

The optimization of gas production in tubular plastic biodigesters by charging with different proportions of pig and cattle manure

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Abstract

This experiment of 150 days duration consisted of five treatments, with proportions of cattle and pig manure of 100:0, 75:25, 50:50, 25:75 and 0:100. (DM basis) in a 5x5 Latin Square arrangement of five proportions of manure mixtures, five biodigesters and five periods. The first 20 days of each period was for adaptation followed by 10 days of measurements. Five plug-flow biodigesters were installed using tubular polyethylene film (internal diameter 0.64m; 2m length) with total volume of 640 litres, of which 80% corresponded to the liquid volume equal to 510 litres. The solids concentration was fixed at 6.54% and applied to every treatment with loading rate of 3.27 kg DM manure per cubic metre of liquid volume. The retention time was fixed at 20 days, requiring a daily input of 25.5 litres of manure-water mixture.

When the proportion of pig manure was increased the rate of gas production was increased by more than 50%. when the cattle was 100% replaced by pig manure. The proportion of ammonia-N in total N increased as the manure was mixed with water (influent) and after being fermented in the biodigester (effluent), with higher values when the manure was from pigs rather than cattle.

It is concluded that compared with manure from pigs, manure from cattle produces less biogas and effluent of lower fertilizer value. It is suggested that it may be more appropriate to recycle cattle manure through earthworms rather than using it as substrate in biodigesters.

Key words: Ammonia, biodigesters, cattle, gas production, manure, pigs

Introduction

Developing countries are facing a low living standard and dangers to the environment because of increasing population, exploitation of natural resources and growth of industries, and at the same time increasing demand for food and fuel. These problems have led to scientific and social imitatives focused on sustainable development including the use of renewable energy sources. In ASEAN member countries, energy from biomass such as wood and agricultural residues represents about 40% of the total energy consumption, equivalent to some 2.5 million Tetra-joules per year. The bulk is from wood, with an estimated value of US\$ 7 billions per year (Biomass energy in ASEAN member countries 1997).

The world presently derives some 60% of its energy from fossil fuels. The supplies of these are limited and at projected future rates of consumption are likely to be depleted well before the end of this century (ASPO 2002).

There is therefore an urgent need to develop alternative energy sources. For rural areas, the use of local resources in integrated farming systems is projected to bring most benefit to small scale farmers and the environment (Leng and Preston 2005). The recycling of live stock wastes through biodigesters to produce biogas for cooking and nutrient-rich effluent as fertilizer is one of the ways to reduce dependence on fossil fuel-derived inputs in an environmentally friendly way that benefits small scale farmers (Preston 2000).

Recent research has shown that the effluent from biodigesters is a better fertilizer than the original manure when applied to crops such as cassava and duckweed (Le Ha Chau 1998a,b) or when used in fish ponds (Pich Sophin and Preston.2001).

Small scale farmers in Cambodia usually keep small numbers of both pigs and cattle, the former as a source of income in times of need and the latter as an investment. The manure from both species can be used as substrate in biodigesters; however, there are no comparative data in the Cambodian context on their relative values for this purpose.

In Cambodia, pigs are generally fed a more balanced diet than are the cattle for which the main feed resources are grazing

on rice field stubbles and rice straw. It is therefore hypothesized that gas production and effluent composition will be superior when biodigesters are charged with manure from pigs rather than from cattle.

Methods and Materials

Location and timing

The experiment was carried out at the CelAgrid experimental farm, in Khandar province. It lasted for 150 days, from April 6 to August 11, 2004.

Design

The trial comprised five treatments, consisting of different proportions of pig and cattle manure (P and C).

- 100% of pig manure and 0% of cow manure (P100C0)
- 75% of pig manure and 25% of cow manure (P75C25)
- 50% of pig manure and 50% of cow manure (P50C50)
- 25% of pig manure and 75% of cow manure (P25C75)
- 0% of pig manure and 100% of cow manure (P100C0)

The proportions of pig and cattle manure were converted from dry to fresh for loading into the biodigester. The experimental design was a Latin Square arrangement of five treatments and five periods, each of 30 days (Table 1). The first 20 days of each period were for adaptation to the treatment followed by 10 days of measurement. The hydraulic retention time was fixed at 20 days.

Table 1: Allocation of treatments

| Days \ biodigester | I | II | III | IV | V |
|--------------------|--------|--------|--------|---------|--------|
| 0-30 | P100C0 | P75C25 | P50C50 | P25C75 | P0C100 |
| 31-60 | P75C25 | P50C50 | P25C75 | P0C100 | P100C0 |
| 61-90 | P50C50 | P25C75 | P0C100 | P100 C0 | P75C25 |
| 91-120 | P25C75 | P0C100 | P100C0 | P75C25 | P50C50 |
| 121-150 | P0C100 | P100C0 | P75C25 | P50C50 | P25C75 |

Biodigesters

Five plug-flow biodigesters were installed using tubular polyethylene film (internal diameter 0.64m; 2m length) (San Thy et al 2003). They were installed in an area with the same microclimate condition and overall environment. Total biodigester volume was 640 litres, of which 80% corresponded to the liquid volume equal to 510 litres.

