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Development of a Batch Type Bio-Digester

Adeniran, K. A., Opara, M. and Iyanda, M.O.

¹Department of Agricultural and Biosystems Engineering, University of Ilorin, P.M.B. 1515, Ilorin, Kwara State, Nigeria.

Corresponding E-mail: -kadeniran_2003@yahoo.com

Abstract

A bio-digester was designed, constructed and tested for the production of biogas. The digester was designed and constructed using a 32 liter – digester tank, an 18.5 liter water displacement tank and a 20 liter temporary storage tank of 16 liter. Biogas was produced by charging the slurry into the digester through the inlet channel and then closing the inlet channel and a hose was used to connect the digester and the water displacement tank which was already filled with water to the bream, a second hose was also used to connect the water displacement tank to the temporary storage tank where the displaced water is channeled to and the volume of water displaced was measured and recorded daily for the two types of slurry. A digital thermometer was used to take the ambient temperature of the digester. The digester was tested with two types of slurry that is made up of poultry litters and water at the ratio of 1: 4 and 1: 2, one poultry litter was mixed with water in the ratio of five liter to twenty liters respectively and the other in the ratio of five liters to ten liters. On the first and second day after loading there was no significant production of gas. The third day a gas production of 1.53ml was noted and the volume continued to increase until the eighth day with 7.52ml and the reduction continued from 7.34, 7.09, and 6.41 on the 9th, 10th, 11th day respectively. However with the reduction observed on the 8th day in which the average temperature was 33°C. The reduction in the volume of gas can be linked to the decrease in the amount of organic matter present in the slurry. The volume of the slurry retained in the digester tank was about nineteen liters which means that about five liters of slurry were converted to biogas. Change in the color of slurry evacuated was noticed with non offensive odour. From the result it can be deduced that the concentration of the slurry is directly proportional to the rate of gas production and also the ambient temperature of the digester is directly proportional to the production of biogas.

Keywords:-Batch type bio-digester, biogas, slurry, ambient temperature

1. Introduction

In Nigeria, over 70% of the population lives in the rural area and most of them use firewood as their main source of energy comprising 4/5th of the total household energy used (Momoh and Soaga, 1999). A rural person uses an average of one ton of dry wood per annum (Momoh and Soaga, 1999). The extensive use of this wood will lead to wood scarcity and environmental degradation as the rate of felling wood is not matched with forest reclamation. In most West African countries, livestock producers simply drain animal manure into creeks, streams and rivers which reduce dissolved oxygen as decomposing bacteria in the waste compete with available oxygen. Because farmers lack skills and knowledge in livestock waste management, potential organic fertilizers that be derived from livestock feed are wasted. Small scale anaerobic digesters for farmers would better utilize livestock wastes. The current disposal system for waste has created a negative impact through pollution and disease problems. Valuable marine resources and underground water are also threatened

(Ajuyah 1998). Development and popularization of biogas technology as an alternative energy source for rural areas will not only increase their total energy supply but will also reduce the rate of felling trees for fuel. The technology will help in fighting ecological imbalance created by felling of trees for fuel and desertification. The primary aim of this project was to design, construct and evaluate a batch type biogas that can be used generation of biogas utilising animal wastes such as poultry droppings, cow dung and piggery wastes.

2. Materials and Methods

2.1 Design Concept

A batch-type biogas digester (Fig 1) was designed and constructed to generate biogas from animal wastes. The components of the digester include: main tank, water displacement tank, storage tank, gas exit pipe, inlet pipe, thermal insulator that helps to stabilize the temperature during the fermentation period. The digester ensures the anaerobic degradation of the feedstock in order to generate biogas. The batch type of digester was considered in the design and construction of this digester.



Fig 1. Biogas digester set up during the time of gas production

2.2 Components of the Digester

2.2.1 Water displacement tank

In this tank, the biogas generated in the digester tank displaces the water inside the tank and the displaced water will be forced to flow into the storage tank.

2.2.2 Storage tank

This is the structure where the displaced water is collected and measured.

Table1. Material selection and construction procedures

Component parts	Material selection	Quantity	Procedures
Cylindrical shape	Mild steel of 1.5mm thickness	1	The mild steel was cut to a length of 2m and then folded to form a cylinder of diameter 3
Cone shape	Mild steel of 1.5mm	1	The mild steel was

	thickness		
Inlet pipe	20mm diameter mild steel pipe	1	cut to the required size and was folded to form a cone This was made by welding the 20mm diameter pipe to the digester tank
Outlet pipe	20mm diameter mild steel pipe	1	At the lower part of the digester tank, a hole was made and the 20mm diameter pipe was welded to it
Water displacement tank	Galvanized steel of 1.5mm thickness	2	The galvanized steel was cut into the required sizes and was folded to form a cylinder
Hose	A rubber hose 10m long	2	The rubber hose was used in passing gas from the digester to the water displacement tank, and also from the water displacement tank to the storage tank.

3. Design Calculation

3.1 Capacity of the tank

The capacity of the tank to be designed was estimated as 32 litres. Based on the capacity, diameter and the height of the component were computed. The biogas storage tank was made up of conical and cylindrical shapes there by making it to have two heights.

