International Journal of Applied Engineering Research ISSN 0973-4562 Volume 13, Number 22 (2018) pp. 16055-16059

Improving the Quality and Production of Biogas from Swine Manure and Jatropha (*Jatropha* curcas) Seeds

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Abstract

The main purpose of this study is to improve the production and quality of biogas from varying mixture levels of swine manure and ground jatropha seeds. The physico-chemical characteristics, biogas yield, methane yield and total mass removal efficiency was investigated and cost analysis was performed. Fifteen (15) portable biogas bigesters adopted from ITDI was used. Ratio of swine manure and ground jatropha seeds used as substrates in the study were varied and served as the treatments: T1 (1:0), T2 (3:1), T3 (1:1), T4 (1:3), and T5 (0:1). Preparation of the starter and feedstock, and mixing of the slurry were based on the Philippine Agricultural Engineering Standards.

Correlation of pH with the biogas yield and temperature of the slurry with biogas yield revealed strong relationship which means biogas production is dependent on the pH and temperature of the slurry. Based from the results obtained, T3 (1:1) obtained the highest biogas yield, methane yield, and total mass removal efficiency with values of 360.40 L, 199.66 L, and 95.77%, respectively. On the other hand, T5 (0:1) obtained the lowest biogas yield and methane yield with values of 84.12 L and 25.20 L, respectively. The addition of feedstock with ground jatropha seeds at optimum amount increases the biogas production and quality.

With substrate composition of 1 part swine manure and 1-part ground jatropha seeds at 1:4 dilution ratio, production and quality of biogas can be maximized. Economically, an additional return of ₱ 78.78 can be generated from adding ground jatropha seeds to swine manure.

Keywords: biogas, swine manure, ground jatropha seeds, methane

INTRODUCTION

Biogas production in animal waste and agricultural biomass is of great interest as alternative to the fossil fuels and natural gas which offers great environmental benefits. Thus, producing biogas to be the substitute for fossil fuel is very promising where greenhouse gas emissions that affect the ozone layer could be minimized and avoided. Some direct benefits from the biogas generations aside from methane is the product of a high-quality organic fertilizer. One of the promising industries in biogas production is in swine raising since it is the largest animal raising industry in the country. Studies showed that the biogas generated from swine manure is not enough to supply the energy needs.

Hence, this study aimed to increase the production and quality of biogas from swine manure and jatropha seeds. Specifically, it aimed to; (1) determine and evaluate the biogas yield and its methane yield from different mixtures of swine manure and jatropha seeds, (2) quantify the average total volatile solids mass removal efficiency from the mixture of swine manure and jatropha seeds, and (3) perform a simple cost analysis in the biogas production of swine manure and jatropha seeds.

MATERIALS AND METHODS

Conceptual Framework

Biogas production have significant goals in the Philippines: 1) energy generation and 2) waste pollution control. In most of the off-grid rural areas, energy generation is of utmost important while in populated areas where large farm animals are abundant, waste pollution control will be an attractive goal in adopting the biogas technology.

Aside from producing biofuel from jatropha oil, the potential of utilizing jatropha seeds in biogas production becomes a promising concern. In order to realize the value of jatropha seeds, these were used as feedstock for biogas production in this research activity. Figure 1 illustrates the conceptual framework of the study.

Preparation of the Starter

Starter is a term used for the initial raw material placed in the digester before the feedstock to initialize the activation of the bacteria in the digestion process. The starter was composed of swine manure and water mixture at 1:1 dilution ratio comprising the 10% of the tank capacity (200.00 L). Ten (10) kg of swine manure and 10 liters of water were mixed and placed inside the digester tank. The starter was not disturbed for 15 days to activate the bacteria.

