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Development of an Anaerobic Digester for Animal Waste

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Abstract— Advancement in biotechnology and bioengineering has provided ways that resources, which hitherto were classified as wastes, now form the basis for energy production. Anaerobic digestion is a highly promising technology used for processing biomass materials (crop residue, human excreta, animal waste and food) in the absence of oxygen to a methane-rich biogas. This work developed a small-scale anaerobic digester to produce biogas from animal waste. The anaerobic digester consisted of three major components: bioreactor with an incorporated stirrer driven by an electric motor, gas scrubber and gas collector. Batch feeding operation was adopted while pig waste was used as test material. Lime water was used as a scrubbing medium for methane enrichment. Loading result revealed that there was seven days delay in gas production from day of loading. The daily temperatures and pH recorded for a period of 50 days were in the range of 29 - 34°C and 5.5 - 7.5 respectively, and the average yield of clean biogas was 0.13 *l/kg of* slurry/day. Biogas generation increased with days in digester and was a two-stage process with a peak production day between 40 and 45 days. There was observed reduction in carbon dioxide content and methane enrichment as the days increased confirming the effectiveness of the scrubber. The biogas produced comprised between 55.1 and 74.1% of methane, and a range of 22.5 to 38.2% of carbon dioxide and was combustible after the 10th day of digestion. The results obtained showed the overall functionability of the developed anaerobic digester. The digester could be deployed and adopted in farmsteads as well as household to meet their energy demand

Keyword- Anaerobic, Digester, biogas, biomass, renewable energy, animal

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1 INTRODUCTION

The growing energy needs for both rural and urban populace and the fear of depletion of fossil fuels (Petroleum, Coal, Natural gas, etc.) requires that alternate sources of energy should be developed. Biogas, a clean and renewable form of energy that could substitute (especially in the rural sector) for conventional sources of energy (fossil fuels, oil, etc.) which are causing ecological-environmental problems (Yadvika *et al.,* 2004). Biogas generation from microbial conversion of biogenic organic wastes under anaerobic condition has become attractive globally because of its importance as a method of waste treatment and resource recovery.

In the production of biogas, the biomass is allowed to decompose anaerobically at room temperature, producing a gaseous product which contains methane, carbon dioxide, hydrogen sulphide and other impurities. The biogas which is mainly methane has to be refined of CO_2 and H_2S in other to improve its efficiency and thermal content which can be used for cooking and generating power (Abdulkareem *et al.,* 2005). Biogas plays an important role of providing alternate sources to replace petroleum, both for energy production, raw materials and input for industrial plants (Hall, 1977). Research involving rural digesters has been aiming at projects that are economical and have very good performance (Adeoti *et al.,* 2000; Aburas *et al.,* 1996; Benincasa *et al.,* 1991).

Anaerobic Digestion (AD) is the conversion of organic material directly to gas, termed biogas, a mixture of mainly methane (CH_4) and carbon dioxide (CO_2) with small quantities of other gases such as hydrogen sulphide (H_2S), Ammonia (NH_4), water vapour, Hydrogen (H_2), Nitrogen (N_2) etc. Anaerobic digestion is a controlled biological degradation process and allows for efficient capturing and utilization of biogas (approximately 60% methane and 40% carbon dioxide) for energy generation. Benincasa *et al.,* (1991) reported that digesters can be classified according to their complexity, and this varies from country to country, depending upon experience, availability of results to work out projects that are more adapted to each situation, technical, scientific and economic development, and different types of construction materials and raw materials available for digestion. In India and China they are used to produce fuel critically needed in rural areas and the effluent is utilized as fertilizer (Helenice, 2003). A typical anaerobic digester consists of a fermentation tank for fresh organic matter, (biomass), a scrubber tank containing water which serves as a cleaning medium for the biogas by removing the impurities in the raw biogas and a gas holder where the gas produced in the digester is stored.

