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Performance Study of a Biogas Pilot Plant Using Domestic Wastes from Benin Metropolis

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Abstract
Increasing demand for energy and high waste generation in Nigeria necessitates the adoption of technologies that promote renewable energy and wastes conversion into viable commodity. The biogas technology is one of such systems that have been found to be cost effective and environmentally friendly. In this paper the performance study of a biogas pilot plant using domestic wastes from Benin metropolis was done. Two different samples of substrates composition were made to undergo anaerobic digestion at two different mesophillic temperatures and pH ranges. The gas produced was analyzed for percentage composition. It was observed that good mesophilic temperature range leads to faster digestion and that pH of slurry depend on substrates composition, period of production and temperature.

Keywords: *Pilot plant, anaerobic digestion, Domestic wastes, Benin metropolis*

1. Introduction

Adelekan and Adelekan [1] pointed out that the use of firewood, kerosene and charcoal to supply energy in households significantly and negatively influence the state of health of the populace. Using waste biomass to produce energy can reduce the use of fossil fuels, reduce greenhouse gas emissions and reduce pollution and waste management problems [2, 3] Adeyosoye et al. [4] reported production of biogas from domestic wastes. Benin metropolis has similar characteristics with other major metropolis across Nigeria like Onitsha metropolis, Lagos metropolis, Port-Harcourt metropolis etc. Domestic wastes are seen in huge heaps on any piece of unused land, around buildings and in the open market places. Living with domestic wastes littered around appears to be an acceptable way of life among the people in the metropolis in recent years. Benin metropolis encompasses Benin City the capital city of the ancient Bini kingdom and it is made up of three local government areas; Oredo, Egor, Ikpoba-Okha local government areas. These local government areas are located within the three geographical zones of Benin metropolis; the traditional core zone, the transitional zone and the outer zone [5].

GTZ [6] mentioned that biogas is a mixture of gases that is composed chiefly of methane 40-70 vol.%, carbon dioxide 30-60 vol.% and other gases 1-5 vol.% including hydrogen (H_2) 0-1 vol.% and hydrogen sulfide (H_2S) 0-3 vol.%. According to another source FAO/CMS [7] the optimum temperature for the digestion process is 35°C. The optimum biogas production is achieved when the pH value of input mixture in the digester is between 6 and 7 [8]. The recommended pH of digester should be mainly from 7.0 to 7.4, which is the healthy environment for methane forming bacteria, in order to minimize the toxicity of both free ammonia and free volatile acids [9]. The best pH value that is preferred by methanogenes is around 7, therefore high or low pH values decrease or stop the activity of methanogenes which will effect adversely on the biogas production [7].

2. Materials and Method

Two different samples of domestic wastes after being cut in pieces to increase its surface area, and then mixed with water in ratio of ½ were charged into a biogas pilot plant reactor differently and made air tight. The digester content was stirred several times per day with the aim of mixing the substrates inside the digester for efficient biogas generation. Pressure and temperature readings are taken daily. A biogas analyzer is used to analyze the percentage composition of biogas and the pH of the slurry is taken with the help of the analog pH meter.

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2.1. Sample Preparation

Sample X was made up of corn cob, potato peel, pineapple peel, rice waste, yam peel, cassava peel, orange peel and banana peel weighing a total of 90 kg. The volume of water used was $0.18m^3$ while the volume of slurry formed was $0.27m^3$.

Sample Y on the other hand consisted of rice waste, beans waste, garri waste, potato peel, yam peel and fufu waste having a total weight of 82 kg. Volume of discharged slurry was $0.24m^3$. The expected volume of slurry inside the digester after discharge was $0.03m^3$. $0.164m^3$ of water was used and $0.246m^3$ of slurry was formed.