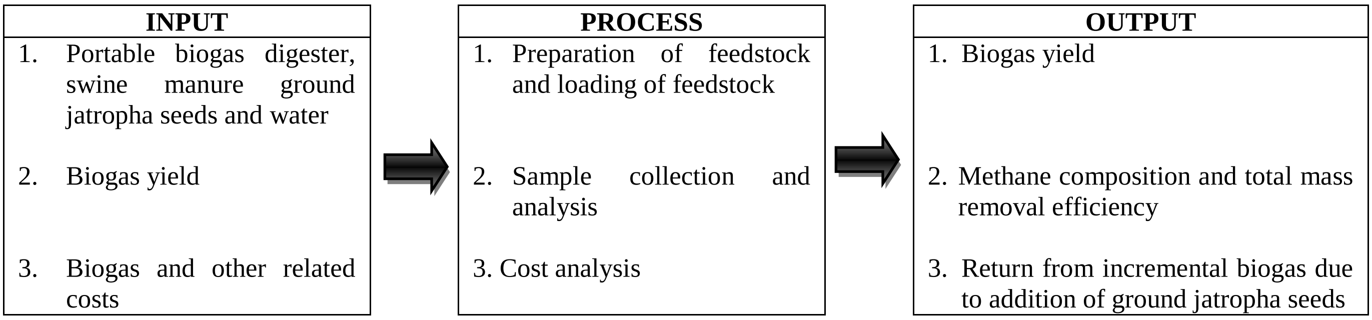

Figure 1. Conceptual framework of the study

Preparation of the Feedstock

The feedstock concentration is expressed as ratio of wet weight of swine manure and ground jatropha seeds to the weight of water. The jatropha seeds were ground using a manually operated grinder and sifted in 5-mm diameter sieves. The feedstock was prepared by diluting swine manure and jatropha seeds with water at 1:4 dilution ratio. Each 200 li-capacity digester tank was filled with only a volume of 180 li mixture to allow space for the production of biogas.

Five (5) mixing levels of the swine manure and jatropha served as the treatments which were observed for 60 days retention period. The treatments are shown in Table 1:

Table 1. Treatments used in the study

TREATMENT	MIXING RATIO (SM : GJS)*	COMPOSITION	
		Swine Manure, kg	Ground Jatropha Seeds, kg
T1	1 : 0	36.0	0.0
T2	3 : 1	27.0	9.0
T3	1 : 1	18.0	18.0
T4	1 : 3	9.0	27.0
T5	0 : 1	0.0	36.0

*SM = swine manure; GJS = ground jatropha seeds

Experimental Layout of the Study

The treatments in the study were replicated three times. Results on the mixing levels of swine manure and jatropha seeds were gathered, tabulated, and statistically analyzed using the Analysis of Variance of the Completely Randomized Design (CRD). Comparison among treatment means was done using the Duncan's Multiple Range Test (DMRT).

A yield model was done in relating the retention time and the composition of the mixture (ratio of swine manure to the ratio of ground jatropha seeds) to the yield (biogas and methane) of the biogas digesters. The retention time, ratio of swine manure, and ratio of ground jatropha seeds as the independent variables have been used in determining the equation for biogas and methane yield:

$$Y = f(X_1, X_2, X_3) \quad (1)$$

where: Y = the production yield (biogas and methane)

X_1= the retention time

X_2 = the ratio of swine manure

X_3 = the ratio of ground jatropha seeds

Mixing of the Slurry

Mixing of feedstock in each digester was done daily: three minutes in the morning and three minutes in the afternoon. The stirring in each digester was done 360º in one direction, then 360º in the opposite direction completely (PAES, 2001). Approximately, 12-15 turns in one minute.

Data Collection

Biogas collection and determination of the methane content of the produced biogas was done on the following day. The volume of gas produced was determined using the water displacement method. The volume of water displaced from the water container was assumed to be equal to the volume of gas produced from the digester. The water was measured everyday for 60 days using a beaker.

Gas samples were collected daily from each digester using a 50-mL syringe. The syringe was filled completely with gas. The 15 gas samples were injected to the port of the gas analyzer one by one to determine the methane content of the biogas.

The pH meter and thermometer were used to determine the acidity and the temperature of the slurry, respectively. The probe of the pH meter and the thermometer were placed at the water and feedstock pipe. The pH and temperature of the slurry were determined and recorded.

The physico–chemical properties of the feed material such as pH, moisture content, total solids, and volatile solids were also determined. The sample variables were collected daily.

RESULTS AND DISCUSSION

Physico-chemical Characteristics of the Feedstock

Analysis of the ground jatropha seeds showed that it had a mean of 8.3% moisture content, total solids (TS) of 91.7%, 95.0% of which was volatile solid (VS). However, the swine manure had 23% moisture content, 77.0% total solids (TS), 92.0% of which was volatile solids (VS).

pH Level

Correlation analysis was done to determine the effect of pH on the biogas production in the biogas digesters. Based on the results, there is a relationship between pH and the biogas generated in the digester (r=0.74) which means that an increase in the pH resulted in an increase in the biogas yield, and vice versa.

Temperature

Slurry temperature ranged from 25–30ºC which means that it falls under the mesophillic range of temperature. Correlation analysis revealed that there is a strong relationship between the temperature and the amount of biogas produced (r=0.94). This indicates that an increase in the temperature of the slurry would also increase the biogas produced in the portable biogas digesters and vice versa.

