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Performance Evaluation of the Effect of Temperature and pH on Biogas Yields from Anaerobic Co-Digestion of Food Waste and Pig Dung

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Abstract: *This research work is focused on the performance evaluation of the effect of pH variation and temperature on biogas yield from anaerobic co-digestion of food waste and pig dung. The food waste that comprises of beans waste, rice waste, plantain peel, cocoyam waste, yam waste, fufu waste, etc., were collected from households in Benin City, Nigeria and co-digested with pig dung collected from Lysan farm, Mosogar that served as a seeding agent. The co-digested food waste was divided into four portions and varied as follows; sample A with pH range of pH≤5.5, sample B with pH range of pH≥8.5, sample C was stabilized within pH range of 6.9≤pH≤7.4, and sample D was used as co-digested without stabilization. The co-digestion was maintained at mesophilic temperature range of 20°C≤°C≤45°C. The slurry was charged differently into a three stage continuous anaerobic digestion plant fabricated from metallic stainless steel material and allowed for complete hydraulic retention time to take place. The results obtained show that for an optimum biogas yield to be achieve, a pH range of 6.9≤pH≤7.4 and a mesophilic temperature of 37°C is required. Therefore, for optimum biogas yield, the anaerobic digestion plant should be run at a neutral pH level and mesophilic temperature range of 36°C-37°C.*

Keywords: Anaerobic Co-digestion, Biogas Yield, Food Waste, Mesophilic Temperature, pH, Pig Dung

INTRODUCTION

The demand for energy consumption and waste generation in Nigeria necessitates the adoption of technologies that can convert wastes into viable commodity. The biogas technology is one of such systems and has been found to be cost effective and environmentally sound (Orhorhoro *et al.*, 2016). Several researchers (Earnest and Singh, 2013; Bani *et al.*, 2015; Ebunilo *et al.*, 2015; Orhorhoro *et al.*, 2018) have reported production of biogas from different waste composition such as cassava peels, sweet potato peel, wild cocoyam peel, plantain peel, talinum triangulare (water leaves) , maize cob, rice husks and various bulk organic wastes in Nigeria.

Thus, it is possible that domestic wastes in Nigerian towns can be used to produce biogas as this will not only be a source of renewable energy but will also reduce the level of environmental and public health hazards caused by the current practice. The production of biogas from such wastes has a great potential to address some of Nigeria's energy challenges especially in the area of dependence on traditional biomass from fire wood for cooking (Osunde *et al.,* 2018). The anaerobic digestion (AD) process which involves the conversion of organic matters into biogas and fertilizer is an established technology for environmental protection through the treatment of organic waste (Adekunle *et al.,* 2011). It is a biological treatment process that recovers valuable products, energy and nutrients, from organic waste streams in useable forms in the absence of oxygen (Lim *et al.,* 2012; Orhorhoro *et al.,* 2017). Biogas is a mixture of gases evolved from AD of organic matter by anaerobic bacteria at anaerobic conditions. Biogas is composed mainly of methane (CH_4), carbon (IV) oxide (CO_2) and negligible amount of other gases such as Hydrogen Sulphide (H_2S), Water Vapour (H_2O), Nitrogen gas (N_2), etc. (Ebunilo *et al.,* 2016; Orhorhoro *et al.,* 2018). However, the quality and quantity of biogas generated by organic waste does not remain constant but varies with the period of hydraulic retention time (Ray *et al.,* 2013; Franco *et al.,* 2015). The ratio of CH_4 to CO_2 is normally stable in the reactor; any variation in the ratio is due to process imbalance resulting from effect of operation and process parameters such pH, temperature, organic loading rate, etc. (Ebunilo *et al.,* 2015). Since the dissolution of CO_2 is strongly dependent on pH, fluctuation of pH can also change biogas composition (Orhorhoro *et al.,* 2016).

The pH value of a stable anaerobic digestion process ranges between 6 and 9 (Chrish, 2013). Methanogenesis which is the stage at which methane is produced is very sensitive to acidity. Therefore, a pH range, which is healthy for methane forming bacteria, is required to minimize the toxicity of both free ammonia and free volatile acids (Jonas *et al.,* 2014). The pH value of AD process is often used to assess process stability. A high VFA concentration from the acidogenesis fermentation and acetogenesis fermentation stages result in drop of pH. The main reason for this can be found in the total alkalinity (TA) of the process which acts as a buffer for the pH value. For adjusting pH value, acidic materials such as sodium bicarbonate are added to the digester contents (or with loaded organics) in the case of significant pH rising, while lime or any other basic material may be added in the case of pH falling (Paramagurua *et al.,* 2017). Temperature on the other hand is considered as one of the most important variables for process stability as anaerobic bacteria populations can only survive in certain temperature ranges. Besides, sudden changes and fluctuations in the process temperature lead to inhibition of bacteria populations. Therefore, for efficient results and stable anaerobic digestion plants operation to be attained, controlling the process temperature always is required. Three different temperature ranges are required for high biogas yields (Moset *et al.,* 2015).

