

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

San Thy, P Buntha, T Vanvuth, T R Preston\*, Duong Nguyen Khang\*\*, Soukanh K\*\*\*, Boualong Phouthone\*\*\*, Choke Mikled\*\*\*\* and N Sopharoek

*CelAgrid, UTA Cambodia,*

[thy.pfd@online.com.kh](mailto:thy.pfd@online.com.kh)

*\*University of Tropical Agriculture Foundation, Colombia,*

[trpreston@mekarn.org](mailto:trpreston@mekarn.org)

*\*\* Nong Lam University, Vietnam*

*\*\*\* National Agriculture Forestry Research Institute, Lao PDR*

*\*\*\*\* Chiang Mai University, Thailand*

### Abstract

The treatments arranged as a 4\*2 factorial were: Length and diameter ratio and retention time of plastic plug-flow biodigesters. The design was a single changeover with experimental periods of 40 days on each retention time. The length: diameter ratios were 8:0.6, 5:0.6, 3:0.6 and 2:0.6m with hydraulic retention times of 10 or 20 days. For each retention time, the amount of manure (DM) was kept constant by adding water according to retention times. The manure solid concentration in the influent for 10 days retention time was 4 % and for 20 days was 8 %.

The proportion of ammonia-N in total N increased markedly with different forms from the raw manure of 13.2±1.83, influent slurry in the range of 27.55± 3.05 and the effluent of 48.17±1.27 as per cent.

Biogas production as litres per 100 litres liquid volume biodigester, and ammonia concentrations in effluent, did not differ between different length:diameter ratios nor between retention times.

**Key words:** biodigester, length of biodigester, retention times, gas production, pig manure, effluent composition

### Introduction

Biodigesters play an important role in the recycling of organic wastes, producing methane-rich gas for cooking, with positive impacts on the environment and on human and animal health (Preston and Rodríguez 1998). Soeurn Than (1994) and Bui Xuan An et al (1997a) showed that biodigesters made from tubular polyethylene were well accepted when introduced to households in rural areas of Cambodia and Vietnam **because** of the low price and simple installation. The impact of the technology in South Vietnam is demonstrated by the more than 30,000 units that have been paid for and installed by farmers between 1996 and 2002 (Duong Nguyen Khang et al 2000). Biodigesters provide methane-rich gas for cooking while the effluent is a good source of fertilizer nutrients for crops growing on land and water (Kean Sophea and Preston 2001), and for fishponds (Pich Sophin and Preston 2001; San Thy and Preston 2003).

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):

- LR2: Length: diameter ratio of 2:0.63 (3:1)
- LR3: Length: diameter ratio of 3:0.63 (5:1)
- LR5: Length: diameter ratio of 5:0.63 (8:1)
- LR8: Length: diameter ratio of 8:0.63 (13:1)

#### 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.

	LR2	LR3	LR5	LR8
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	L2	L3	L5	L8
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).

**Photo 1:** The construction details of each unit of four biodigesters

## Manure

Pig manure was used in each location. The loading rate was 4 kg DM per m<sup>3</sup> 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

	<b>L2</b>	<b>L3</b>	<b>L5</b>	<b>L8</b>
Biodigester volume, m <sup>3</sup>	0.637	0.955	1.59	2.54
Liquid volume, liters	477	716	1194	1910
<b>Period 1(1-40 days)</b>				
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
<b>Period 2 (41-80 days)</b>				
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.



**Photo 2:** The inverted containers for collecting the biogas by water displacement

## 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:

- $Y_{ijk}$ : Dependent variable
- $\mu$ : Overall mean
- $T_i$ : Treatment effect
- $P_j$ : Period effect
- $A_k$ : Biodigester effect
- $e_{ijk}$ : Random error

## 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

	<b>Cambodia</b>	<b>Lao</b>	<b>Vietnam</b>	<b>Thailand</b>	<b>SE/P</b>
DM, %	33.1	35.2	29.1	26.8	2.82/0.356
OM, %	69.7	70.3	76.5	75.7	2.48/0.18
Total N, mg/kg	6221	7453	4350	7856	802.7/0.086

NH <sub>3</sub> -N, mg/kg	581	1114	654	803	77.65/0.006
NH <sub>3</sub> -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		SE	Prob
	10*	20**		
DM, %	4.78	7.38	0.286	0.001
OM, %	67.5	71.0	1.039	0.022
N, mg/litre	994	2156	161.7	0.001
NH <sub>3</sub> -N, mg/litre	297	402	22.3	0.003
NH <sub>3</sub> -N in Total N, %	32.2	20.8	1.89	0.001

\* manure/water ratio: 1:4 for 10 days retention time and solid concentration with 4%