Manure application and management

Pig manure was bought from a nearby, and stored in an enclosed plastic bag for two days prior to use. Cattle manure was collected each morning from animals in an experiment in CelAgrid, in which the basal diet was untreated rice straw and ensiled cassava foliage. The loading rate was fixed at 3.27 kg manure DM per cubic metre of biodigester liquid volume. The the actual amounts were determined according to the experimental treatment and the DM content of the manures. Water was added to give a solids content (DM) of 6.54% for every treatment. Thus the total daily charge to the biodigester was 25.5 litres of suspended manure and water.

Table 2: The quantity of manure in mixtures and water according to DM of manure types

| | Ratios of pig manure to cattle manure as % | | | | |
|------------------------------------|--|------------|------------|------------|------------|
| | 100: 0 | 75: 25 | 50: 50 | 25: 75 | 0: 100 |
| Total daily charge, litres | 25.5 | | | | |
| Loading rate, kg DM/m ³ | 3.27 | | | | |
| Total manure, kg DM/day | 1.64 | | | | |
| Solid concentration, % | 6.54 | | | | |
| Manure DM, kg/day | 1.64: 0.00 | 1.23: 0.41 | 0.82: 0.82 | 0.41: 1.23 | 0.00: 1.63 |
| Manure fresh, kg/day | 5.1: 0.00 | 3.8: 1.6 | 2.5: 3.2 | 1.3: 4.8 | 0.00: 6.4 |
| Water added, litres/day | 20.5 | 20.1 | 19.7 | 19.4 | 19.1 |

Measurements

Samples of fresh pig and cattle manure and the corresponding effluents were taken daily on days 1 to 10 of the measurement period immediately before (manure) and after (effluent) charging the biodigester. They were stored in a refrigerator at -20°C until required for analysis. At this point the samples were thawed, bulked over the 10 day measurement period and analyzed for nitrogen and ammonia using a Foss-Tecator Kjeldahl apparatus and for organic matter by asking the samples in a furnace oven (AOAC 1990). DM content was determined by microwave radiation (Undersander et al 1993). Gas production was measured daily by collecting the gas in inverted plastic bags suspended in oil drums filled with water (San Thy et al 2003).

Statistical analyses

The data were subjected to analysis of variance (ANOVA) using the General Linear Model (GLM) of the SPSS software (Release 12.0, 2003). Two way ANOVA, descriptive statistics and regression equations were used to describe trends in gas production, and the characteristics of the manure, slurry (manure mixed with water) and effluent.

Sources of variation were: manure ratios, periods, biodigester number and error

Result and Discussion

Manure, slurry and effluent

The DM and OM contents were higher in pig than in cattle manure (Table 3). There were no differences between the manures in overall mean values for total N, ammonia N, and ammonia-N as proportion of total N.

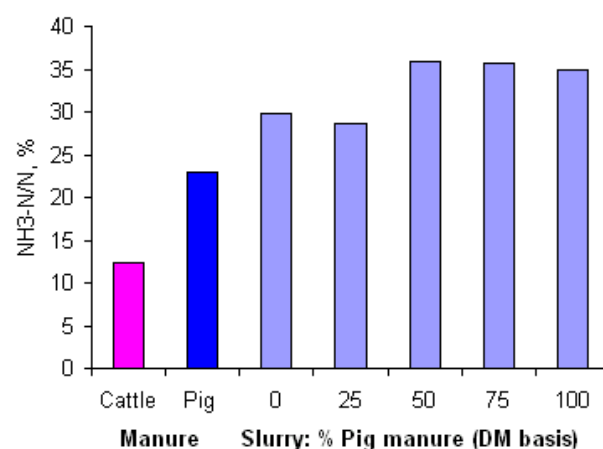
Table 3: Mean values and ranges of characteristic of pig and cattle manure during the experimental (measurement) periods (on fresh basis except for OM which is in DM basis)

| | Mean | | SE/P | Min-Max | |
|-------------------------|------|--------|------------|------------|------------|
| | Pig | Cattle | | Pig | Cattle |
| DM, % | 32.1 | 25.7 | 1.54/0.001 | 29.1- 35.2 | 20.6-28.7 |
| OM, % in DM | 82.7 | 77.1 | 1.58/0.04 | 71.5-79.2 | 76.1- 88.6 |
| N, mg/kg | 4162 | 5922 | 810/0.18 | 2183-5421 | 1673-3060 |
| NH ₃ , mg/kg | 1034 | 873 | 270/0.69 | 332-1197 | 270-903 |
| NH ₃ -N/N, % | 22.9 | 12.4 | 5.80/0.25 | 9.32-15.6 | 4.59-17.3 |

The proportion of the total N as ammonia-N increased when water was mixed with the manure (input slurry). A similar finding was reported in a previous experiment (San Thy et al 2005). In the slurry the ammonia N as % total N increased linearly according to the proportion of manure derived from pigs (Table 4: Figure 1).