Table 1. Result for Sample X

Day	Time	Pressure (bar)	Temp (^{0}C)	Remarks
1	Afternoon	0.00	31	No gas
2	Afternoon	0.00	30	No gas
3	Morning	0.00	26	No gas
4	Evening	0.00	29	No gas
5	Afternoon	0.00	30	No gas
6	Evening	0.00	29	No gas
7	Afternoon	0.00	29	No gas
8	Evening	0.00	30	No gas
9	Evening	0.00	31	No gas
10	Afternoon	0.00	28	No gas
11	Morning	0.00	27	No gas
12	Evening	0.00	31	No gas
13	Evening	0.00	30	No gas
14	Afternoon	0.20	32	No flame
15	Evening	0.37	31	No flame
16	Morning	0.46	26	Yellow flame
17	Evening	0.60	32	Blue flame
18	Afternoon	0.78	32	Blue flame
19	Evening	0.92	30	Blue flame
20	Evening	0.85	31	Blue flame
First: Evacuation to storage takes place				
21	Evening	0.52	31	Blue flame
22	Morning	0.63	30	Blue flame
23	Morning	0.75	26	Blue flame
24	Afternoon	0.94	32	Blue flame
25	Evening	0.88	32	Blue flame
Second: Evacuation to storage takes place				
26	Evening	0.58	32	Blue flame
27	Afternoon	0.76	30	Blue flame
28	Evening	0.88	31	Blue flame
Third: Evacuation to storage takes place				
28	Evening	0.57	30	Blue flame
29	Afternoon	0.73	30	Blue flame
30	Evening	0.87	32	Blue flame
Fourth: Evacuation to storage takes place				
31	Evening	0.55	29	Blue flame

32	Morning	0.60	27	Blue flame
33	Afternoon	0.69	32	Blue flame
34	Afternoon	0.77	31	Blue flame
35	Evening	0.88	32	Blue flame
Fifth: Evacuation to storage takes place				
36	Evening	0.58	32	Blue flame
37	Afternoon	0.66	30	Blue flame
38	Afternoon	0.79	32	Blue flame
39	Evening	0.92	32	Blue flame
Sixth: Evacuation to storage takes place				
40	Evening	0.51	32	Blue flame
41	Evening	0.72	31	Blue flame
42	Afternoon	0.76	29	Blue flame
43	Evening	0.87	32	Blue flame
Seventh: Evacuation to storage takes place				
44	Evening	0.53	32	Blue flame
45	Afternoon	0.67	30	Blue flame
46	Morning	0.72	25	Blue flame
47	Afternoon	0.85	31	Blue flame
Eighth: Evacuation to storage takes place				
48	Morning	0.51	29	Blue flame
49	Afternoon	0.60	31	Blue flame
50	Evening	0.71	33	Blue flame
51	Evening	0.85	32	Blue flame
Ninth: Evacuation to storage takes place				
52	Evening	0.50	32	Blue flame
53	Morning	0.57	28	Blue flame
54	Afternoon	0.55	32	Blue flame
55	Morning	0.55	26	Blue flame
56	Evening	0.52	33	Blue flame
57	Evening	0.51	31	Blue flame
Tenth: Evacuation to storage takes place				

Table 2: Result of Sample Y

Day	Time	Pressure (bar)	Temp (^{0}C)	Remarks
1	Morning	0.00	33	No gas
2	Afternoon	0.00	35	No gas
3	Evening	0.00	37	No gas
4	Afternoon	0.00	35	No gas
5	Afternoon	0.29	36	No flame
6	Morning	0.43	32	Yellow flame
7	Evening	0.59	35	Blue flame
8	Afternoon	0.76	36	Blue flame
9	Evening	0.86	37	Blue flame
First: Evacuation to storage takes place				
10	Evening	0.52	36	Blue flame