i. Psychrophilic bacteria: $0^0C \leq T \leq 20^0C$
ii. ii. Mesophilic bacteria: $20^0C \leq T \leq 45^0C$
iii. Thermophilic bacteria: $45^0C \leq T \leq 70^0C$

Anaerobic digestion process can be operated in one of these three temperature ranges with the corresponding bacteria population. However, the mesophilic temperature range is preferred for most anaerobic digestion plants (Osita, and Lawan, 2014). The main reasons for this are that anaerobic digestion performance by psychrophilic bacteria and thermophilic bacteria is slower than those of mesophilic bacteria. Also, it is difficult to maintain anaerobic digestion plants under psychrophilic temperature condition due to low process temperature. Furthermore, thermophilic bacteria are known to be very sensitive to disturbances, which require costly process monitoring and control. Therefore, this research work will evaluate the effect of temperature and pH biogas yields from anaerobic co-digestion of food waste and pig dung.

MATERIAL AND METHOD

2.1 Materials

Table-1 shows the list of materials used in this research work.

Table-1 List of Materials and their Usage

S/N	List of Materials	Usage
1.	Weighing balance	It was used for the measurement of substrate and biogas yield.
2.	Three-stage continuous anaerobic digestion plant	It was used for co-digestion of food waste and pig dung.
3.	Nose mask	For protection against poisonous gases, contaminants from collected household wastes.
4.	Substrate	It was used for production of biogas. The substrates used in this project work include: Pig dung and food waste.
6.	Gesa thermometer	Connected to the anaerobic digestion plant and it was used to monitor the temperature reading of the slurry.
7.	Pressure	For monitoring pressure build up of generated biogas
8.	Hand gloves	For protection
9.	Wash bottles	Used for rinsing
10.	Gas cylinder	Used for biogas storage
11.	Gas hose	For evacuation of biogas
12.	pH	For measuring pH readings

The food waste and pig dung used in this research work were collected from household in Benin City and Lysan pig farm, Mosogar. Fig. 1 shows the substrate composition used in this research work.

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Fig.1 Substrates Composition (Pig dung and food waste)

2.2 Methods

The following methods were adopted in this research work.

2.2.1 Determination of the Effect of pH on Biogas Yield

Four different samples of the same substrate composition were used. The samples were grouped as follow: Sample A, Sample B, Sample C, and Sample D. Sample A was stabilized within $pH \leq 6$, sample B stabilized within $pH \geq 8$, sample C stabilized within the range of $6.9 \leq pH \leq 7.4$, while sample D pH was not stabilized. Calcium hydroxide was used to stabilize the pH of the slurry. Each of the sample composition was mixed with water in ratio of 1:2 to form slurry. The formed slurry was charged into the AD reactor separately under optimum mesophilic temperature condition of 20^0C-45^0C. The pH of the formed slurry of each sample was monitored before, during, and after completed hydraulic retention time. An ATC digital pH meter was used to measure the pH readings (Fig. 2).

Fig.2 ATC Digital pH Meter

The rate of biogas yield, frequency of evacuations, and cumulative frequency of evacuation rate were calculated from derived equations. The results obtained were analyzed statistically with the help of tables and graphs. The rate of biogas yield and frequency of evacuation of biogas yield was calculated from Equation (1) and (2) respectively.

$$R_{BY} = \frac{BY}{HRT} \quad (1)$$

$$FE_R = \frac{FE}{HRT} \quad (2)$$

The total and average pH of each process is calculated from Equation (3).

$$A = \frac{\sum X}{n} \quad (3)$$

where,
R_{BY} = Rate of biogas yield
FE_R = Frequency of evacuation rate
FE = Frequency of evacuation
$\sum X$ = Sum of each process n = Number of each process
A = Average value of each process

2.2.2 Determination of the Effect of Temperature on Biogas Yield

To achieve an optimum mesophilic temperature that will favour improved biogas yield, an experimental design was carried out to determine the effect of temperature on biogas yield. Collected substrate composition was thoroughly mixed with water in ratio of 1:2. The mixture was charged into the biogas digesters and made air tight. The average pressure, temperature readings, and biogas yield were taken at each evacuation. Also, the frequency of evacuation was monitored with respect to change in mesophilic temperature. The results are shown in Table-2.