There is a great concern about the rapid growth and concentration of the livestock industry in the developing countries due to high population density; these create environmental problems related to the livestock waste generated at dairy, swine, and poultry farms. Traditionally, these wastes have been handled directly or after composting, as fertilizer in agricultural industry. A serious problem facing most

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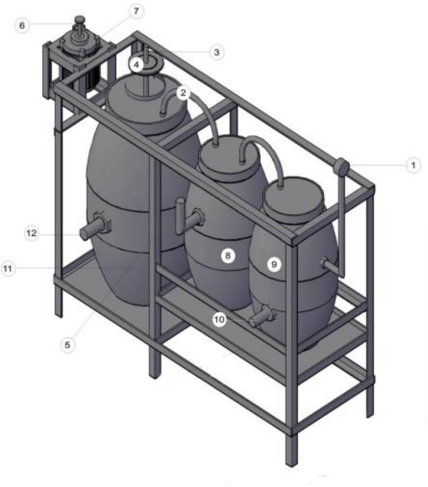
developing countries of the world including Nigeria is the rising cost of petroleum products, this imply that other natural sources agricultural wastes into renewable energy (biogas) could be a leeway to solving some of these energy problems. This study therefore developed an anaerobic digester capable of producing biogas for pig dung using a two-stage loading method.

2 MATERIALS AND METHOD

The bio-digester conceptual design consisted of a cylindrical tank (digester) which would contain the slurry, a scrubber tank containing water which serves as a cleaning medium for the raw biogas and a gas holder where the cleaned gas produced in the digester is collected or stored. A schematic diagram of the conceptual digester is as shown in Fig 1 while Fig 2 is the actual machine after fabrication.



1	Gas gauge
2	Connecting Rubber hose
3	Stirrer Shaft
4	Stirrer Pulley
5	Frame
6	Electric Motor Pulley
7	Electric Motor
8	Gas scrubber
9	Gas Holder
10	Valve
11	Digester
12	Discharge outlet

Fig, 1: Conceptual design of digester

Fig 2: The fabricated anaerobic digester with its components

2.1 CAPACITY OF BIOREACTOR AND SLURRY VOLUME

A 120 liters capacity polyethylene cylinder with a closed end was chosen as the bioreactor for portability. A conical plastic funnel, connected to the digester by a plastic tube, 8 cm diameter, fixed at 10 cm from the top side of the digester served as inlet pipe for the slurry. A tap draining to the outside at the base of the digester also served as an outlet for the digested sludge. A tap was provided to serve as an outlet for the slurry at about 2/3 from the bottom of the total height of the digester. A level- metre was included to maintain the level of the mixture in order not to exceed the desired level. The volume of slurry V_{oc} was calculated using Equation (1) according to Oumarou (2010) with capacity of digester (V_d) of 0.12m^3

$$V_{oc} = \frac{2}{3} \, of \; V_d \qquad (1)$$

$$V_{oc} = \frac{2}{3} \, x \; 0.12 = 0.08\text{m}^3$$

2.2 DESIGN OF THE AGITATOR SHAFT

Shafts form the important elements of machines. They are the elements that support rotating parts like gears and pulleys and in turn are themselves supported by bearings resting on the rigid machine housings. The agitator shaft is liable to torsion and bending due to rotary motion during the digestion process. Therefore, the diameter of the agitator shaft was determined from Equation (2) given by Hall *et al.* (1987)

$$\tau = \frac{16T}{\pi d^3} \qquad (2)$$

According to Erik *et al* (2004), for a line shaft carrying pulleys, the torque on the shaft is given by Equation 3 as:

$$T = \frac{9.55 \; X \; 10^6 P}{N} \qquad (3)$$

Also the diameter of the agitator shaft was determined using Equation (4), a modified form of Equation 2, according to Erik *et al*. (2004) gave

$$d = \sqrt[3]{\frac{5.1T}{\tau}} \qquad (4)$$

Where τ is the torsional stress, T is torque on the shaft, P is the power input, N is the rotational speed of the shaft and d is the diameter of the shaft.