Diameter of the biogas containing vessel = 250mm, Conical height= 250mm (0.2m)

The cylindrical height= 350mm (0.35m)

3.2 Thickness of the digester wall

The biogas tank is subjected to two different stresses i.e. circumferential and longitudinal stress. But here only the circumferential stress was used to compute the stress since the pressure must be based on maximum stress i.e. circumferential stress. The pressure of biogas is 490Nm² (average pressure of biogas = 490Nm², Pedro 2009). The circumferential stress is expressed as:

$$\alpha = \frac{pd}{2t} \quad (1)$$

Where p = pressure of the gas, d = internal diameter of biogas containing vessel

t = thickness of the tank

$$t = \frac{pd}{2\alpha} \quad (2)$$

Yield stress

Circumferential stress = Yield stress $\times$ allowable stress, where the allowable stress here is 0.2, Therefore, circumferential stress = $0.2 \times 200 = 40\text{Nmm}^2$, $t = 0.49 \times \frac{250}{2} \times 40 = 1.5\text{mm}$

3.3 Thickness of the insulating material

According to Fourier's law, $Q = KA \frac{dt}{dx}$ (3)

Where K = thermal conductivity (W/M°K) and A = area (m²)

$$\frac{dQ}{dt} = -KA \frac{dt}{dx} \quad \text{temperature gradient (K/M)}$$

By integrating the above expression we obtain, $\int Qdx = -\int KAdt$,

$$Qx = AK (t_2 - t_1)$$

Therefore, $Q = -(AK/x)(t_2 - t_1)$ (4)

Which can also be expressed as $Q = (AK/x)(t_2 - t_1)$ (5)

Where, Q = heat, K = thermal conductivity, t_1 = mesophilic temperature

t_2 = ambient temperature, x = thickness of the insulating material and A = area of the cylinder

For this digester, the following assumptions were made, ambient temperature (t_2) = 28°C

mesophilic temperature (t_1) = 35°C, K = 0.04W/mk (Young, 2010),

Area of cylinder $\{2\pi r(r+h)\}$, = 1.713m²

But $Q = MC\theta$ (6)

Where Q = heat, M = mass of slurry, C = specific heat capacity of the slurry (4.05KJ/kg/K) (Manfred et al., 2007), θ = ambient temperature

Since equations (5) and (6) are equal, therefore $MC\theta = (AK/X) (t_1 - t_2)$

Hence $x = (AK/MC\theta) (t_1 - t_2)$

By substituting the various values of the parameter our thickness of the wall $x = 9.37\text{mm}$

Hence, the minimum thickness of the lagging wall is 9.37mm, thus the thickness of the design is 30mm.

3.4 Volume Capacity

$V = \pi r^2 h$, where V = volume (m³), r = radius (m), h = height (m), $\pi = 3.142$

Volume of digester (V_d)

Cylindrical volume of digester (V_{cy})

$$r = 0.14\text{m}, h = 0.52\text{m}, V_{cy} = 3.142 \times (0.14)^2 \times 0.52 = 0.320919112\text{m}^3 = 0.032\text{m}^3$$

Conical volume of digester (V_{co})

$$r = 0.14\text{m}, h = 0.104\text{m}, V_{co} = \frac{1}{3} \times \pi \times r^2 \times h = \frac{1}{3} \times 3.142 \times (0.14)^2 \times 0.104 = 0.0021\text{m}^3 = 2\text{litres}$$

Volume of digester (V_d) = 32 litres

Volume of the water displacement tank (V_w)

$$r = 140\text{mm} = 0.14\text{m}, h = 300\text{mm} = 0.3\text{m} \quad V_w = \pi r^2 h = 0.0185\text{m}^3 = 18.5\text{litres}$$

Volume of the gas carriage hose (V_{dw})

From digester to water holder tank

$$r = 6.2\text{mm} = 0.0062\text{m}, l = 0.2\text{m}$$

$$V_{dw} = \pi r^2 l = 3.142 \times (0.0062)^2 \times 0.2 = 0.024\text{litres}$$

Volume of gas carriage hose (V_{ws})

$$\text{From water holder to storage, } r = 0.0062\text{m}, l = 0.22\text{m} \quad V_{ws} = 0.00002656782075\text{m}^3 = 0.026\text{litres}$$

$$\text{Pressure (P)} = \frac{F}{a}$$

where P = pressure (N/m²), F = force (N), A = area = πr^2 (m²), $F = m \times g$

where m = mass (kg), g = acceleration due to gravity (9.81m/s²)

where r = radius (m), For the digester tank, m = 20kg, g = 9.81m/s², r = 0.14m,

$$A = 3.142 \times (0.14)^2 = 0.062\text{m}^2, F = 20 \times 9.81 = 196.2\text{N} \text{ and } P = 196.2/0.062 = 3164\text{N/m}^2$$

3.4 Mixture Rate of Feedstock

One feedstock was used (poultry litters) and it shall be mixed with water using the ratios 1:4 and 1:2. The total mass of slurry content was 20kg.

