

# Gas production from pig manure fed at different loading rates to polyethylene tubular biodigesters

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## Abstract

Pig manure was fed at different loading rates (0.66, 1.33, 2, 2.66 kg dry matter/m<sup>3</sup> digester liquid volume/day) to four plug-flow plastic tube biodigesters of 1.5 m<sup>3</sup> liquid volume. The design was a 4\*4 Latin square arrangement. The hydraulic retention time was 30 days and each experimental period was 8 weeks, the first 7 weeks for adaptation to the chosen loading rate and the last week for measurements. The temperature in the digester varied from 25.3 to 27.3°C and loading concentrations were 2, 4, 6, 8% of dry matter in the constant daily liquid input of 50 litres. The gas and methane yields increased linearly with increase in the loading rate ( $P < 0.001$ ) but the efficiency or gas production (gas or methane production per unit of manure dry matter loaded into the digester) was highest with the 2 kg DM / m<sup>3</sup> loading rate. The temperature of the effluent was higher than in the input material ( $P < 0.05$ ) but inlet and effluent temperature, and pH of inlet and effluent were not affected by loading rate.

*Key words: Polyethylene tube digester, loading rate, pig manure, biogas, methane*

## Introduction

In recent years biogas technology has received increasing attention due to its potential to:

- Alleviate dependence on fossil fuels
- Reduce deforestation
- Replace chemical fertilizers
- Decrease pollution caused by disposal of agricultural, industrial and sanitary wastes

Many biodigester designs have been created for individual families and communities in developing countries but the technology has not always been sustainable, mainly because of high installation costs and difficulties of maintenance associated with the classical Indian (floating dome) and Chinese (fixed dome - hydraulic displacement) designs (Marchaim 1992). In rural areas of Vietnam the greatest impact has been with the plastic tube digesters ([Bui Xuan An et al 1997a,b](#)) because of low cost (less than USD 50.00 for materials), simple installation and maintenance and the beneficial effect on the environment. Nevertheless the technology is still very new and farmers require answers to questions about "optimum" quantities of manure to be loaded into the digester, preferred ratios between manure and water, the quantities of gas that will be produced and the

working life of the plastic tube. Most current data in the literature concerning operating conditions such as loading rate and hydraulic retention time, come from temperate countries and from fixed dome or floating dome biodigester plants (Marchaim 1992). There appears to be no comparable information concerning the plug-flow tubular plastic biodigester design.

## Material and methods

### Treatments, design and procedure

The experiment was done on the experimental farm of the College of Agriculture and Forestry, of the National University of Ho Chi Minh city. Four plug-flow biodigesters made of tubular polyethylene film were mounted in shallow trenches lined with bricks, ensuring the exact dimensions of 5m length, 0.6 m depth and 0.6m width, to provide a liquid volume of 1,500 litres. The quantity and characteristics of the materials that were used and the installation procedure are set out in Appendices 1 and 2. These are the general guidelines given to farmers for installation of tubular plastic biodigesters (Bui Xun An et al 1994).

The treatments were four loading rates of pig manure equivalent to 0.66, 1.33, 2, 2.66 kg dry matter (DM) per day per 1,000 litres of liquid volume of the digester. The appropriate quantities of fresh manure were mixed with water to give a total volume of 50 litres which was added daily to each digester. This resulted in a hydraulic retention time of 30 days. Thus the loading rate treatments were equivalent to concentrations of dry matter in the input material of 2, 4, 6 and 8% (weight / volume basis). The treatments were arranged in a 4\*4 Latin square design with 4 digesters, 4 loading rates and 4 experimental periods each of 8 weeks. The first seven weeks were for adaptation to the chosen loading rate. Measurements were made during the eighth week. At the beginning of each experimental period, the biodigesters were emptied and then filled with fresh pig manure and water in the proportions indicated for each loading rate treatment. The manure was collected daily from growing pigs fed a commercial concentrate diet (Table 3). The crude protein in the manure varied from 20.3 to 27.3% in the dry matter.