2.3 DETERMINATION OF AGITATOR SPEED

The selection of the electric motor for the stirring the slurry was based on the following factors; the motor duty (continuous), power rating and speed required and type of enclosure (closed). The speed of the agitator was determined from Equation (5) according to Khurmi and Gupta, 2005).

$$\frac{D_A}{D_M} = \frac{N_M}{N_A} \qquad (5)$$

where, D_M is the diameter of the motor pulley; D_A is the diameter of the pulley on the auger shaft, N_M represents the speed of the electric motor in r.p.m and N_A represents the speed of stirrer.

2.4 FABRICATION OF STIRRER

A stirrer was fabricated and installed in the digester to ensure adequate mixing and homogenization of the materials been digested. Baffles were incorporated inside the digester to develop turbulence in the fluid while agitating for good mix. It was made of metal sheet 5cm wide and fixed on the bio-digester walls at 60^o apart. A space of 4cm was allowed between the stirrer and baffles to allow the stirrer to rotate adequately without any hindrance; while the distance between the stirrer and the floor of the digester was 17cm. Flat paddles made from steel material were fitted unto the stirrer.

2.5 RETENTION TIME (TR)

The retention time for the test material was calculated using Equation (6) by Oumarou (2010)

$$T_r = \frac{V_d}{M_O} \qquad (6)$$

Where M_o (Quantity of waste needed for initial feeding, kg/day) was obtained using Equation (7)

$$V_{oc} = \frac{M_o}{\rho_m} \qquad (7)$$

V_{oc} is volume of slurry in the digester (0.08m^3) V_d is Volume of the digester (0.12m^3), ϱ_m is Average bulk density of a pig slurry experimentally determined as 50kg/m^3 $M_o = V_{oc} \times \varrho m = 4$kg

Daily feeding rate of the digester = 4kg/day (semi batch feeding process)

The retention time calculated as 30 days from Equation (6) was used for the semi batch feeding design.

2.6 TEMPERATURE AND PH MEASUREMENT

The temperature of the surrounding environment and that of the slurry was measured and recorded twice daily with a mercury-in-tube thermometer (0 to 100^{o}C). The pH was monitored daily by collecting samples in the evening and using a portable pH meter to determine its acidity or alkalinity.

2.7 DIGESTER TESTING

Fresh pig dung of known weight was transferred to the mixing tank while water in the ratio of 2:1 (i.e. two parts of water to one part of pig dung by weight) added to produce a properly homogenized mixture.

3 RESULTS

The various fabricated components of the anaerobic digester were individually tested and were found to perform their intended functions as presented in Table 1. They were then assembled for the no-load testing of the digester. The motor was connected to the stirrer through the belt and the various pipes were also connected properly with the gate valves. The operation of the valves was satisfactory with no leakages experienced during the operations in draining of water from the digester and the scrubber.

Table 1. No load test result for the designed anaerobic digester

Component	**Test**	**Remark**
Digester	Leakages	None
Scrubber	Water and air leakages	None
Motor and stirrer	Vibration	Low
Gas storage	Air leakage	None
Valves	Air leakages	None
Pressure gauge	Functionality	Ok
Gas gauge	Functionality	Ok

3.1 LOADING TEST

The initial loading was done with 80litres of slurry while the gas scrubber was filled with 60litres of lime water. The daily temperature recorded remained in the range of 29 and 34°C throughout the period of operation, while the pH of the slurry measured are also indicated to range between 6.0 and 7.5, a condition favorable for gas production in the mesophilic temperature range. A trial run done first bypassing the scrubber and with the scrubber is shown in Table 2. The effect of the scrubber was evident in reduction in gas volume measured. Carbon dioxide and H_2S are more dissolvable in water than methane and were assumed removed by the lime-water in the scrubber as reported by Abatzoglou and Boivin (2009).