Table 4: The effect of adding water to pig and cattle manure mixtures (slurry input)

| Proportion, % as | | DM, % | OM, % | N, mg/litre | NH ₃ , mg/litre | NH ₃ -N/N, % |
|------------------|------------|-------|-------|-------------|----------------------------|-------------------------|
| DM | DM | | | | | |
| Pig | Cattle | | | | | |
| 0 | 100 | 5.15 | 77.9 | 718 | 247 | 29.9 |
| 25 | 75 | 4.05 | 73.0 | 842 | 300 | 28.7 |
| 50 | 50 | 4.47 | 72.1 | 834 | 358 | 35.8 |
| 75 | 25 | 4.47 | 75.4 | 995 | 430 | 35.6 |
| 100 | 0 | 4.96 | 72.5 | 1073 | 434 | 34.9 |
| | SE | 0.683 | 3.32 | 72.7 | 47.5 | 4.47 |
| | P | 0.80 | 0.703 | 0.014 | 0.036 | 0.68 |

**Figure 1:** Mean values of ammonia-N as proportion of total N in original manure and in the slurry after mixing the different proportions (DM basis) of pig and cattle manure with water

There were no differences in the concentrations of DM, OM and total N in the effluent, but the proportion of the total N as ammonia increased linearly with increasing proportions of pig manure (Table 5: Figure 2). Increases in the proportion of ammonia-N in total N in effluent compared with influent (slurry input) have been consistently reported by Pedraza et al (2002) and San Thy et al (2003, 2005).

Table 5: The effect of biogasifier on effluent from manure mixture proportions

| Proportion, % | | DM, % | OM, % | N, mg/litre | NH ₃ , mg/litre | NH ₃ -N/N, % |
|---------------|------------|-------|-------|-------------|----------------------------|-------------------------|
| Pig | Cattle | | | | | |
| 0 | 100 | 5.18 | 69.0 | 836 | 219 | 32.2 |
| 25 | 75 | 5.42 | 74.8 | 989 | 392 | 42.9 |
| 50 | 50 | 6.23 | 68.5 | 994 | 441 | 40.1 |
| 75 | 25 | 2.71 | 67.0 | 833 | 503 | 53.7 |
| 100 | 0 | 4.03 | 61.5 | 800 | 595 | 62.6 |
| | SE | 1.04 | 4.72 | 141 | 46.2 | 7.36 |
| | P | 0.17 | 0.41 | 0.78 | 0.001 | 0.026 |

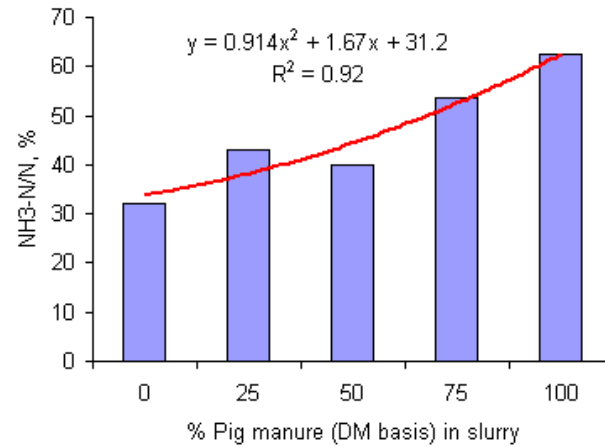


Figure 2: Relationship of ammonia-N as proportion of total N in effluent with increased pig manure in the mixtures

The concentrations of ammonia-N, as % of total N, in manure, influent (slurry) and effluent show that in all cases the values are higher when the original manure is from pigs rather than cattle (Figure 3).