**Table 1:** Experiment design with different loading rates (kg DM /m<sup>3</sup> digester liquid volume/day)

Period \ Digester	A	B	C	D
1	0.66	1.33	2	2.66
2	2.66	0.66	1.33	2
3	2	2.66	0.66	1.33
4	1.33	2	2.66	0.66

### Measurements

The dry matter content of the manure was measured weekly by drying representative samples at 105°C until constant weight in a forced draught oven. These data were used to adjust the daily quantities of fresh manure to the indicated loading rates. During each of the last 7 days of each period the following measurements were made:

- Temperature and pH (with digital pH meter) of the input and effluent material at the time of loading the digesters at 08.00 hours
- Air temperature at a point 20cm above the digesters at 05.00 and 15.00 hours
- Soil temperatures at 4 different points at a 40-cm depth and a distance of 20 cm from the digesters at 08.00 hours
- Gas production using industrial gas metres (model K875-1 of Yazaki Keiki Co., Japan) permanently connected to the gas outlets.
- The methane proportion in the gas using a Crowcon Triple Plus inflammable-gas detector

from Halma Group Co., UK.

Representative samples of manure and the feed given to the pigs were analysed for nitrogen, ether extract, crude fibre and ash following the procedures of AOAC (1980) at the beginning and at the end of each period.

## Statistical analysis

Data were analysed using the General Linear Model option of the Analysis of Variance package by Minitab (1993). The model used (after Mead et al 1993) was:

$$y_{ij} = \alpha_i + \beta_j + \gamma_{k(ij)} + \varepsilon$$

Where:

- $y_{ij}$  = record of the periods and digesters assigned to the loading rates,
- $\alpha_i$  = the effect associated with the periods,
- $\beta_j$  = the effect associated with the digesters,
- $\gamma_{k(ij)}$  = the effect associated with the loading rates in periods and digesters,
- $\varepsilon$  = the random effect.

Means were compared by Tukey= pair-wise test. Regression analysis was made using the Minitab software.

## Results and discussion

### Experimental conditions

There were no significant differences in the temperature of air and soil among the different periods (Table 2). The average air temperature ranged from 25.3 to 27.3°C. This range of temperature is suitable for mesophilic bacteria (Fair and Moor 1937, cited by Gunnerson and Stuckey 1986). The mean temperature difference between day and night was the largest (11.3°C) in period 4 when the night temperature went down to 17.8°C.

Mean values (of the four periods) for composition of the pig feed and of the resulting manure are presented in Table 3. The measured elements (crude protein, fibre, ether extract and ash) were in significantly higher concentrations in the manure than in the corresponding feed.

### Gas production

Gas production data are presented in Table 4. The gas yields differed according to loading rate ( $P < 0.001$ ), increasing linearly as the loading rate increased (Figure 1).

**Table 2:** Temperature of air and soil during the last week of each experimental period

Periods	1	2	3	4
<b>Air temp. (°C)</b>				
Maximum	32.9	27.4	27.9	29.1
Minimum	21.7	23.2	24.6	17.8
Average	27.3	25.3	26.3	26.4
Daily difference	9.2	3.8	3.3	11.3
<b>Soil temp. (°C)</b>				
	26.1	25.6	26.0	24.8

**Table 3:** Mean values ( $\pm$ SE) for chemical composition of feed and manure from the pigs

	Feed	Manure	Prob.
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There were significant differences of gas production efficiency, expressed as gas yield per unit dry matter of manure fed into the digester, between the lowest (0.66 kg DM/m<sup>3</sup>) and the higher (1.33 to 2.66) loading rates ( $P < 0.05$ ) but not among the higher loading rates.