11	Morning	0.58	29	Blue flame
12	Afternoon	0.79	34	Blue flame
13	Evening	0.88	36	Blue flame
Second: Evacuation to storage takes place				
14	Evening	0.57	35	Blue flame
15	Evening	0.80	36	Blue flame
Third: Evacuation to storage takes place				
16	Evening	0.56	36	Blue flame
17	Evening	0.81	37	Blue flame
Fourth: Evacuation to storage takes place				
18	Evening	0.59	37	Blue flame
19	Afternoon	0.79	35	Blue flame
20	Evening	0.91	36	Blue flame
Fifth: Evacuation to storage takes place				
21	Evening	0.55	35	Blue flame
22	Afternoon	0.67	34	Blue flame
23	Evening	0.88	36	Blue flame
Sixth: Evacuation to storage takes place				
24	Evening	0.56	34	Blue flame
25	Afternoon	0.77	34	Blue flame
26	Evening	0.83	36	Blue flame
Seventh: Evacuation to storage takes place				
27	Morning	0.50	32	Blue flame
28	Afternoon	0.69	35	Blue flame
29	Evening	0.85	37	Blue flame
Eighth: Evacuation to storage takes place				
30	Evening	0.59	36	Blue flame
31	Afternoon	0.71	35	Blue flame
32	Evening	0.82	36	Blue flame
Ninth: Evacuation to storage takes place				
33	Morning	0.51	32	Blue flame
34	Afternoon	0.69	35	Blue flame
35	Evening	0.80	37	Blue flame
Tenth: Evacuation to storage takes place				
36	Evening	0.53	35	Blue flame
37	Morning	0.57	33	Blue flame
38	Afternoon	0.45	34	Blue flame
39	Evening	0.42	37	Blue flame
40	Evening	0.37	36	Blue flame
Eleventh: Evacuation to storage takes place				

Table 3. A comparison of evacuation frequency of the three charges

Sample	**N_e**											**P_p**	**B_{re}**
	1st	**2nd**	**3rd**	**4th**	**5th**	**6th**	**7th**	**8th**	**9th**	**10th**	**11th**		
X	20	5	3	3	5	4	4	4	4	6	-	43	0.233
Y	9	4	2	2	3	3	3	3	3	3	5	35	0.314

3. Results and Discussion

Table 1 shows the results obtained from charging sample X. The pressure gauge starts to indicate some reading on the 14th day but there was no combustion. Weak yellow flame was observed on the 16th day, and there was complete combustion when the pressure gauge reading is above 0.5bar.

Table 2 shows the results obtained from charging sample Y. The pressure gauge starts to indicate some reading on the 5th day. Weak flame was observed the following morning and complete combustion took place on the 7th day. Complete combustion starts when the pressure rises to 0.5 bar. Above 0.9 bar, there is reduction in production rate and this eventually led to drop in pressure. Due to reduction in production rate above 0.9bar, evacuation becomes necessary once the pressure gauge reading rises up to 0.8 bar.

Table 3 shows that evacuation was more frequent in sample Y and this was due to the optimum mesophilic temperature range of 32 ºC to 37 ºC when compared to the mesophilic temperature range of sample X of 26 ºC to 33 ºC. The mesophilic temperature range in sample Y enhanced faster digestion in the digester and this made the period of production shorter

Equation (1) shows the rate of biogas evacuation;

$$B_{re} = \frac{N_e}{P_P} \quad (1)$$

Where;

B_{re} = Rate of biogas evacuation

N_e = Number of evacuation

P_p = Period of production

Table 4, Figure 1 and Figure 2 shows the percentage composition of biogas analyzer results of carbon dioxide, methane and other gases present (Hydrogen sulphide, Water vapour, Hydrogen and Nitrogen). The percentage composition of carbon dioxide and methane keep on varying with the duration and extent of biomethanation over retention time. As the anaerobic digestion continues in the digester, more methane is formed and this subsequently leads to drop in production of carbon dioxide, and other gases (Hydrogen sulphide, Water vapour, Nitrogen, and Hydrogen) that are present in small quantities. Sample Y has better methane composition thanks to the faster digestion of sample Y in the pilot plant reactor.