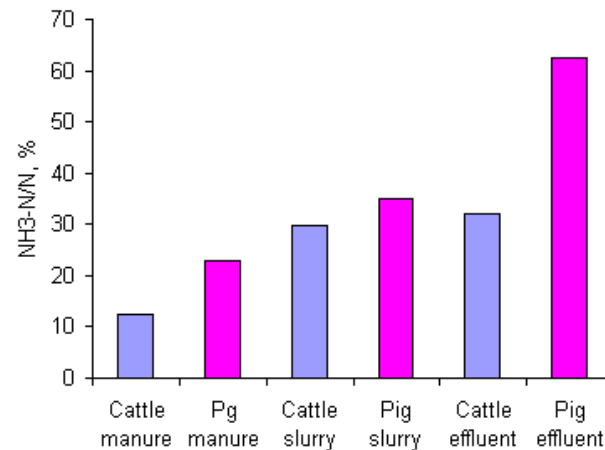


Figure 3: Comparison of the ammonia-N as proportion of total N in raw manure, slurry and effluent from pigs and cattle.

Biogas production

When the proportion of pig manure was increased the amount of gas production was increased by more than 50% (Table 6; Figures 4 and 5).

Table 6: Mean values of gas production for different proportions cattle and pig manure put into the biodigester

| Proportions | | Gas production | | |
|-------------|--------|----------------|--|--------------------|
| Pig | Cattle | Litres/day | m ³ /m ³ biodigester liquid volume | Litres/kg OM in DM |
| 0 | 100 | 193 | 0.41 | 36.7 |
| 25 | 75 | 250 | 0.52 | 50.7 |
| 50 | 50 | 273 | 0.57 | 59.4 |
| 75 | 25 | 310 | 0.65 | 72.8 |
| 100 | 0 | 322 | 0.67 | 81.9 |
| SE/P | | 19.8/0.001 | 0.047/0.001 | 4.33/0.001 |

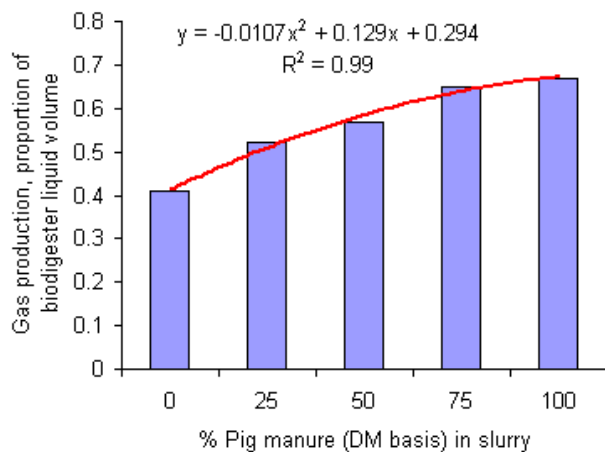


Figure 4: Relationship between biogas production as proportion of biodigester liquid volume and proportion of pig manure in the influent

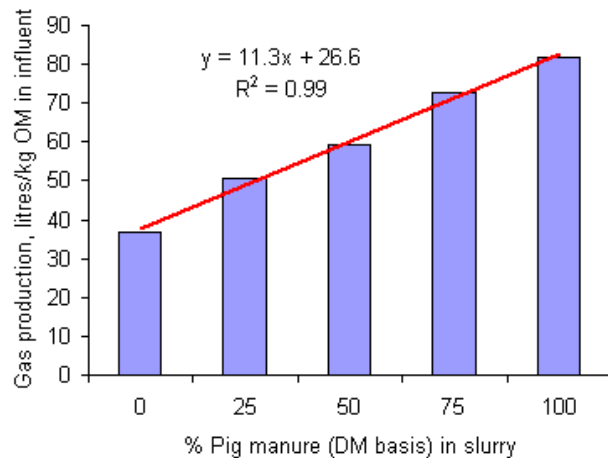


Figure 5: Relationship between biogas production per unit of OM in the influent and proportion of pig manure in the influent

Higher rates of gas production using manure from pigs (0.040 to 0.059 m³/kg) than from cattle (0.023 to 0.040 m³/kg) were also reported by Sathianathan (1975). Similar advantages for pig manure were recorded by Steffen et al (2000) (0.25- 0.5 m³/kg DM manure from pigs compared with 0.2- 0.3 m³/kg DM for cattle). These differences almost certainly reflect the higher fibre content of diets fed to cattle compared with pigs. The fact that responses in rate and efficiency of production of biogas were essentially linear, as pig manure replaced cattle manure, indicates an absence of synergism from combining the two sources of manure.

In terms of future recycling strategy, manure from cattle may be better employed as substrate for earthworms to produce compost (the worm casts) rather than as feedstock for biodigesters. By contrast, pig manure is generally considered unsuitable for earthworm culture but, as reported in this paper, it is a preferred feedstock for biodigesters.

Conclusions

- Compared with pigs, manure from cattle produced less biogas and effluent of lower fertilizer value.
- It is suggested that it may be more appropriate to recycle cattle manure through earthworms rather than using it as substrate in biodigesters.

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