Crude protein	17.6±4.3	24.4±1.6	0.03
Ether extract	5.26±0.75	13.7±0.23	0.002
Crude fibre	4.63±0.48	12.6±0.27	0.001
Ash	9.88±0.21	30.4±0.27	0.001

The relationship between gas production efficiency and loading rate was quadratic ( $R^2 = 0.80$ ,  $P < 0.001$ ) with the maximum efficiency recorded for the 2 kg DM/m<sup>3</sup> loading rate (Figure 2).

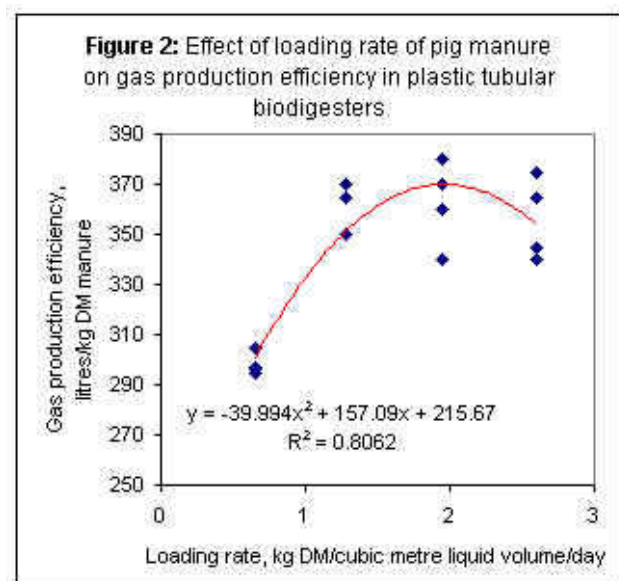
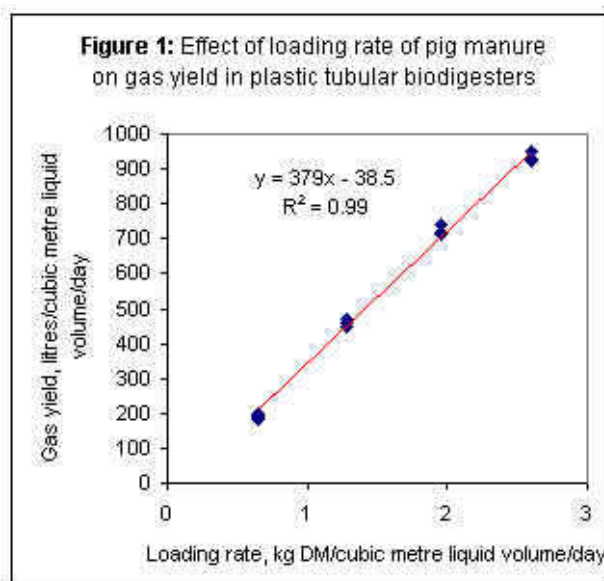
**Table 4:** Effects of loading rates (kg DM/m<sup>3</sup> digester liquid volume) on gas production in plastic tubular digesters

Yongfu et al (1989) concluded that in summer and autumn (25-27°C), the optimum DM concentration of material entering the digester is 6%. Data from tubular plastic digesters fed cow dung (Boodoo et al 1979) showed a linear increase from 2 to 6% DM.

The range of DM concentration that biogas fermentation requires is rather wide, usually from 1% to 30% (Yongfu et al 1989). The experience from field studies in Vietnam indicated loading concentrations in the range 2% to 8% DM and loading rates from 0.1 to 1.2 kg DM/m<sup>3</sup> digester liquid volume (Bui Xuan An et al 1997a). Practical observations in the field (Bui Xuan An, unpublished data) indicate that with higher concentrations, the mixing of the manure and water is difficult and the flow of digester contents is disturbed, especially after the digesters have been in use for a long time.

