Biogas Production from Hog and Poultry Manure Substrates using Plastic Drum Biogas Digester during Night and Daytime Collection

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Abstract— *Plastic drum biogas digester (PDBD) is a low-cost yet an efficient system in biogas production using different manure substrates as feedstock. Hence, this study was conducted to determine the volume of biogas produce using the PDBD system in daytime and nighttime collection using swine slurry (SS) and chicken manure (CM) as substrates. Likewise, to assess the economic feasibility of the low-cost biogas system. A 8-drum PDBD system was designed, fabricated and immersed in the manure or slurry lagoon of private piggery and poultry farms in Science City of Munoz, Nueva Ecija and San Antonio, Quezon Province, Philippines, respectively. The captured methane gas produced was observed and measured during day and night times. The volume of gas produced after 96 hours (4 days) was 2,580.64 ℓ or 1316.65 kg which tested 4 hours of uninterrupted cooking or a flow rate of 10.98 ℓ/minute using the system with SS. While, 8,856.72 ℓ which when allowed to a continuous depletion or emptying the submersion of the PDBD, the recorded time consumed was 16.5 minutes through a double burner stove with maximum level of fire using the PBDB system with CM. Higher methane captured was recorded during daytime compared to nighttime in both SS and CM substrate using the PDBD system. Lastly, the PDBD system is economically feasible. The PBDB system has proven to capture biogas or methane in an open-pit lagoon with minimal cost of production and economically viable to invest and include in a swine and poultry enterprises*.

Keywords*— *A Biogas, Chicken Manure, Methane and Swine Manure.

I. INTRODUCTION

Livestock and poultry production are significant contributors to greenhouse gas emission particularly the volatilization of methane from the manure. Moreover, methane has 23 times global warming potential compared to carbon dioxide (Phillippe et al., 2007), hence strategies for methane capture would be indispensable towards mitigating the adverse effects of climate change. The biogas digester is an appropriate design towards preventing methane emission. As a matter of fact, the use of biogas as effective farm equipment is an excellent example of sound integrated crop and livestock management. Waste from livestock such as cattle, swine and poultry can be utilized as a renewable energy source which is the biogas. Moreover, biogas sludge can be applied to crops and in ponds as source of organic fertilizer. Likewise, biogas technology will solve environmental pollution and convert livestock waste into energy, savings or income (Largo, 2012).

Presently, because of the scarcity of resources and a worldwide market competition, the hike in price of some market product is continuously increasing, and because of this, people tend to find alternatives that are lower energy cost. The search for alternative sources of non-fossil based energy has all the more been very relevant than now due to its substantial positive impact on climate change. Moreover, the use of biogas as alternative to LPG is environment friendly.

The construction of biogas facility such as the fixed dome is quite expensive due to prohibitive cost of cement, steel bars and labor. It is on this premise, that the Plastic Drum Biogas Digester (PDBD) was tested to demonstrate its techno-viability for possible prototyping and subsequently techno-commercialization. This has unique features, which include: 1) production of biogas in an open pit lagoon (unlike the fixed dome digester); 2) production of odorless CH4 gas; and 3) conversion of the biogas sludge into an organic fertilizer. Moreover, the PDBD is simple, practical, low cost, versatile, maintenance free and can be readily replicated by backyard and commercial pig farmers (Barroga, 2015). The latter researchers claimed that a four 200 - ℓ PDBD from an 8 sow level farm recorded a biogas production of 710.43 - ℓ with a flow rate of 5.92 - ℓ/minute. The savings derived with the use of biogas instead of the LPG is PhP 16.90/ℓ. The ROI was 103.30% with a Marginal Benefit Cost Ratio of 1.28 and a Payback Period of 0.97 year indicating that investing in the PDBD was financially viable. Lastly, this system of biogas production is considered novel because the plastic drum can serve as a mixer, digester floater, aerobic fermentation chamber, ammonia neutralizer, desulphizer, composting vat and a processor of a rich nutrient packed odorless effluent or pig liquid fertilizer. Hence, this study was conducted to determine the dynamics of biogas production using different animal manure substrates in day and night collection.

II. MATERIALS AND METHOD

The study was conducted in two separate locations relative to the substrate used in biogas production. For the poultry manure as substrate, it was conducted in the poultry manure lagoon of a 248,000 broiler tunnel ventilated house in Barangay San Jose, Quezon Province. While, the for the pig manure, it was conducted at ELR Family Trading Co. Inc., Brgy. Bagong Sikat, Science City of Muñoz, Nueva Ecija. The biogas flow monitoring and data collection was simultaneously done in both locations from April to May, 2017.

