sherridan D R 1979 Anaerobic digestion. *Appl. Sc. London, UK*
9. Lotte C, Lassen M and Nielsen K H 1996 Evaluation of Small Scale Biogas digesters in Turiani, Nronga and Amani, Tanzania <http://www.ihh.kvl.dk/hml/php/tune96/16Knielsen.htm>.
10. Polprasert C, Edwards P, Rajput V S and Pacharaprakiti C 1985 Integrated Biogas Technology in the Tropics Performance of Small Scale Digesters, Waste management and Research 1986. Asian Institute Technology Thailand
11. Polprasert C, Edwards P, Rajput V S and Pacharaprakiti C 1982a Recycling rural and urban night soil in Thailand. Asian of Institute Technology research report no 143.
12. Safley L M, Vetter R L and Smith L D 1987 Management and Operation of a full scale poultry waste digester. *Poultry Science* 66:941-945
13. San Thy and Preston T R 2003 Effluent from biodigesters with different retention times for primary production and feed of Tilapia (*Oreochromis niloticus*). MSc Thesis, MEKARN-SLU
14. San Thy, Preston T R and Ly J 2003: Effect of retention time on gas production and fertilizer value of biodigester effluent. *Livestock Research for Rural Development* 15 (7). Retrieved , from <http://www.cipav.org.co/lrrd/lrrd15/7/sant157.htm>
15. San Thy, T R Preston and J Ly 2003 Effect of retention time on gas production and fertilizer value of biodigester effluent, *Livestock Research for Rural Development* 15 (7) 2003, <http://www.cipav.org.co/lrrd/lrrd15/7/cont157.htm>
16. Soeurn Than 1994. Low cost biodigesters in Cambodia. *Proc. National Seminar-workshop in sustainable Livestock Prod. on local feed resources. Agric. Pub. House Ho Chi Minh*, pp.109-112.
17. Undersander D, Mertens D R and Thiex N 1993 Forage analysis procedures. National Forage Testing Association. Omaha pp:154.

Citation of this paper



Oui