	Loading rate (kg DM/m <sup>3</sup> digester)				
	0.66	1.33	2.0	2.66	SE/Prob
Loading rates achieved, kg DM/m <sup>3</sup> liquid volume	0.65	1.28	1.95	2.6	
Loading concentration achieved, (% DM)	1.94	3.85	5.84	7.79	
Gas yield (litres/m <sup>3</sup> liquid volume)	193 <sup>a</sup>	466 <sup>b</sup>	729 <sup>c</sup>	932 <sup>d</sup>	22/0.001
Gas production efficiency, litres/kg DM manure	299 <sup>a</sup>	363 <sup>b</sup>	374 <sup>b</sup>	359 <sup>b</sup>	21/0.008
Methane ratio (% v/v)	56	54	55	55	2/0.19
Methane yield, litres/m <sup>3</sup> liquid volume	112 <sup>a</sup>	256 <sup>b</sup>	402 <sup>c</sup>	512 <sup>d</sup>	13/0.001
Methane production efficiency, litres/kg DM manure	167 <sup>a</sup>	196 <sup>b</sup>	206 <sup>c</sup>	197 <sup>b</sup>	4/0.003

*abcd Treatment means within rows with different superscripts differ significantly ( $P < 0.05$ )*



The potential yield of biogas from manure is the volume of biogas produced by a unit of DM in 60 days of fermentation (hydraulic retention time) at a temperature below 35°C and a DM

concentration on the input material of 6% (Yongfu et al 1989). According to these authors, the average potential value of pig manure from several institutes in China was 393 litres per kg of dry matter. The results of the present study showed a yield close to 95% of the value quoted above.

Comparing data from this experiment and from field observations (Bui Xuan An et al 1997a), it was observed that on-farm gas yield (litres/m<sup>3</sup> digester volume) and the gas production efficiency (litres/kg DM manure) were similar to our results at the lower loading rate (0.7 kg per cubic metre digester volume). In order to increase gas production, it is recommended that the farmers should increase the amount of manure fed into the digester (up to 2 kg DM per cubic metre digester volume) and reduce the amount of water. However, as noted earlier, this should be done with caution so that manure concentrations do not exceed the 6-8% dry matter in the input which appears to be the ceiling above which scum formation and interrupted flow inside the digester become problems

## Methane production

The concentration of methane in the biogas was relatively constant at all loading rates, thus trends in methane yield and in methane production efficiency followed closely those of the biogas.

## pH and temperature

It is recommended that the pH of the digester contents value of the slurry should be maintained above pH 7 for maximum gas production. In our experiment, the effluent pH varied little within the range of 6.4 and 6.6 (Table 5).

Average temperature was higher (P=0.003) in the effluent (26.3±0.087) than in the input material (25.5±0.11) which is in accordance with the known exothermic characteristics of a mesophylic fermentation (Murthy and Kulshrestha 1985).

**Table 5:** Effects of loading rates (kg DM/m<sup>3</sup> digester liquid volume) on temperature and pH of loading and effluent from plastic tubular digesters

	Loading rate ( kg DM /m <sup>3</sup> liquid volume)				
	0.66	1.33	2	2.66	SE/Prob.
Loading temperature	25.4	25.5	25.3	25.8	0.95 /0.50
Effluent temperature	26.0	26.4	26.3	26.3	0.21 /0.70
Loading pH	6.47	6.57	6.62	6.48	0.07 /0.45
Effluent pH	6.47	6.57	6.62	6.48	0.07 /0.45

## Conclusions and recommendations

In polyethylene tube biodigesters, the biogas and methane yields increased linearly with increasing loading rates, but there was a tendency for the highest efficiency of biogas and methane production at 2 kg DM /m<sup>3</sup> digester liquid volume/day of loading rate. The optimum loading rate of pig manure in polyethylene tube biodigesters at 25-27°C was 2 kg DM /m<sup>3</sup> digester liquid volume/day. In order to increase gas production, the farmers should feed more manure and reduce the amount of water loaded to the digester.

