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DESIGN AND FABRICATION OF AN ANAEROBIC DIGESTER FOR BIOGAS PRODUCTION

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ABSTRACT

The rise in the price of fossil fuel coupled with the negative environmental impact of global warming and exhaust emissions has aroused interest of researcher in exploring alternative sources of energy and this research focused on methane production. The project aimed at design and fabrication of a biogas digester using locally sourced materials that is affordable for low income earners. Test was carried out with the fabricated 10 litres anaerobic digester for three (3) different times at 5 litres working volume, for the fermentation of different substrates labeled digester A (pig waste), digester B (poultry droppings) and digester C (cattle dung) with their cumulative biogas production of, 0.438, 0.331 and 0.253m^3 respectively, while each was incubated for forty four (42) days at ambient mesophilic temperature of 37±1 ^{o}C at an initial pH of 6. 10±10.31 for PW, 6. 51±1.23 for PD and 7. 12±4.65 for CD. The *flow was set to the maximum of 7 litres per day in order to fill the reactor of 5 L working volume within the period of 18 to 20 hours. Digester A shows greater yield, its higher biogas production was attributed to better synergy of microorganisms in the digester and the C/N ratio which was within the normal range for optimum biogas production.*

Keyword: Design, Fabrication, Digester, Methane, Anaerobic.

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1. INTRODUCTION

Energy is one of the imperative needs of man and it is a means through which numerous other needs can be met. It can be produced from several sources such as coal, nuclear power, fossil fuels and biomass. The world today has soft-pedalled its over-dependence on fossil fuel, as people have come to realize that fossil fuel is depleting the ozone layer tremendously, leading to the current challenge of global warming [1-4]. Rise in the prices of fossil fuel, coupled with the negative environmental impact from global warming and exhaust emissions, has aroused the interest of developed countries in exploring alternative sources of energy (Renewable energy sources) like wind, solar, hydro energy and biomass [5,8-9].

An overwhelming quantity of Biomass is wasted yearly in Africa as they are not being used. Not long ago, Ethanol was discovered to be a source of energy, and this has motivated deep research into the use of Biofuels as a source of energy [6]. Methane is one of the major greenhouse gases that occur randomly in our environment either from landfills, animal dung and wetlands causing undesirable changes in our environment. The production of biogas from waste will help prevent the release of methane gas into the environment either from anthropogenic activities or bio-deterioration [7, 10-15].

Biogas production and its digester design has posed a major challenge to most developing countries, because the small-scale digesters developed failed for this reason: the design of the digester when compared to its relative economical use is not profiting, due to high capital cost of the digester and its sub-component.

Therefore, we propose to design and construction of a suitable anaerobic digester that will be efficient in the generation of methane at a minimal cost for the low income earners and thereafter, evaluate the performance of the developed digester by performing a thorough experimental analysis on methane production and compare it with an equivalent experimental digester in energy laboratory in Landmark University.

2. MATERIALS AND METHODS

2.1. Materials for the Design and Construction of the Anaerobic Digester

During the selection of material for the design and construction of the anaerobic digester, the following factors were put into consideration.

2.2. Design Analysis

In the design, the structure of bioreactor and the inculcation of temperature regulation were considered so as to have a controlled digestion process.

