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# 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*
**University of Tropical Agriculture Foundation, Colombia,*
*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 wee 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 pfor ent.

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 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

| | L2 | L3 | L5 | L8 |
|---|---|---|---|---|
| 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.

**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:

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

Where:

- $Y_{ij\,k}$: Dependent variable
- $\mu$: Overall mean
- $T_i$: Treatment effect
- $P_j$ : Period effect
- $A_k$ : Biodigester effect
- $e_{ijk}$ : Ramdom 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 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 | 2.82/0.356 |
| 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 |

| | | | | | |
|---|---|---|---|---|---|
| $NH_3$-N, mg/kg | 581 | 1114 | 654 | 803 | 77.65/0.006 |
| $NH_3$-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*** | **20**** | **SE** | **Prob** |
| 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 |
| $NH_3$-N, mg/litre | 297 | 402 | 22.3 | 0.003 |
| $NH_3$-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, 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 | 65.1 | 59.0 | 76.2 | 76.7 | 1.47/0.001 |
| N, mg/liter | 1188 | 1802 | 1923 | 1386 | 228.7/0.001 |
| $NH_3$-N, mg/liter | 348 | 511 | 251 | 288 | 31.6/0.001 |
| $NH_3$-N as % of total 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).

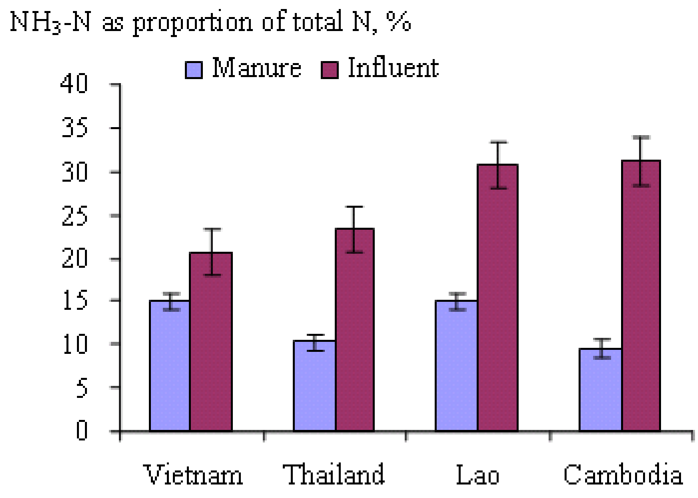


**Figure 1**: Effect of adding water to pig manure on the proportion of $NH_3$-N in total N

## 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** | **3** | **5** | **8** | SE/P |
| | 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 | 0.40/0.113 |
| | 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 | 2.08/0.423 |
| | N, mg/litre | | | | |
| 10 | 1237 | 1214 | 1349 | 1248 | 240/0.088 |
| 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 | 5.812/0.236 |
| 20 | 49.0 | 39.0 | 49.9 | 62.3 | |
| Mean | 49.6 | 41.8 | 54.9 | 56.1 | 4.17/0.06 |

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.