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## Appendix 1: Materials for a family sized polyethylene tubular digester

### Biodigester

- Transparent polyethylene tubular film of 280cm circumference (89cm diameter; thickness about 0.2mm). The thickness can be estimated by the weight of a given length of tube which should normally be 10 kg for 20m of length.
- 2 ceramic tubes of 100cm length and 15cm internal diameter (id).
- 2 m of 21mm id plastic hosepipe.
- 2 PVC adapters (male and female) of 21mm id.
- 2 rubber washers (from car inner tube) of 10cm diameter and 1mm thickness with a 21mm diameter central hole.
- 2 PVC washers of 10cm diameter and 1mm thickness with 21mm central hole.
- 2 m of PVC pipe of 21mm id.

- 5 to 20m of PVC 21mm id rigid tube or flexible plastic hose-pipe (the length depends on the distance from digester to the kitchen).
- 4 waste car inner tubes cut into 5cm bands.
- 1 transparent plastic bottle.
- 1 PVC elbow of 21mm id.
- 3 PVC "T" pieces of 21mm id.
- 1 tube of PVC cement.

### Single stove for cooking:

- *3 steel tubes of 21mm id, each 10cm long.*
- *1 tap of 21mm id.*
- *1 metal elbow of 21mm id*

### Appendix 2: Procedure for installing a polyethylene tube digester.

- A trench is dug to receive the biodigester. The walls must be firm and the floor must be flat or with only a minimum slope. There must be no sharp stones or protruding roots in the walls or floor.
- The cross-section of the trench for a tubular film biodigester of 90 cm diameter has dimensions of 90 cm width at the top, 70 cm width at the bottom, and 70 cm depth. The length depends on the amount of manure available. The average is 10 m which requires manure from at least 2 cows or 8 pigs.
- Two lengths of the polythene tube are cut, each 11 m long (for 10 m long biodigester), laid on smooth ground, and one inserted into the other.
- A small hole is made in the two layers of the plastic tube, approximately 1.5 m from one of the ends. One PVC and one rubber washer are fitted on the flange of the male adapter which is then threaded through the hole from the inside to the outside. A second PVC washer and rubber washer are put on the male adapter from the outside of the tube and secured tightly with the female adapter. The exit of the female adapter is closed temporarily with a small square of plastic film and a rubber band.
- A ceramic pipe is inserted to two thirds of its length into one end of the plastic tube. The plastic film is folded around the pipe and secured with 5cm wide rubber bands (made from the used inner tubes). The bands are wrapped in a continuous layer to cover completely the edges of the plastic film, finishing on the ceramic tube. The inlet tube is then closed temporarily with a square of plastic (or a plastic bag) and a rubber band. From the open end, air is forced into the tube in waves formed by flapping the end of the tube. The tube is then tied with a rubber band about 3m from the end so that the air does not escape. The procedure for fitting the outlet tube is the same as for the inlet tube. The complete assembly is then carried carefully to the trench and placed inside. The ceramic tubes are laid at 45° inclination and fixed temporarily.
- A safety valve is made from a transparent plastic bottle, a T-piece and 3 PVC tubes (one of 6 and the other two of 30 cm length). Water is poured into the bottle and maintained at 5 cm depth (above the mouth of the tube).
- The biodigester is filled with water up to two thirds of the depth, moving up and down the outlet (as indicator of the water level inside the tube). The air trapped inside the tube escapes from the safety valve as the volume of water increases.
- The gas pipe leading to the kitchen is then attached (it must not be on the ground and the water trap should be at the lowest point in the gas line).
- The gas reservoir is made from a length of polyethylene tube (3-4 m) and a PVC "T". It can be located horizontally or vertically but should be shaded from the sun and have a weight (brick or stone) suspended from the bottom to increase the pressure. It is fitted into the gas

line as close as possible to the kitchen to maximize the rate of gas flow to the burner since the system operates at very low pressure (only 3-5cm water head).

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