2.2.3 Determination of Biogas Yield

The AD plant cylindrical digester vessel was initially seeded with pig dung. Samples of collected substrate composition were weighed with a weighing balance. The collected substrate composition was ground into fine particles to increase its surface area, and then mixed with waste water collected from slaughter house and ice fish cold room in a ratio of 1:2 as recommended by Ebunilo *et al.* (2015). The pH and temperature were evaluated using an ATC digital pH meter and Gesa maximum and minimum thermometer. The mixture was finally charged into the digester and made air tight. The digester content was stirred several times per day with the aim of mixing the substrates inside the digester for optimum biogas yield. The pressure and temperature readings were monitored and recorded. The gas evacuated was purified in the purification chamber and manually compressed into a mild steel gas cylinder. The samples of purified and raw biogas were analyzed for percentage composition of gaseous components present at each evacuation. The pH of the slurry was monitored and recorded during charging, discharging, and at each evacuation using a digital pH meter. Before each evacuation of biogas, the initial mass of the gas cylinder and the final mass after biogas evacuation were recorded. The mass of biogas evacuated was calculated by subtracting the initial mass of the gas cylinder from the final mass of the gas cylinder. That is:

$$M_{GE} = M_2 - M_1 \quad (4)$$

where,
M_{GE} = Mass of biogas evacuated
M_2 = Final mass of the gas cylinder
M_1 = Initial mass of the gas cylinder
Figure 3 shows the fabricated three-stage continuous anaerobic digestion plant used.

Fig. 3 Fabricated three-stage continuous anaerobic digestion plant

RESULTS AND DISCUSSION

The results of biogas yield at each evacuation with respect to effect of mesophilic temperature range are shown in Fig. 4. Maximum biogas yield was obtained for mesophilic temperature range of 36^0C to 37^0C. Also, within the aforementioned mesophilic temperature range, it took shorter hydraulic retention time and an improved biogas yield. A good pressure builds up is an indication of generated biogas yield ready for evacuation. Thus, evacuation of biogas was frequent within approximate mesophilic temperature range of 36^0C to 37^0C. As showed in Fig. 4, at optimum mesophilic temperature range, the digestion of substrates go to completion at shorter HRT with an improved biogas yield since more methanogenic bacteria are working upon substrate (Moset *et al.,* 2015). Furthermore, the temperature inside the digester must be stable, since the methanogenic bacteria are highly sensitive to changes and variations of temperature inside the digester (Edmond *et al.,* 2017). In this analysis, the mesophilic temperature range of the AD plant that favour optimum biogas yield was 36^oC-37^oC.

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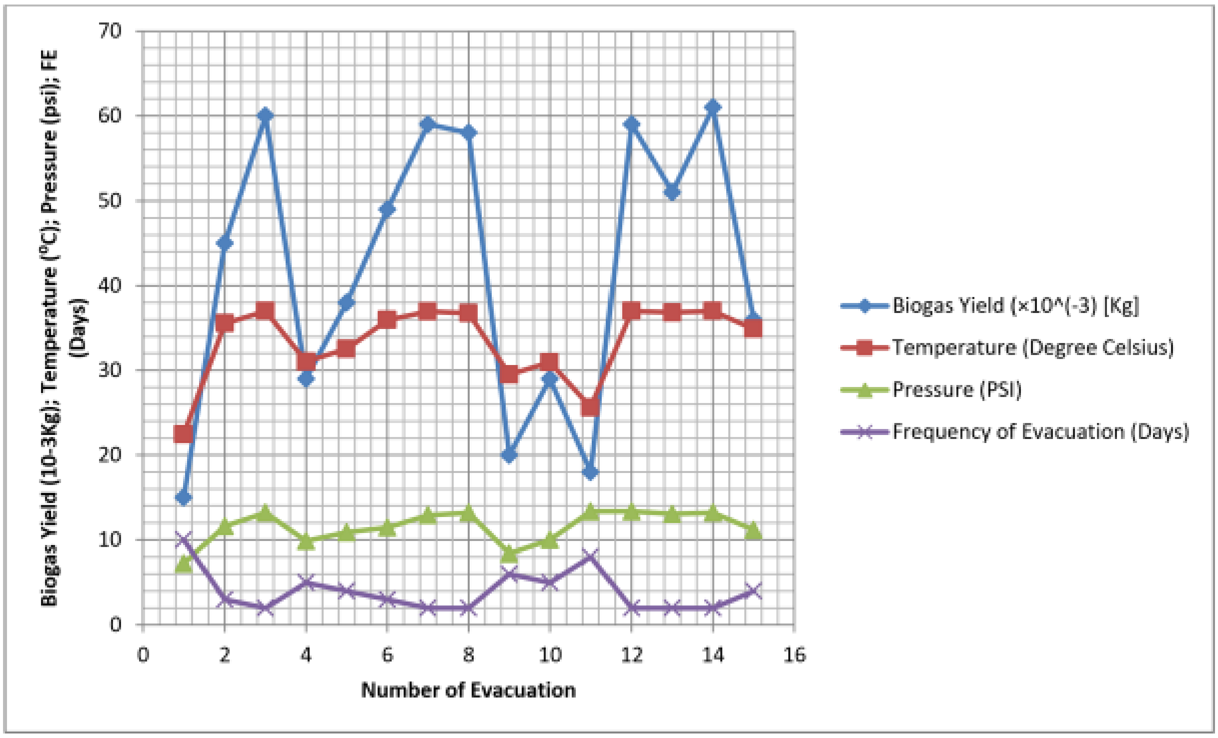