Table 2. Reduction of Biogas produced in digester from Scrubbing with NaOH

Day	Without Scrubber (Raw Biogas), cm^3	With Scrubber (cm^3)	% Reduction
0	0	0	-
5	12.5	3.51	71.92
10	18.5	13.21	28.60
15	25.9	19.03	26.54
20	32.8	24.42	25.54
25	33.9	25.88	23.67
30	35.3	27.31	22.63
		Average	33.15

3.2 GAS PRODUCTION

The mean volume of scrubbed biogas production is presented in Table 3. There was a delay period of ten days before an appreciable amount of gas was produced though a reading on the gas gauge was observed from the fifth day. The amount of gas produced was monitored by measuring its volume until a decline was observed. This took about 50days of digestion.

The cumulative quantity of gas produced (168.69*l*) for the whole experimental period is presented in Fig 3.

Table 3. Mean values of biogas produced against Temperature and pH

Day	Temp °C	pH	Biogas (l)/kg	Day	Temp °C	pH	Biogas (l)/kg
1	31	5.5	0.00	26	32	7.4	3.73
2	30	6.5	0.00	27	34	7.3	3.25
3	32	6.3	0.00	28	34	7.2	3.06
4	31	6.5	0.00	29	32	7.1	2.87
5	30	6.8	0.50	30	32	7.4	3.45
6	31	7	0.50	31	31	7.3	3.44
7	31	7.1	0.52	32	29	7.2	3.76
8	31	7.1	0.55	33	30	7.4	3.33
9	31	7.2	0.77	34	29	7.1	3.55
10	30	7.3	0.88	35	30	7.1	3.76
11	31	6.8	1.44	36	29	6.9	4.19
12	30	6.7	1.66	37	31	7.4	4.69
13	29	7.1	1.99	38	30	7.2	4.92
14	30	7.2	2.10	39	30	7.2	5.32
15	31	7.2	2.32	40	30	7.4	6.38
16	30	7.2	2.32	41	30	7.4	6.67
17	32	7.2	2.65	42	33	7.6	7.35
18	32	7.4	2.87	43	33	7.6	7.54
19	33	7.5	3.20	44	32	7.6	7.83
20	31	7.5	3.65	45	31	7.2	6.67
21	29	7.5	3.85	46	31	7.2	6.77
22	30	7.4	3.84	47	30	7.1	5.80
23	29	7.3	3.54	48	30	7.1	4.83
24	31	7.4	3.35	49	29	7.1	5.09
25	31	7.3	3.73	50	30	7.1	5.18

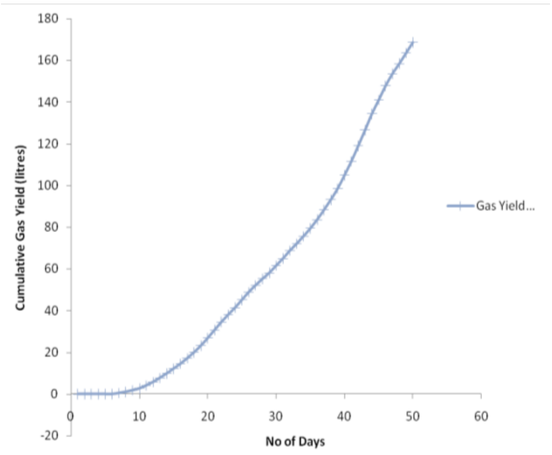


Fig 3. Cumulative biogas yield against no of days of animal waste in digester

3.3 COMPONENTS OF GAS PRODUCED

The various components of the gas produced from the bio-digester were obtained using Pascal manometric glass tube gas assay method. Table 4 shows the result for samples taken on the 10th, 20th, 30th and 50th days respectively; the biogas sample taken without passing through the scrubber on the tenth day was taken as the control. There was observed reduction in carbon dioxide content and methane enrichment as the days increased confirming the effectiveness of the scrubbing medium. This observation is in consonance with research findings using lime as a removing agent for carbon dioxide and Hydrogen sulphide (Nijaguna, 2012; Mittal, 1996; Shah *et. al*., 2016).