Biogas Yield

Table 2 showed that the highest biogas production is obtained in T3 (1:1) with a mean of 360.40 L. followed by T1 (1:0), T2 (3:1), and T4 (1:3) with biogas production of 252.26 L, 176.26 L, and 156.05 L, respectively. T5 (0:1) had the lowest biogas generation with a mean of 84.12 L. Comparison among means further revealed that biogas yield in treatments T1, T2, T3, and T4 were statistically similar as well as in T1, T2, T4, and T5. However, biogas yield in T5 is significantly lower than in T3. Addition of ground jatropha seeds to swine manure as feedstock generally increased the biogas yield. This can be attributed for in the oil content present in the jatropha seeds which helped in the degradation process.

Table 2. Biogas yield (L) as affected by varying mixture levels of swine manure and ground jatropha seeds

TREATMENT	MEAN
1 : 0	252.26[ab]
3 : 1	176.26[ab]
1 : 1	360.40[a]
1 : 3	156.05[ab]
0 : 1	84.12[b]
Grand Mean	205.82

Note: Means followed by same letter are not significantly different at 5% level of significance in DMRT.

The relationship between the o of swine manure and ground jatropha seeds are responsive to the biogas yield. The trend in biogas production using 1:1 ratio of swine manure and grounds jatropha seeds is further described by the equation:

$$Y_{biogas} = 0.391X_1 + 5.139X_2 + 1.217X_3 - 0.007X_1^2 - 2.232X_2^2 - 1.275X_3^2 - 0.423X_1X_2 - 0.0461X_1X_3 + 3.316X_2X_3 \quad (2)$$

where: Y_{biogas} = biogas yield, L

X_1 = retention time, day

X_2 = percent of swine manure

X_3 = percent of ground jatropha seeds

Methane Yield

Table 3 showed that T3 (1:1) obtained the highest methane yield with a mean of 199.66 L, followed by T1 (1:0), T2 (3:1), T4 (1:3), T5 (0:1) with means of 101.42, 56.79, 46.48, and 25.20 liters, respectively. Comparison among means further revealed that methane yield in T3 is statistically higher than those under T1, T2, T4, and T5 treatments.

Table 3. Cumulative methane yield (L) as affected by varying mixture levels of swine manure and ground jatropha seeds

TREATMENT	MEAN
1 : 0	101.42[b]
3 : 1	56.79[b]
1 : 1	199.66[a]
1 : 3	46.48[b]
0 : 1	25.20[b]
Grand Mean	77.20

Note: Means followed by the same letter are not significantly different at 5% level in DMRT.

According to Yen and Brune (2007), advantages of addition of oil to feedstock in biodigestion include hygienic stabilization and increased digestion rate. Codigestion of different materials may enhance the anaerobic digestion process due to better carbon and nutrient balance.

The trend in methane yield production as affected by T3 (1:1) in 60 days of operation is further described by the equation:

$$Y_{methane} = 0.239X_1 + 2.944X_2 + 1.013X_3 - 0.005X_1^2 - 1.013X_2^2 - 1.067X_3^2 - 0.011X_1X_2 - 0.007X_1X_3 + 2.065X_2X_3 \quad (3)$$

where: $Y_{methane}$ = the methane yield, L

X_1 = retention time, day

X_2 = percent of swine manure

X_3 = percent of ground jatropha seeds

The relationship between the swine manure and ground jatropha seeds are responsive to the methane yield with an R^2 of 0.976.

Total Mass Removal Efficiency

Total Solids

Table 4 shows the total solids content of the five treatments. The highest total solids was obtained in T5 (0:100) with 91.70% solids content. This is followed by T4 (1:3), T3 (1:1) and T2 (3:1) with total solids content of 88.30%, 86.67% and 83.60%, respectively. The lowest total solids content was obtained in T1 (1:0) which is 77.00%. Comparison among means revealed that T5, T4, and T3 were comparable to each other. Also, T2, T3, and T4 were not significantly different from each other. On the other hand, the total solids under T5 is significantly higher than those in T1.

Table 4. Total solids content (%) at varying mixture levels of swine manure and ground jatropha seeds

TREATMENT	MEAN
1 : 0	77.00^{c}
3 : 1	83.60^{b}
1 : 1	86.67^{ab}
1 : 3	88.30^{ab}
0 : 1	91.70^{a}
Grand Mean	85.46

Note: Means followed by the same letter are not significantly different at 5% level in DMRT.