Fig.4 Effect of Mesophilic Temperature on Biogas Yield

Table-2-Table-5 shows the results obtained with experimental determination of effect of pH on biogas yield. From the results obtained, sample C which was stabilized within the pH range of 6.9≤pH≤7.4 has the highest number of evacuation and this was as a result of fast completion of the AD process stages (i.e., hydrolysis, acetogenesis, acidogenesis and methanogenesis).

Table-2 Evaluation of Effect of pH≤6 on Biogas yield

			Sample A			
S/N	pH (m)	BY (kg)	HRT(Days)	NE	FE	R_{BY}
1	4.85	0.00	4	-	-	0.0000
2	5.02	0.00	7	-	-	0.0000
3	5.11	0.00	10	-	-	0.0000
4	5.20	0.08	17	1st	12	0.0066
5	5.50	0.11	20	2nd	6	0.0183
6	5.70	0.13	25	3rd	6	0.0217
7	6.00	0.15	28	4th	5	0.0300
∑N =7	∑pH=37.38	∑BY= 0.47		∑NE = 4		$\sum R_{BY}$ = 0.0766
A = 1	A=5.34	A=0.1175		A =1		A= 0.01915

*A = Average, *FE-Frequency of Evacuation, * R_{BY}-Rate of Biogas Yield, *BY-Biogas Yield, *NE-Number of Evacuation, Table-3 Evaluation of Effect of pH≥8 on Biogas Yield

Sample B						
S/N	pH	BY	HRT (Day)	NE	FE	RBY
1	8.00	0.00	4	0.0	-	0.0000
2	9.80	0.00	7	0.0	-	0.0000
3	8.35	0.00	9	0.0	-	0.0000
4	9.40	0.09	16	1st	11	0.0082
5	9.60	0.13	19	2nd	6	0.0217
6	8.90	0.15	24	3rd	5	0.0300
7	8.80	0.18	28	4th	6	0.0300
∑N=7	∑pH=62.85	∑BY= 0.55		∑NE = 4		$\sum R_{BY}$ = 0.0899
A =1	A=8.98	A=0.138		A =1		A = 0.0225

Table-4 Evaluation of the Effect of 6.90≤pH≤7.4 on Biogas yield

Sample C						
S/N	pH	BY	HRT	NE	FE	RBY
1	6.90	0.00	4	-	-	0.0000
2	6.95	0.00	6	-	-	0.0000
3	7.00	0.00	14	1st	-	0.0000
4	6.99	0.23	16	2nd	14	0.0164
5	7.10	0.26	19	3rd	3	0.0867
6	7.20	0.27	21	4th	2	0.1350
7	7.00	0.29	23	5th	3	0.0967
8	7.30	0.31	26	6th	3	0.1033
9	7.40	0.15	28	7th	3	0.0500
∑N =9	∑pH= 63.84	∑BY= 1.51		∑NE = 7		$\sum R_{BY}$ = 0.4881
A=1	A=7.093	A=0.2517		A = 1		A= 0.08135

Table-5 Evaluation of Effect of Uncontrolled pH on Biogas Yield

S/N	pH	BY	HRT	NE	FE	RBY
1	4.85	0.00	4	-	-	0.0000
2	5.30	0.00	7	-	-	0.0000
3	5.75	0.00	9	-	-	0.0000
4	9.94	0.07	14	1st	14	0.0050
5	6.10	0.17	17	2nd	3	0.0567
6	5.58	0.22	22	3rd	5	0.0440
7	7.00	0.25	25	4th	3	0.0833
8	7.30	0.23	28	5th	3	0.0767
∑N=8	∑pH=51.82	∑BY= 0.94	∑HRT= 252	∑NE = 4		$\sum R_{BY}$ = 0.2657
A = 1	A=6.4775	A=0.188	A=28	A = 1		A= 0.0332

Fig. 5 shows the plot of average pH and biogas yields. Sample C has the best biogas yield (0.2517) in comparison to sample A (0.1175), sample B (0.138), and sample D (0.188).