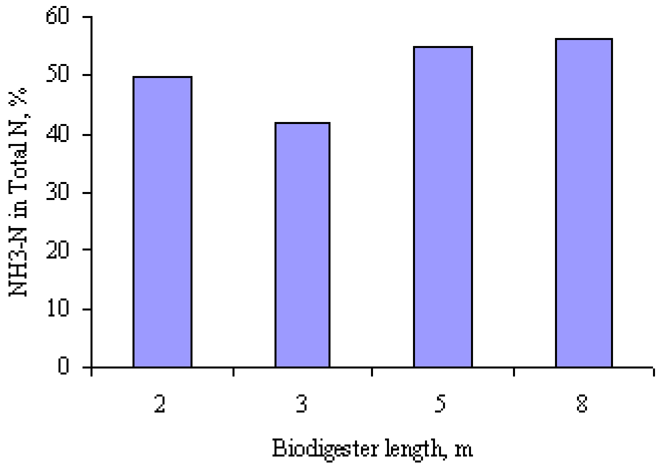


**Figure 2:** Effect of biodigester length on the proportion of NH3-N in total N in effluent

## 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).

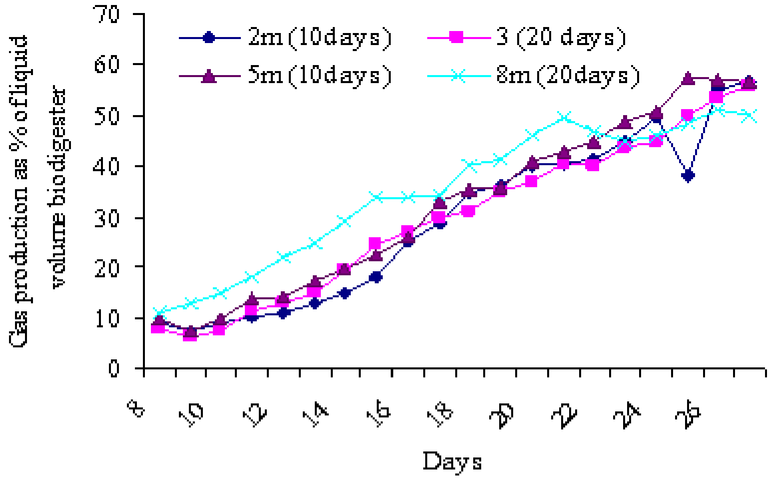


**Figure 3**: Biogas production rate after adaptation after inoculation (period 1)

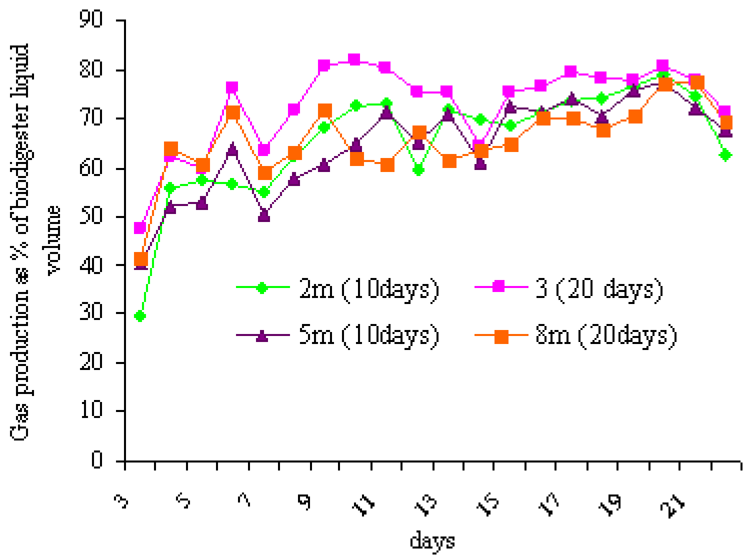


**Figure 4**: Biogas production rate after adaptation (period 2)

### *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

| | Biodigester length, m | | | | |
|---|---|---|---|---|---|
| HRT, day | 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 | 86.8 | 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 | 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**: 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 |

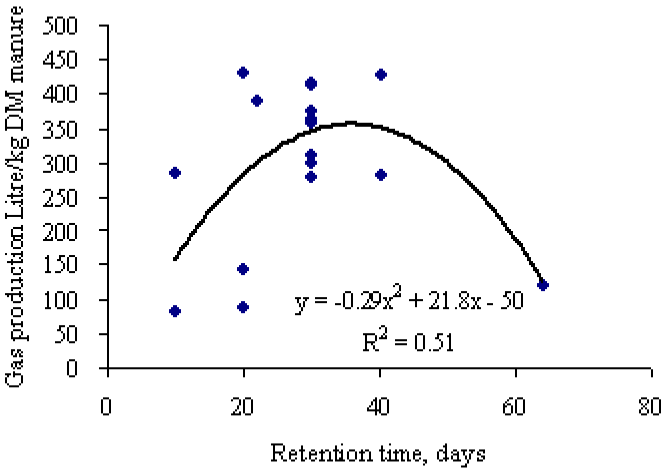


**Figure 5**: Relationship between retention times and gas production (literature data: Boodoo et al 1979, San Thy et al 2004 b, San Thy et al 2003, Safley et al 1987, Polprasert et al 1982a, Hayes et al 1979, Bui Xuan An and Preston 1999, Lotte et al 1996, Khang et al 2002, Bui Xuan An et al 1995)

## Conclusions

- The diameter: length ratio did not effect rate of gas production nor the proportion of $NH_3$-N in total N in the effluent
- The proportion of NH3-N in total N increased in the transition from manure to influent to effluent

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