3.4.2 Temperature Regulation

The temperature range between the mesophilic temperature (15°C - 40°C) is the best range for producing biogas. For this study, mesophilic temperature of 35°C was kept constant throughout the study to avoid the effect of ambient temperature influencing the temperature of the slurry. Ambient temperatures during period of loading the two slurry ratios was measured early in the morning (7:00 GMT) and latter in the day (19:00 GMT).

3.4.3 Retention Period

The retention period for each of the batch sample was 30 days. Baserja (1984) reported that it possible to obtain biogas within 16 – 20 days.

3.4.5 Yield of biogas

The yield of biogas shall be determined using the expression given by Adeniran et al.,(2014) which is expressed as follows:

$$\text{Yield} = \text{Volume of gas collected} / \text{Mass input waste} \quad (7)$$

4. Results

The digester designed had a radius, cylindrical height, conical height, and volume capacity of 0.14m, 0.52m, 0.104m, and 0.32m³ respectively. The digester was tested with two types of slurry one made up of poultry litters mixed with water in the ratio of five liter to twenty liters respectively and the other in the ratio of five liters to ten liters. Tables 1 and 2 and Fig 2 show the results obtained from the biogas digester. For Table 1, on the first and second day after loading there was no significant production of gas. The third day a gas production of 1.53ml was noted and the volume continued to increase until the eighth day with 7.52ml and the reduction continued from 7.34, 7.09, and 6.41 on the 9th, 10th, 11th day respectively. However with the reduction observed on the 8th day in which the average temperature was 33°C.

Table 1: Volume of biogas produced for slurry ratio 1:4 (poultry droppings:water)

Day	Date	Volume (ml)	T _{1a} (°C)	T ₁ (°C)	T _{2a} (°C)	T ₂ (°C)
1	10/09/2011	0.00	32	32	35	35
2	11/09/2011	0.00	33	33	34	33
3	12/09/2011	1.53	33	34	35	30
4	13/09/2011	2.50	34	35	35	33
5	14/09/2011	4.80	34	35	36	33
6	15/09/2011	5.82	30	36	36	32
7	16/09/2011	8.12	35	37	37	34
8	17/09/2011	7.52	34	37	35	33
9	18/09/2011	7.34	33	36	34	30
10	19/09/2011	7.09	32	35	33	32
11	20/09/2011	6.41	33	34	33	32

where T_{1a} (°C) and T_{2a} (°C) are morning and evening ambient temperatures and T₁ and T₂ are morning and evening gas temperatures respectively.

Using a slurry mixture of ratio 1 to 2 poultry droppings and water, gas production started on the second and largest volume of 8.31 liters, with a corresponding temperature of 39°C was produced on the sixth day.

Table 2: Volume of biogas produced for slurry ratio 1:2 (poultry droppings:water)

Day	Date	Volume (ml)	T_{1a} (°C)	T_1 (°C)	T_{2a} (°C)	T_2 (°C)
1	10/09/2011	0.00	31	31	32	32
2	11/09/2011	0.92	32	32	33	34
3	12/09/2011	3.12	32	34	33	35
4	13/09/2011	5.20	33	35	33	35
5	14/09/2011	8.22	35	37	36	38
6	15/09/2011	8.31	35	38	36	39
7	16/09/2011	8.12	35	38	36	38
8	17/09/2011	7.64	32	35	34	36
9	18/09/2011	6.11	31	34	33	35
10	19/09/2011	4.23	32	33	33	35
11	20/09/2011	2.10	32	33	33	34

where T_1 and T_2 are as defined in Table 1.

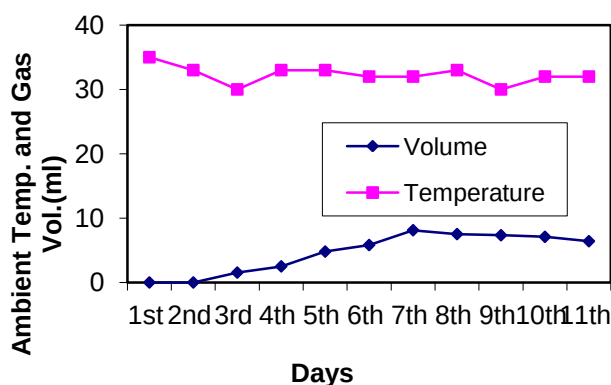


Fig 2. Volume of gas produced per day

5. Discussion

The results show that slurry ratio 1:2 (poultry droppings: water) produced more gases than that of 1:4. Also the higher the temperature, the more the volume of gas produced. The reduction in the volume of gas as the days of testing increased could be linked to the decrease in the amount of organic matter present in the slurry. The volume of the slurry retained in the digester tank was about nineteen liters which means that about five liters of slurry were converted to biogas. Change in the color of slurry evacuated was noticed with non offensive odour.

6. Conclusion

The biogas developed produced biogas which increases as the dilution ratio of poultry droppings to water reduces. Also increase in temperature of the gas resulted in corresponding increase in the volume of biogas produced

7. References

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