2.2.1. The Structure (housing) of the Bioreactor

Length of digester $= 800mm$

Width $= 800mm$

Height $= 600mm$

Diameter of the outer cylinder $= 383mm$

Diameter of inner cylinder $= 341mm$

Diameter of cylinder cover $= 341mm$

Height of digester $= 537.31mm$

Length of shaft $= 588.37mm$

Shaft diameter $= 17mm$

Bearing internal diameter $= 16.99mm$

Bearing outer diameter $= 40mm$

Heater tank $= 400x300x200mm$

Storage tank

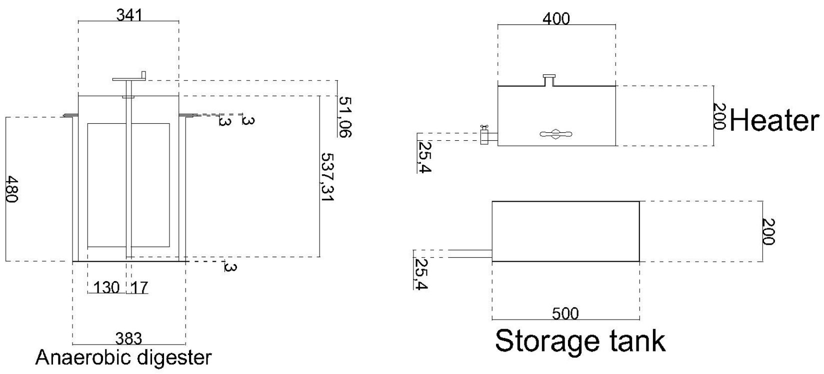

Figure 1 Isometric drawing of design component

Total surface area for cylinder, $A = 2\pi rh + 2\pi r^2$

Where h for outer cylinder $= 0.53731m, r = 0.1915m$

h for inner cylinder $= 0.474m, r = 0.1300m$

Area of outer cylinder $= 0.8769m^2$

Area of inner cylinder $= 0.4934m^2$

Area of cylinder cover $= 0.0913m^2$

Inner cylinder cover with seal area $= \pi(0.130)^2 = 0.0531m^2$

Total area of tank $= 2L_1B_1 + 2L_2B_2 + 2L_3B_3$

Total area of heater tank $= 2(400x300) + 2(400x200) + 2(300x200)$

Total area of heater tank $= 0.52m^2$

Total area of storage tank $= 2(5400x400) + 2(500x200) + 2(400x200)$

Total area of storage tank $= 0.76m^2$

Volume of heater tank $= LBH = 400x300x200 = 0.024m^2$

Volume of storage tank $= LBH = 500x400x200 = 0.76m^2$

Volume of cylinder $= \pi r^2 h = 0.0619m^3$

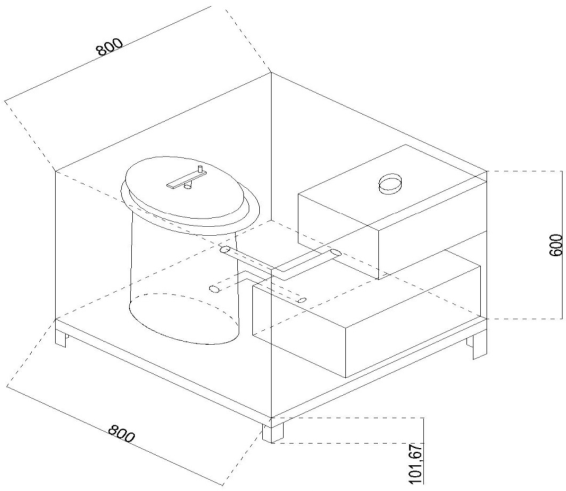

Figure 2 Isometric drawing of the main component

2.2.2. The Analysis of the Bioreactor Stir

Shaft subjected to twisting moment only;

Torque $= \frac{\pi}{16} xtxd^3$

Waste weight $= 26kg$

Torsional shear stress of mild steel, $T = 42MPa$

Radius, $R = 138.5mm = 0.1385m$

Torque, $T = Weight(f)xRadius(r)$

$T = 26x9.81x0.1385 = 35.33x10^3 N - mm$

$$d = \sqrt[3]{\frac{35.33x10^3 x16}{\pi x42}} = 16.214mm$$

Based on selected bearing diameter, $d \cong 16.99mm$

2.3. Bearing Selection for the Stir

According to international standard for radial ball bearing;