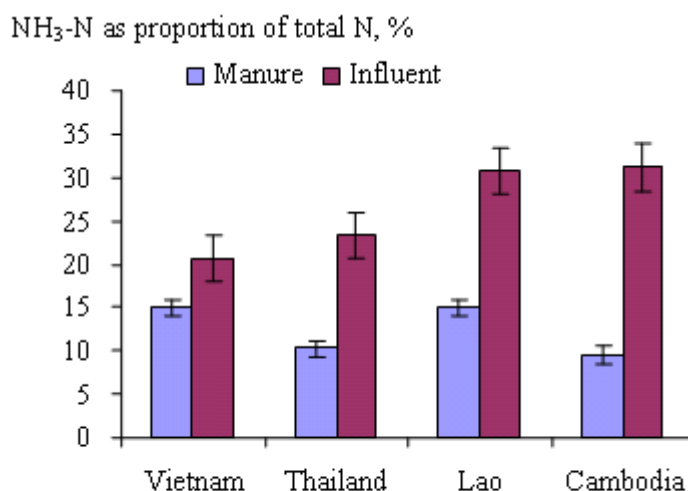
\*\*manure/water ratio: 1:1.5 for 20 days retention time and solid concentration with 8%

OM content of the DM of the manure was lower in Lao and Cambodia than in Thailand and Vietnam (Table 6). Correspondingly, NH<sub>3</sub>-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	65.1	59.0	76.2	76.7	1.47/0.001
N, mg/liter	1188	1802	1923	1386	228.7/0.001
NH <sub>3</sub> -N, mg/liter	348	511	251	288	31.6/0.001
NH <sub>3</sub> -N as % of total N					
N	31.1	30.7	23.4	20.7	2.67/0.022

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<sub>3</sub>-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

HRT, days	Biodigester length, m				SE/P
	2	3	5	8	
	DM, %				
10	3.11	5.09	3.98	5.7	0.55/0.009
20	6.72	6.24	5.07	5.53	
Mean	4.91	5.67	4.53	5.62	
	OM, %				
10	62.8	57.5	62.2	62.0	2.90/0.938
20	71.6	67.6	68.8	69.9	
Mean	67.2	62.6	65.5	66.0	
	N, mg/litre				
10	1237	1214	1349	1248	240/0.088
20	1773	2266	1237	2063	
Mean	1505	1740	1293	1656	
	Ammonia-N, mg/litre				
10	615	536	746	582	191/0.136
20	1017	886	555	1270	
Mean	816	711	650	926	
	NH <sub>3</sub> -N as proportion of total N, %				
10	50.3	44.7	60.0	49.9	5.812/0.236
20	49.0	39.0	49.9	62.3	
Mean	49.6	41.8	54.9	56.1	

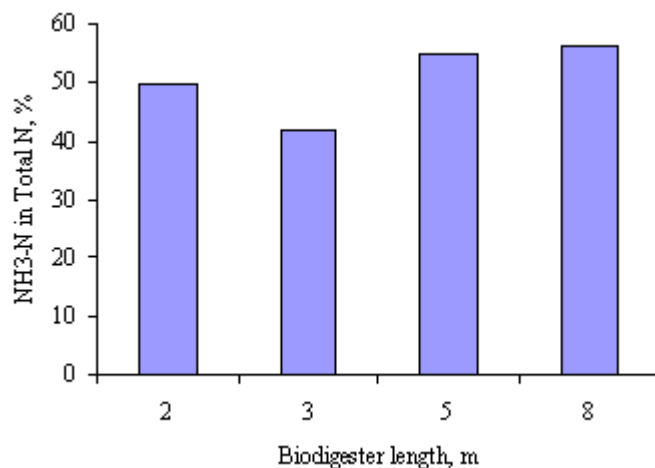
There was no effect of the manure dilution rate (retention time) on the proportion of total N in effluent in the form of ammonia (Table 8), nor of the biodigester length (Figure 2).

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

	Manure/water ratio		SE	Prob
	1:4	1:1.5		
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 <sub>3</sub> -N, mg/litre	747	1095	128.8	0.061
NH <sub>3</sub> -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/m<sup>3</sup> 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.