2.1 Experimental Setup:

The PDBD was fabricated and composed of eight 200 - ℓ plastic drum with an open bottom and a gas collection fitting above to facilitate extraction of biogas towards the cooking stove. The eight plastic drums were linked with a strong nylon thread and tied to a stable post to ensure stability during the daily biogas accumulation. This is because there was an alternate rise and fall of the floating drum when cooking is periodically done daily. The PBDB system was immersed in the poultry waste lagoon measuring 463.6 cubic while, open pit septic tank for the swine slurry. Furthermore, Odor Erasing Microbial Concoction (OEMC) was top-dressed at 5 grams per m2 twice-weekly basis in the open lagoon and open septic tank. The time of monitoring and measuring the volume of biogas production which is day time (DT) and night time (NT) served as treatments of the study. Data for total gas production from night-time and day-time collection, flow rate per minute, ℓ and depletion time per 6 inch, was replicated 4 times.

2.2 Data Gathered:

The data collected include: 1) quantity of volume of biogas trapped; 2) profitability and viability of PDBD; and 3) assess environmental impact of the PBDB. The quantity of volume of biogas trapped was expressed in: a) period to full capacity in hour, which was computed by the number of hours consumed when the PDBD is in full capacity; b) total volume of methane captured per drum computed through the formula, c) total volume of methane captured/drum = 200 ℓ x % elevation/drum ÷ 100 % ; d) flow rate, ℓ/minute computed as, flow rate/ minute = total volume of methane, ℓ/drum / time consume till full depletion, minute; and e) period every 6-inch depletion /minutes calculated as total time consumed in ℓ for every 6 inch depletion of the PDBD (a total of five six inch depletions was recorded as the length of the plastic drum is 30 inches in length). The profitability and viability of PDBD was expressed in terms of the cost to produce per ℓ of biogas, in pesos. Lastly, the economic efficiency was expressed through: return on investment, %; payback period, year; and marginal benefit cost ratio in pesos.

III. RESULTS AND DISCUSSION

3.1 Volume of Collected Biogas at Day and Night Time on Swine Manure Substrate:

Table 1 shows the comparative periodic increase in height in inch of the PDBD when collected during daytime and night-time for four consecutive days. During daytime collection, the mean elevation of the PDBD was 27.43 ± 0.28 inches while at night-time collection, it was only 15.48 ± 0.21 or a reduction rate of 43.58%. The data indicated that the DT collection of biogas resulted to a significantly ($p<0.05$) faster conversion of the slurry into biogas fuel. Therefore, the PDBD was filled up with biogas more rapidly during daytime than night-time. The faster collection of biogas at daytime apparently support the claim that biogas production can be influenced by several factors namely; 1. substrate 2. pH 3. C/N ratio and, 4. presence of inhibitory substances such as detergents, antibiotics, and antiseptic. Moreover, temperature has a strong influence over the quality and quantity of biogas production (Dobre et al., 2014). Therefore, the rapid filling up of the PDBD at daytime could be due to the activation of the Thermophilic bacteria for methane gas conversion considering that the parameter daytime temperature was higher than night-time temperature.

TABLE 1
PERIODIC INCREASE IN HEIGHT (INCH) OF THE PDBD, RELATIVE TO TIME OF COLLECTION

Day	DT	NT
1	26.70	15.00
2	28.00	16.00
3	27.70	15.40
4	27.30	15.50
Mean	27.43 ± 0.28[a]	15.48 ± 0.21[b]

DT = Daytime, 12 hours biogas collection from 6:00 AM to 6:00 PM for 4 consecutive days
NT = Night-time, 12 hours biogas collection from 6:00 PM to 6:00 AM for 4 consecutive days
DT and NT means are significantly different based on t-test ($p < 0.05$)

The comparative volume in liters of biogas captured by PDBD relative to collection time is shown in Table 2. Results showed that during the 4-day collection period, the total volume of the biogas collected at daytime was 1415.48 ± 14.49 while the total volume of biogas collected at night-time was 798.70 ± 10.63. The higher volume produced during daytime collection was consistent and related also to the higher elevation of the PDBD at daytime compared to night time. The conversion value of the volume of biogas trapped to CH4 gas in kg is 0.45 or is equivalent to 0.45 kg CH4 gas, therefore the 1415 ℓ biogas captured by the PDBD in the present study when converted to kg CH4 gas is 1.415 m3 (1000 ℓ biogas trapped = 1 m3 biogas trapped) multiplied by 0.45 was equivalent to 0.637 kg CH4 gas or 637 ℓ of CH4 gas.