Volatile Solids

Table 5 shows the volatile solids content at varying mixture levels of swine manure and ground jatropha seeds. The highest volatile solids is obtained in T3 (1:1) having a mean of 95.77%. This was followed by T5 (0:1), T4 (1:3), and T1 (1:0), and T2 with means of 95.00%, 94.27%, 92.00%, and 90.33%, respectively. Comparison among means showed that the total volatile solids in treatments T1, T3, T4, and T5 were not significantly different from each other. Volatile solids in T1 and T2 have no significant difference between their means. However, total volatile solids in T2 was significantly lower than those in T3. Volatile solids were the available solids that were converted to biogas.

Table 5. Total volatile solids (%) at varying mixture levels of swine manure and ground jatropha seeds

TREATMENT	MEAN
T1	92.00^{ab}
T2	90.33^{b}
T3	95.77^{a}
T4	94.27^{a}
T5	95.00^{a}
Grand Mean	93.47

Note: Means followed by the same letter are not significantly different at 5% level in DMRT.

Total Mass Removal Efficiency

Total volatile solids mass removal efficiency is the loss of the volatile solids during the anaerobic process due to conversion of volatile solids primarily into biogas. Table 6 showed that T3 (1:1) obtained the highest total mass removal efficiency with a mean of 95.77%, followed by T5, T4, T1 and T2 with means of 95.00%, 94.27%, 92.00%, and 90.33%, respectively.

Table 6. Total mass removal efficiency (%) as affected by varying mixture levels of swine manure and ground jatropha seeds

TREATMENT	MEAN
T1	92.00^{ab}
T2	90.33^{b}
T3	95.77^{a}
T4	94.27^{a}
T5	95.00^{a}
Grand Mean	93.47

Note: Means followed by the same letter are not significantly different at 5% level in DMRT.

Comparison among treatments means revealed that the removal efficiency in T3, T4, and T5 are not significantly different from each other. On the other hand, T2, gave a significantly lower total mass removal efficiency than T3, T4, and T5 but not significantly different from T1.

The addition of jatropha seeds in the digestion process enhances the conversion of the substrates to biogas. However, T5 which is found to be the most efficient in mass conversion gave the lowest biogas yield and methane yield.

Cost Analysis

The partial budget analysis was used in determining the feasibility of adding ground jatropha seeds to swine manure in biogas production. Computation was based on a one m^3 biogas digester capacity, 100 kg jatropha seeds, and with the following assumptions:

Cost of jatropha seeds = ₱2.00/kg

Cost of grinding = ₱0.02/kg

Cost of biogas = ₱0.37/L

Table 7 presents the added income, added cost, reduced income, reduced cost, and the net income that can be generated in using the technology.

Based on the partial budget analysis, shifting from pure swine manure to addition of ground jatropha seeds to swine manure, the cost of ₱120.00 was added to the purchase and grinding of jatropha seeds. However, an increase in income of ₱198.78 was generated from the increase in biogas yield. Therefore, a net income of ₱ 78.78/m^3 of mixture can be obtained from adopting the technology of adding ground jatropha seeds to swine manure.

Table 8. Cost analysis expressed in per m^3 of swine manure and ground jatropha seeds at 1:1 ratio.

INCREASE IN NET INCOME PER M^3 OF SWINE MANURE AND GROUND JATROPHA SEEDS MIXTURE			
Increase in Income (A)		Increase in Cost (B)	
Biogas yield	₱ 198.78	Jatropha seeds	₱ 100.00
		Grinding	₱ 20.00
Total Increase	₱ 198.78	Total Increase	₱ 120.00
Increase in Net Income (A – B)			₱ 78.78

CONCLUSION AND RECOMMENDATION

Conclusions

Based on the results of the study, the following conclusions were drawn:

1. Biogas yield and methane yield were significantly increased when a 1:1 proportion of swine manure and ground jatropha seeds is used.
2. The total volatile solid mass removal efficiency are similar when the mixing ratios of 1:1, 1:3, and 0:1 (swine manure : ground jatropha seeds) were used. These ratios had significantly higher removal efficiency where the 3:1 ratio was used.
3. The cost analysis suggests that a net income increase of ₱ 78.78/m^3 could be realized when the 1:1 ratio of swine manure to ground jatropha seeds is used. Enzyme complex loading of 6% w/w total solids was the optimum dosage for enzymatic hydrolysis of sunflower cake.

Recommendations

Based on the results of the study the following recommendations are made:

1. The 50% ground jatropha seeds and 50% swine manure are recommended for increased biogas production, increased methane production and for efficient conversion of solid into biogas production;
2. Adding of inoculum nutrient may be recommended to determine if it will further enhance the buffering capacity of the substrates (e.g. cow rumen, septage and food waste) may be used.
3. Further study on the effects of different jatropha by-products on biogas production could be done to determine the most economical advantage.
4. For large-scale biogas digesters, use of mechanical grinder is recommended.

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