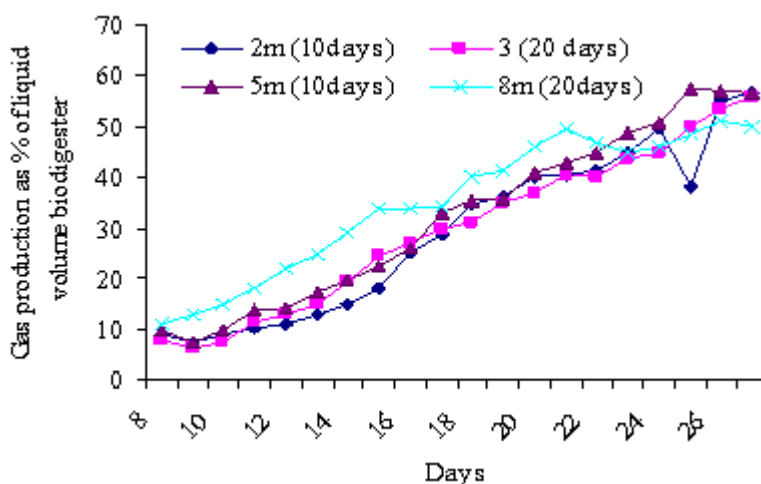


**Figure 2:** Effect of biodigester length on the proportion of NH<sub>3</sub>-N in total N in effluent

## 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).



**Figure 3:** Biogas production rate after adaptation after inoculation (period 1)

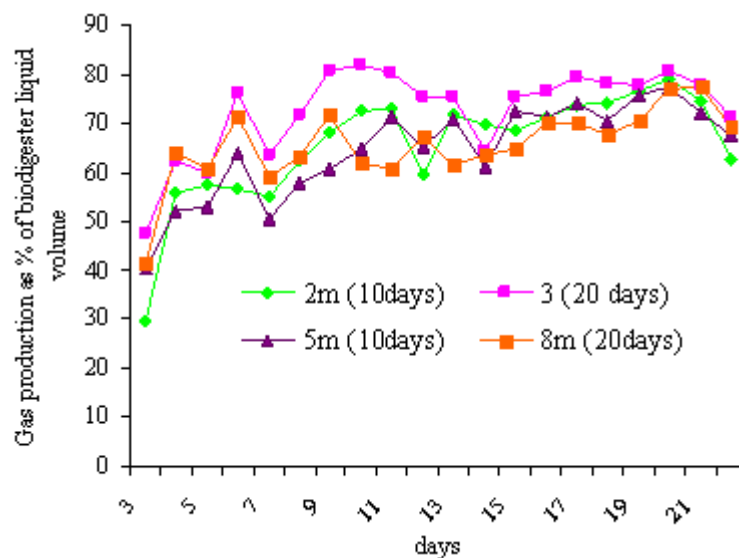


Figure 4: Biogas production rate after adaptation (period 2)

### 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				SE/P
	2	3	5	8	
	<i>Liters /day</i>				
10	233	404	670	962	40.2/0.43
20	272	437	633	1090	
Mean	253	420	652	1026	
	<i>Liters/kg DM</i>				
10	73.4	86.8	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	
	<i>Liters/kg OM</i>				
10	102	124	118	112	4.97/0.21
20	127	127	119	120	
Mean	114	125	118	115	
	<i>Biogas production per liquid volume, m<sup>3</sup>/m<sup>3</sup></i>				
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	
	<i>% of liquid volume</i>				
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	

### Gas production in different countries

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.

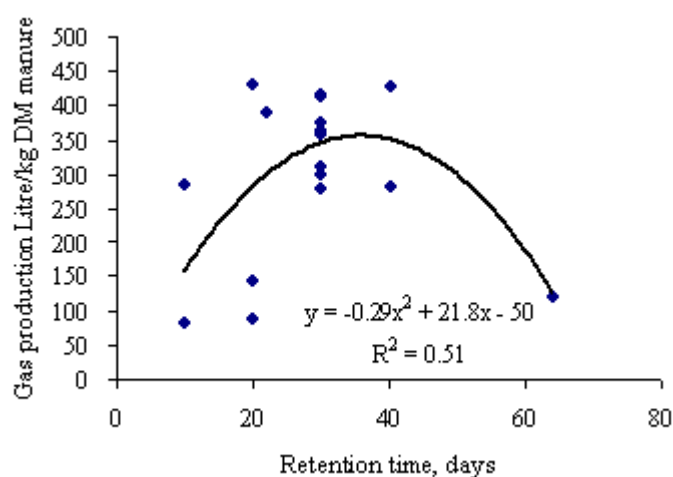
**Table 10:** Biogas production from different countries (average of four dimensions of biodigester)

	Cambodia	Lao	Vietnam	Thailand	SE/P
Liters/day	1122	754	365	110	30.3/0.001
Liters/kg DM	156	102	55.6	23.1	2.68/0.001
Liters/kg OM	224	146	72.7	32.4	3.76/0.001
% of liquid volume	104	72	32.5	11.6	1.89/0.001

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:** Effect of retention time on gas production

Retention time days	Litre/day	Litre/kg DM	Litre/kg OM	m3/m3	% as liquid vol
10	568	80.9	114	0.53	53.0
20	608	87.6	123	0.57	57.1
SE/P	23.6/0.25	2.08/0.03	2.92/0.04	0.02/0.06	1.47/0.06



**Figure 5:** Relationship between retention times and gas production (literature data: Boodoo et al 1979, San Thy et al 2004 b, San Thy et al 2003, Safley et al 1987, Polprasert et al 1982a, Hayes et al 1979, Bui Xuan An and Preston 1999, Lotte et al 1996, Khang et al 2002, Bui Xuan An et al 1995)

## Conclusions

- The diameter: length ratio did not effect rate of gas production nor the proportion of NH<sub>3</sub>-N in total N in the effluent
- The proportion of NH<sub>3</sub>-N in total N increased in the transition from manure to influent to effluent

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