Table 4. Composition of Biogas sample obtained from the bio digester after various days in the digester

Days in Digester	Co_2 (%)	CH_4 (%)	H_2S (%)	Other (%)
*10th day	39.28 ± 1.21	55.1 ± 1.05	5.1 ± 0.21	0.52 ± 0.14
10	28.61 ± 1.08	66.4 ± 1.12	4.49 ± 0.08	0.50 ± 0.08
20	25.54 ± 1.01	71.49 ± 1.21	2.45 ± 0.10	0.52 ± 0.09
30	22.63 ± 1.11	74.39 ± 1.05	2.49 ± 0.09	0.49 ± 0.05
50	22.5 ± 0.91	74.57 ± 1.01	2.44 ± 0.07	0.49 ± 0.04

*without scrubbing (raw biogas)

3.4 FLAMMABILITY TEST

The gas produced from the digester was tested for its flammability using a gas burner; there was no burning from sample gas produced until the 10th day of gas production. This is not unexpected since it has been reported that until the carbon dioxide has been extensively removed burning would not be possible.

4 DISCUSSION

The designed and fabricated anaerobic digester was tested for its functionality and performances by carrying out no-load and loading tests. The average temperature of the slurry during the experimental period was within the range of 29 and 37°C indicating that digestion actually took place in the mesophilic range. The indicated pressure in the slurry container showed that it did not exceed 2.3Mpa throughout the experiment period indicating a low pressure digestion.

The trial run revealed that the scrubber (water and NaOH) was able to remove an average of 33.2% of dissolvable gas from the raw biogas assumed to be carbon dioxide and other impurities. This value was observed to be within the range of 35 to 40% reported by Kavuma (2013).

4.1 BIOGAS PRODUCTION

Gas production was low on the first seven days of digestion with no appreciable change in gas gauge but at the tenth day there was an appreciable change and there was a fair burning when tested for flammability. This is not unexpected since it has been reported that until the carbon dioxide has been extensively removed burning would not be possible (Prasad, 2012). Stable production of biogas started on the 8th day and it continued to increase till the 26th day (i.e. the first twenty days of feeding the digester with the slurry with additional six days), there was gradual decrease in the gas production for the next nine days between the 27th to 35th day and it picked up (increased) from the 36th day while it peaked on the 44th day. There was a gradual reduction in the volume of gas produced after it had reached the peak value. The production could be described as a two stage event as observed from the result, there was a gradual increase in the first 20 days where it showed a constant production which then started to increase after about 30 days until it reached a peak production between the 40th and 45th day. The first phase could be because of the introduction of slurry into the digester for the 20days, after which it was then left without further introduction that might have been the beginning of the second phase. This was different from the observation of Abdullahi *et al*. (2012) where a delay period was observed for the first ten days of digestion. This shorter delay period can be explained from the disparity in the quantity of substrates loaded in the two cases. Abdullahi *et al.*(2012) loaded a total of 1.8kg of slurry in a batch process for a retention period of 40days. The time lag before biogas production stabilized was about 10 days. The gas produced was found to burn with a blue flame when the gas production was stabilized. This observation is similar to the kind of combustion described by Itodo *et al,* (2007) where the biogas obtained from the test burnt with a blue flame.

4.2 INFLUENCE OF PH ON BIOGAS PRODUCTION

Result showed that there was a decrease in pH as the days increased from 45 to about 50 resulting in decreased gas production. This is not unexpected as acidic environment (pH < 7) results in low gas production since it inhibits the methanogen bacteria (Ciller, 2006). Increase in pH indicates acidity a situation that inhibits methanogenesis.