Table 1: Bearing designation

Designation	Bore (mm)	Outside diameter (mm)	Width (mm)
Bearing 203	17	40	12

Capacity: Bearing 203

Static Load; $4.75KN$

Dynamic Load; $7.8KN$

The basic static radial load rating (C_o) for radial ball bearings is given by;

$$C_o = f_o iZD^2 \cos\alpha$$

$i =$ Number of rows of balls in any one bearing

$Z =$ Number of ball per row

$D =$ Diameter of ball in mm

$\alpha =$ Normal angle of contact

$f_n = 12.3$

Basic dynamic radial load rating with ball unit larger than $25mm$;

$$C = f_o (i\cos\alpha)^{0.7} Z^{2/3} D^{1/8} [13]$$

2.2.4. Total load on base plate

Total meter sheet load $= 0.8769 + 0.4934 + 0.0913 + 0.0531 = 1.5147m^2$

Specific weight of 3mm mild steel plate $= 23.6kg/m^2$

Total Load $= 1.5147x23.6 = 35.747kg$

Specific weight of 1mm mild steel plate $= 7.85kg/m^2$

Total Load $= 1.28x7.85 = 10.048kg$

Density of water $= 1000kg/m^3$

Weight of water in the heater tank $= 1000x0.024 = 24kg$

Weight of water in the storage tank $= 1000x0.00619 = 61.9kg$

Food waste weight $= 26kg$

Total load $= (35.747 + 10.048 + 24 + 61.9 + 26)x9.81 = 1546.98N$

2.4. Sample

2.4.1. Materials for Sample Analysis and Experiment

Materials used for the experimental analysis are as presented in Table 3 were obtained from the Energy laboratories of Landmark University.

Table 2: Materials used for experimental analysis.

No	Material	Use
1	Anaerobic digester	To conceal the substrate and generate the biogas
2	Hot air oven	To dry sample of the substrate in order to determine the physiochemical properties.
3	Electronic weighing balance	To weigh the substrate samples, waste material, and gas generated.
4	Plastic containers	Used for storage and mixing the waste.
5	Electric grinder	To grind the waste particle size into smaller size to increase the surface area for efficient reaction.
6	Mercury-in-glass thermometer	To record the values of the temperature during the digestion process.
7	pH Meter	To measure the pH value of the substrate at given intervals.
8	Hose	To Connect the digester to the cylinder for gas flow.
9	Gas cylinder	Used as gas collector for the digester.
10	Test tube	To collect substrate sample for analysis.
11	Calibrated cylinder	To measure the volume of substrate and gas produced.
12	Refrigerator	To reduce the temperature of the substrate while not in use to prevent microbial activities.
13	Plastic funnel	To feed the substrate into the digester.

2.5. Materials Used

The materials used for the research were Pig waste, Poultry droppings and Cattle dung, Hydrochloric acid (HCl), Sodium chloride (NaCl), De-ionized and Water.

2.6. Collection and Preparation of Materials

Pig waste, poultry droppings and Cattle dung were the materials used. The manures were obtained from Landmark University Teaching and Research Farm in an airtight plastic container kept for 5 days to preserve the microbes. The process was batched into A to C test cases for pig waste (PW), poultry droppings (PD) and cattle dung (CD) respectively.

The substrates were feed into the reactor through inbuilt peristaltic pumps and flow steadily at mesolphilic temperature of 38 ± 1^0 C and pH of 6. 51±1.23 for PD, 7. 12±4.65 for CD and 6. 10±10.31 for PW. The flow was set to the maximum of 7 litres per day in order to fill the reactor of 5 L working volume within the period of 18 to 20 hours.

Plate 2. Setup of the designed and constructed anaerobic digester

2.7 Biogas Production at Different Waste Mixture

Table 4 shows the characterization of the substrates before digestion, while table 5 shows the characteristics of the digestates after digestion.

Table 3. Characteristics of the Substrates before Digestion

Types of Analysis	Unit	Poultry droppings	Cattle dung	Pig waste
COD	g/kg	295.42 ± 4.53	521.05 ± 6.32	351.83 ± 1.43
Volatile Solids	g/kg	39.98 ± 5.23	30.13 ± 4.70	43.64 ± 19
Total Solids	g/kg	62.05 ± 6.21	110.48 ± 1.56	55.01 ± 5.23
pH	g/kg	6.51 ± 1.23	7.12 ± 4.65	6.10 ± 10.32
Organic Carbon	g/kg	43.15 ± 4.12	41.21 ± 15.3	59.31 ± 4.93
Total Kjeldahl nitrogen	g/kg	54.54 ± 7.21	26.46 ± 4.13	79.46 ± 34
C/N		18.5 ± 9.32	10.21 ± 1.34	24.34 ± 4.64
Moisture content	g/kg	52.94 ± 31	45.10 ± 1.21	67.41 ± 3.11
Metal				
Phosphorous	ppm	29.4	23.5	32.6
Calcium	ppm	53.6	42.6	58.5
Ferum	ppm	11.4	9.34	14.8
Magnesium	ppm	12.5	13.8	14.8
Sodium	ppm	43.8	42.6	46.2