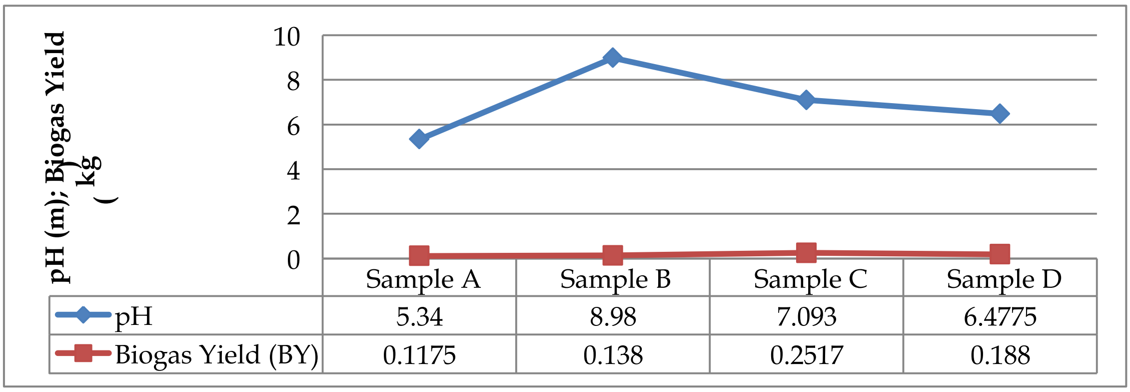

Fig.5 Graph of pH and Biogas Yield

Fig. 6 shows the graph of average pH and rate of biogas yield (R_{BY}). It can be seen that the rate of biogas yield increased in the following order: Sample A < Sample B < Sample D < Sample C. Sample C has the highest rate of biogas yield and this was as a result of stable neutral pH range (6.8≤pH≤7.4) that favours methanogenesis. Thus, for optimum biogas yield, neutral pH is required.

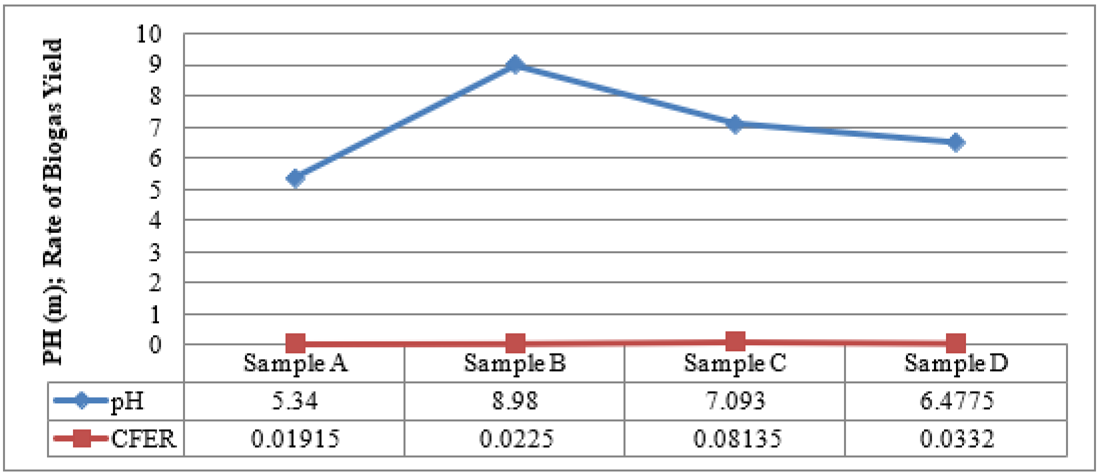

Fig. 6 Graph of pH and Rate of Biogas Yields

CONCLUSION

In this research work, the variation of the effect of pH and temperature on anaerobic co-digestion of food waste and cow dung for the production of biogas was successfully carried out. The results obtained reveal that a neutral pH range of 6.8≤pH≤7.4 and mesophilic temperature range of 36^{o}C-37^{o}C favour optimum biogas yield. Therefore, for optimum biogas yields, biogas users should ensure that the pH of the slurry in the digester is within the neutral range. 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 for the methane forming bacteria.

CONFLICT OF INTEREST

We hereby state that no conflict of interest whatsoever is associated with this research work.

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