TABLE 2
COMPARATIVE VOLUME OF BIOGAS CAPTURED BY PDBD RELATIVE TO COLLECTION TIME

Day	DT			NT		
	PDBD height (inch)	Calculated volume (ℓ)	Total volume (ℓ)	PDBD height (inch)	Calculated volume (ℓ)	Total volume (ℓ)
1	26.70	172.26	1378.08	15.00	96.77	774.16
2	28.00	180.64	1445.12	16.00	103.23	825.84
3	27.70	178.71	1429.68	15.40	99.35	794.80
4	27.30	176.13	1409.04	15.50	100.00	800.00
Mean	27.43 ± 0.28	176.94±1.81	1415.48±14.49	15.48±0.21	99.84±1.33	798.70±10.63

DT: Daytime collection; 6:00 AM – 6:00 PM
NT: Night-time collection; 6:00 PM – 6:00 AM
Formula: Calculated volume of biogas, ℓ = 200 ℓ x % elevation/drum

3.2 Duration of Flaring and Flow Rate of Biogas from Swine Manure:

The comparative duration of flaring of CH4 gas collected by the PDBD at DT and NT is shown in Table 3. Result disclosed that flaring duration at DT collection is 161.25 minutes and was 46.82% longer than NT collection with only 85.75 minutes. Therefore, the 8-drum PDBD is sufficient to serve the daily cooking fuel requirement of a single household of 5, with the DT collection being recommended as flaring time is equivalent to 161.25 ± 1.38 minutes or 2 hours and 65 minutes per day.

TABLE 3
DURATION OF CONTINUOUS CH_4 GAS FLOW BY TWO-BURNER GAS STOVE, MINUTES

Day	DT[1]		NT[2]	
	Total volume[3] (ℓ)	Flaring[4] (minutes)	Total volume (ℓ)	Flaring (minutes)
1	1378.08	158	774.16	84
2	1445.12	164	825.84	88
3	1429.68	163	794.80	85
4	1409.04	160	800.00	86
Mean	1415.48 ± 14.49	161.25 ± 1.38[a]	798.70±10.63	85.75 ± 0.85[b]

[1]Daytime: 6:00 AM to 6:00 PM for 4 consecutive days
[2]Night-time: 6:00 PM to 6:00 AM for 4 consecutive days
[3]Equivalent to eight 200-ℓ plastic drums
[4]Allowing methane gas flow from the PDBD to a simultaneously opened 2-burner gas stove
DT and NT means are significantly different based on t-test ($p < 0.05$).

The comparative flow rate in ℓ per minute of the biogas captured by PDBD during DT and NT for an average of 4 consecutive days is shown in Table 4. The flow rate collected during NT which was 9.31 ± 0.03 ℓ/minute was slightly faster than DT with 8.78 ± 0.02 ℓ/minute. The almost similar flow rate apparently, indicated similar pressure build up inside the PDBD. This can also be attributed to the same substrates fermented by methane fermenting bacteria.

TABLE 4
COMPARATIVE FLOW RATE OF BIOGAS CAPTURED BY PDBD DURING DT AND NT, ℓ/MINUTE

Day	DT[1]			NT[2]		
	Total volume (ℓ)	Total depletion[3] (minute)	Flow rate ℓ/minute	Total volume (ℓ)	Total depletion (minute)	Flow rate ℓ/minute
1	1378.08	158	8.72	774.16	84	9.22
2	1445.12	164	8.81	825.84	88	9.38
3	1429.68	163	8.77	794.80	85	9.35
4	1409.04	160	8.81	800.00	86	9.30
Mean	1415.48±14.49	161.25±1.38	8.78±0.02	798.70±10.63	85.75±0.85	9.31±0.03

[1]Daytime: 6:00 AM to 6:00 PM for 4 consecutive days
[2]Night-time: 6:00 PM to 6:00 AM for 4 consecutive days
[3]Recorded time consumed in minutes when PDBD is almost fully submerged (see Appendix 6)

3.3 Economic Analysis of PDBD System with Swine Manure as Substrate:

Presented in Table 5 is the economic analysis of the PBDB biogas system using swine slurry as substrate. A PDBD with eight 200- ℓ units of drums has a total volume of 1600 ℓ. If the 1600 ℓ capacity of the PDBD will be filled fully with biogas, and the total cost of fabrication of it was PhP 21,860, therefore, a cost per ℓ of biogas from PDBD was PhP 13.66. The MBCR was 0.15, indicating that for every peso of variable cost of OEMC treated PDBD invested PhP 0.15 was the additional profit. On the other hand, the ROI for this project is 143.74%, which indicates that for every peso of investment, the return is equivalent to PhP 1.43. This figure is far better than other projects because it has very low investment and the return or savings is twice the amount when a commercial LPG is used. However, in this study, the cost of the manure was not included, hence in future economic evaluation of the PDBD, the cost of manure can be included. Lastly, the total investment can be recovered in 0.7 yr.