Table 5 shows the pH readings of sample X and sample Y. Due to better pH values of sample Y, methane percentage composition was affected positively as can be seen in Table .4

Table 4. Comparative analysis of Biogas analyzer (Raw Biogas)

	Sample X			**Sample Y**		
	% composition			**% composition**		
Evacuation	**CH_4**	**CO_2**	**Others gases**	**CH_4**	**CO_2**	**Other gases**
First	55	40	5	58	38	4
Second	59	37	4	58	38	4
Third	62	34	4	63	34	3
Fourth	63	34	3	63	34	3
Fifth	64	33	3	65	32	3
Sixth	65	32	3	65	32	3
Seventh	65	32	3	66	31	3
Eighth	67	31	2	67	31	2
Ninth	67	31	2	67	31	2
Tenth	67	31	2	69	30	1
Eleventh	-	-	-	69	30	1

Table 5. pH readings of sample X and sample Y

S/N	**pH TEST**	**pH READINGS**	
		Sample X	**Sample Y**
1	Before charge	7.6	7.4
2	After first evacuation	6.4	6.1
3	After second evacuation	6.6	6.6
4	After third evacuation	6.8	6.8
5	After fourth evacuation	6.8	6.9
6	After fifth evacuation	6.9	6.9
7	After sixth evacuation	6.9	7.2

8	After seventh evacuation	6.9	7.2
9	After eight evacuation	6.8	7.1
10	After ninth evacuation	6.6	-
11	After tenth evacuation	6.3	7.0
12	After eleventh evacuation	-	6.7
13	After discharge	6.1	6.7