4.3 MODELLING OF BIOGAS YIELD

A non-linear model (Equation 8) was chosen using Coefficient of Determination (R^2) value as a criterion, the higher the value the better the model. The preferable model ($R^2 = 0.961$), though not with the best R^2 value, it had the minimal number of coefficients sufficient to describe the biogas yield.

$$y = 3.50 - 0.81x_1 + 0.147x_1{}^2 - 8.28\,x_1{}^3 + 1.93\,x_1{}^4 - 1.59x_1{}^5 - \frac{74.6}{x_2} \qquad (8)$$

Where y is the biogas yield; x_1, *is* number of days of slurry in bio-digester; x_2 is temperature of anaerobic digester and a, b, c, d, e, f, g are coefficients of the model. Figure 4 shows the observed and predicted values of biogas produced using the chosen model of Equation (8). The predicted values were close to the observed value indicating a good fit of the model. Figure 5 shows the response surface plot of the response as a function of temperature and days, where it is shown that the effect of temperature was far less than the corresponding effect of days.

The total cost for the project was estimated at N25,780 (about $100) which is lower than the costs of construction of a fixed dome plant in Tanzania ($700-1200) reported by DFID (2012).

5 CONCLUSIONS

It can be concluded from the study that:

i. A simple, efficient anaerobic digester made from available local materials was designed and constructed to produce biogas and tested for its capability in utilizing pig dung as a by-product in producing basic energy.

ii. There was observed reduction in carbon dioxide content and methane enrichment as the days increased confirming the effectiveness of water-NaOH as a scrubbing medium.

iii. The biogas comprised between 55.1 and 74.1% of methane, and a range of 22.5 to 38.2% of carbon dioxide and was combustible after the 10th day of digestion

iv. The biogas generation increased with days in digester and was a two-stage process with a constant production period of between 20and 30 days. The peak production day was between 40 and 45 days of digestion.

v. The quality of biogas produced was improved by reduction in H_2S and CO_2 content of the biogas to a considerably low concentration after scrubbing and can therefore serve as a substitute for petroleum based cooking gas.

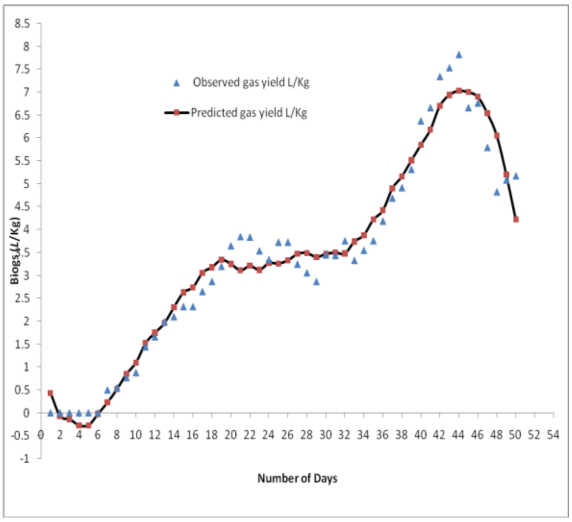


Fig. 4. The observed and predicted values of

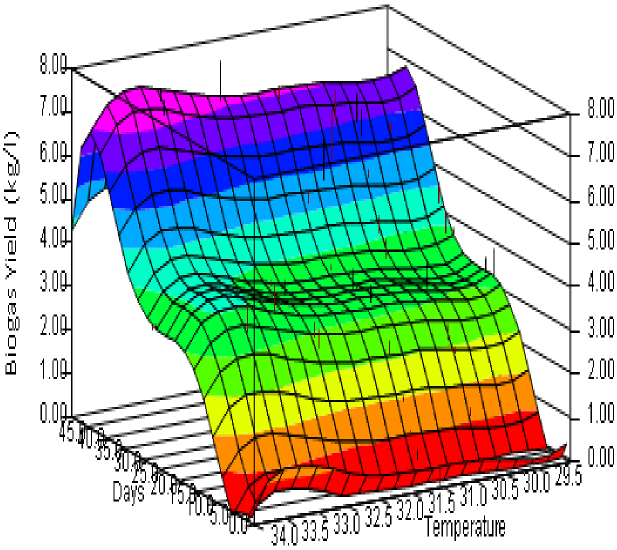


Fig.5: Response surface plot of biogas yield

vi. The developed anaerobic digester could be deployed and adopted in farmsteads as well as household to meet the energy demand.

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