The PDBD equipment has an estimated productive life of 5 years and the only maintenance additive is the OEMC which should be regularly used to produce CH4 and is very effective in reducing ammonia and flies.

TABLE 5
ECONOMIC ANALYSIS OF BIOGAS PRODUCTION

Particulars	Economic Data
Cost to Produce per ℓ, PhP	13.66
Savings per ℓ, PhP	19.61
ROI,%	143.74
Payback Period, yr	0.7
Marginal Benefit Cost Ratio	0.15

3.4 Total Volume of Methane Captured on Poultry Manure as Substrate:

Presented in Table 6 is the total volume of methane captured by the 8-drum PBDB using chicken manure as substrate. It is consistent that more methane are captured during daytime compared to night time. Specifically, an average of 329.04 liters of biogas was captured during daytime at four-day observation period while, 316.12 liters was captured during the night time. The result is similar with the volume of methane captured on swine manure as substrate on the different observation period.

TABLE 6
PERCENT ELEVATION, VOLUME OF METHANE CAPTURED INDIVIDUAL DRUM AND IN EIGHT DRUM

	Day 1		Day 2		Day 3		Day 4		Ave.	
Parameters	DT	NT	DT	NT	DT	NT	DT	NT	DT	NT
Increase (Inches)	4.50	4.00	5.00	5.00	9.00	9.50	7.00	6.00	6.40	6.40
Percent Elevation	14.52	12.90	16.13	16.13	29.03	30.65	22.58	19.35	20.57	19.75
Volume of methane L /drum	29.04	25.80	32.26	32.26	58.06	61.30	45.16	38.70	41.13	39.52
Vol. of methane L in 8 drum	232.32	206.40	258.08	258.08	464.48	490.40	361.28	309.60	329.04	316.12

DT-Daytime; NT Nighttime

3.5 Flow Rate L/min. of Biogas from Poultry Manure:

The volume in liters of biogas consume every minutes of uninterrupted cooking is presented in a Table 7. This was proportionally calculated from the total biogas captured of the eight 200 liters drum was 2580.64 liters divided by 235 minutes which was the time consumed when biogas was fully used for cooking.

TABLE 7
COMPUTED BIOGAS FLOW RATE DAYTIME AND NIGHTTIME COLLECTION DATA

Parameters	DT	NT	DT	NT	DT	NT	DT	NT
Vol. of methane L in 8 drum	232.32	206.4	258.08	258.08	464.48	490.4	361.28	309.6
Depletion Time/ minute	22	19	24	25	44	45	33	23
Flow rate , L/ minute	10.56	10.86	10.75	10.32	10.56	10.89	10.95	13.46

3.6 Economic Analysis of PBDB System Using Poultry Manure as Substrate:

Presented in Table 8 is economic analysis of the PBDB system with chicken manure as substrate. The cost to produce per ℓ of biogas, the following were considered: fabrication cost, labor cost and the cost of the OEMC biogas additive; a total cost of PhP17, 770was calculated and this was divided by 2,580.64 ℓ, resulting to a PhP6.89cost/ ℓ of biogas. The return on investment (ROI) computed was 383.16%, which indicates that for every peso of investment, the return is equivalent to PhP 3.83. On the other hand, based on the savings and cost to produce, the total investment can be recovered in less than of a half of the year (0.26 yr). Lastly, the computed marginal cost benefit ratio was 1.18 which indicates that for every additional peso of variable costs of the biogas project, the gross return is PhP 1.18. The rule of thumb in MBCR is more than 1.0 that one project is efficient. Therefore, PDBD is an effective or efficient to invest money.

TABLE 8
ECONOMIC ANALYSIS OF BIOGAS PRODUCTION

Particulars	Economic Data
Cost to Produce per ℓ,PhP	6.89
Savings per ℓ,PhP	26.4
ROI %	383.16
Payback Period,yr	0.26
Marginal Benefit Cost Ratio	1.18

IV. CONCLUSION

The PBDB system of biogas production using two different substrates such as pig slurry and chicken manure efficiently captured and produce biogas on different observation period. On the pig slurry as substrate, it was observed that more methane are captured during daytime compared to night time and consequently, longer duration of flaring. On the hand, same flow rate was observed between the periods of observation. Similarly, almost the same observation when chicken manure is use as substrate. Lastly, the PDBD system is economically feasible regardless of the type of substrates use.

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