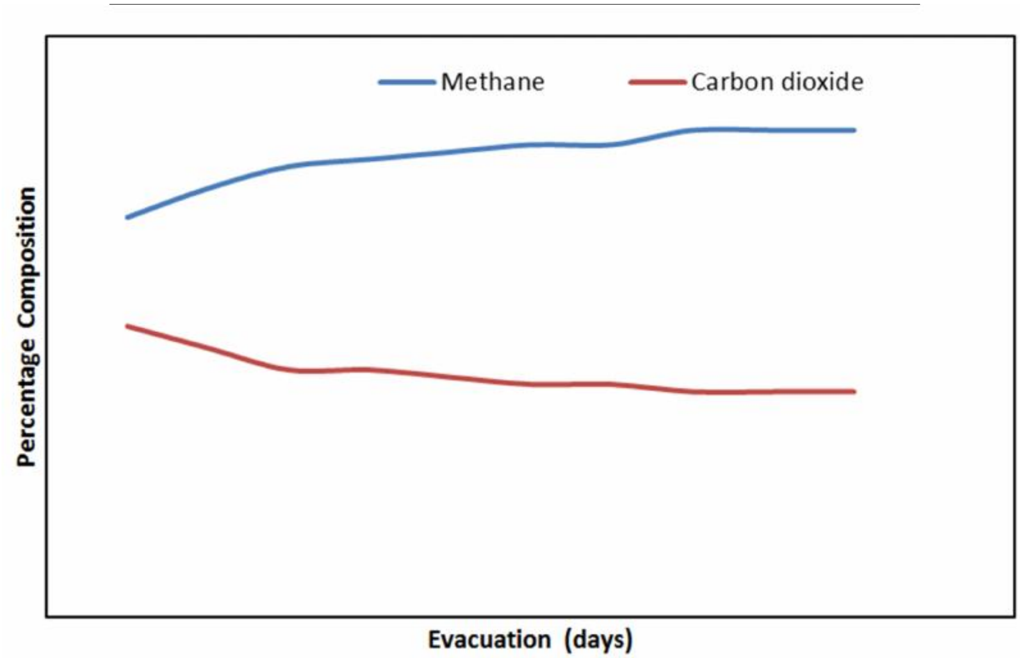

Fig 1. Percentage composition of CO_2 and CH_4 of sample X

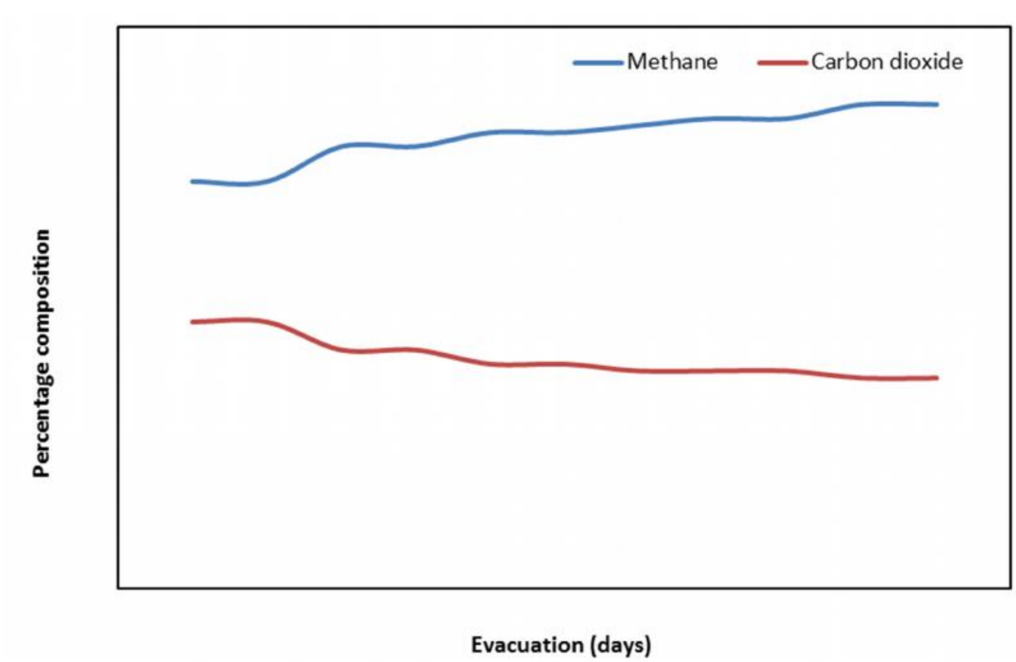

Fig 2. Percentage composition of CO_2 and CH_4 of sample Y

4. Conclusions and Recommendations

4.1. Conclusions

1) In the present scenario of energy crisis in Nigeria and Africa, there is a strong possibility of meeting some of our energy needs if we can adopt biogas technology in Nigeria. The performance of a biogas pilot plant using domestic wastes from Benin metropolis was carried out.

2) It was observed that it took a period of fourteen days for gas to be produced. Though, with seeding it might take less than that. The gas produced at that point did not combust but within a number of days, weak flame was formed and then followed complete combustion.

3) Good mesophilic temperature range lead to faster digestion of the substrates in the digester and this enhanced completion of biogas production on time.

4) The pH values of the slurry depend on the composition of substrates, the period of production and temperature. There is change in the pH of the slurry as digestion takes place in the digester. At the beginning, the pH is alkaline; as the reaction in the digester proceeds it changes to acidic and eventually turns neutral.

4.2. Recommendations

As a result of this study the following can be recommended:

1) Since the temperature in the digester becomes reduced during the rainy season, it is better for biogas users to insulate their digesters in order to maintain an optimum mesophilic temperature range. A plastic digester will be a better option since there is more of rainfall in Nigeria. The problem of rusting or corrosion which typically affects the production of biogas when metals or steels digester are used can be solved by using plastic digesters.

2) Biogas users should ensure that the pH of the slurry in the digester is between 6 and 8. This is because above a pH of 8, free ammonia becomes toxic to methane forming bacteria and below 6, free volatile fatty acids become toxic to the methane forming bacteria.

3) Biogas plants should be constructed across Nigerian cities to reduce the volume of domestic wastes to be disposed and by extension ease the challenge of waste management.

4) Government at all levels should take active part in all biogas projects and utilize research findings to enhance the production of biogas as it is being practiced places like Nepal, China and India.

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