Table 4 Characteristics of the Substrates after Digestion

	Unit	Poultry droppings	Cattle dung	Pig waste
COD	g/kg	195.72±4.53	341.56±8.3	281±3.51
Volatile Solids	g/kg	24.5±6.34	15.75±1.1	28.6±1.5
Total Solids	g/kg	35.67±5.3	65.91±1.4	24.6±9.2
pH	g/kg	6.33±2.4	6.98±5.7	6.01±1.2
Organic Carbon	g/kg	36.4±3.6	32.5±4.6	42.7±7.3
Total Kjeldahl nitrogen	g/kg	49.5±2.4	23.7±9.5	57.2±7.4
VFA	g/kg	1834±394.3	1735±367.6	2145±105.4
C/N		9.21±2.43	7.34±4.34	13.86±7.45

3. RESULTS AND DISCUSSION

Fig. 3 shows the daily biogas yield from cattle dung, pig waste and poultry droppings over a retention time of 42 days. It was deduced that the daily biogas yield started on the first day for digester A (Pig waste), second days for digester B (Poultry droppings) and third days for digester C (Cattle dung). Also the biogas production for digester A (Pig waste) was highest followed by digester B (Poultry droppings) while digester C (Cattle dung) had the least biogas production. Maximum biogas yield for cattle dung, poultry droppings and pig waste were recorded on the 24th, 20th and 17th days respectively before the biogas production started declining. The higher biogas production in digester A can be attributed to better synergy of microorganisms in the digester and the C/N ratio. The daily measurement of methane content of the biogas produced shows a relative increase in the methane content of the digesters with retention time.

Also digester C (cattle dung) had the lowest biogas production due to the present of inhibition which subsequently reduces the biogas yield in a digester (Nwaogazie, 2006).

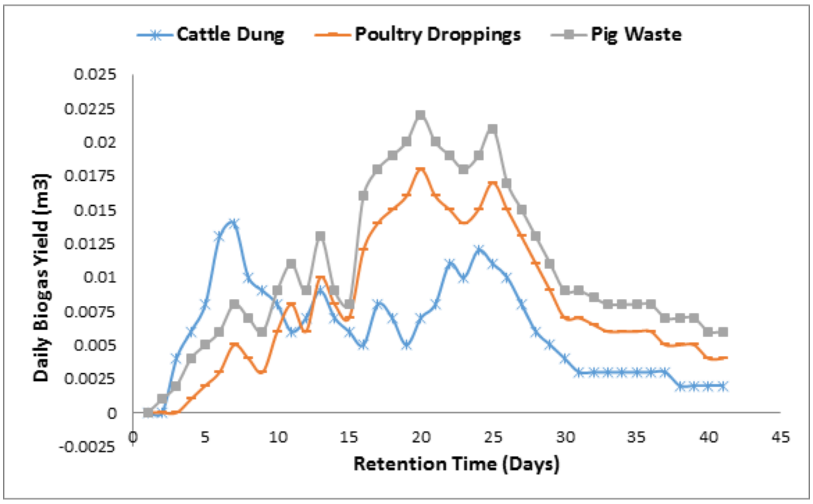

Figure 3 Daily biogas yield from cattle dung, poultry droppings and pig waste

Fig 4. Shows the cumulative biogas production from pig waste, poultry droppings and cattle dung at a retention time of 42 days. It was observed that the cumulative biogas yield increases rapidly due to excessive acetogenic bacteria needed to digest the organic acids to acetic acids. The stabilization of biogas production was recorded on the 38 to 42 days retention time, because there was no methanogenic bacteria needed for further digestion of methane gas. The variations in biogas production were attributed to spontaneous change in metabolism of the bacteria in response to the variations in the pH and temperature of the digestion medium.

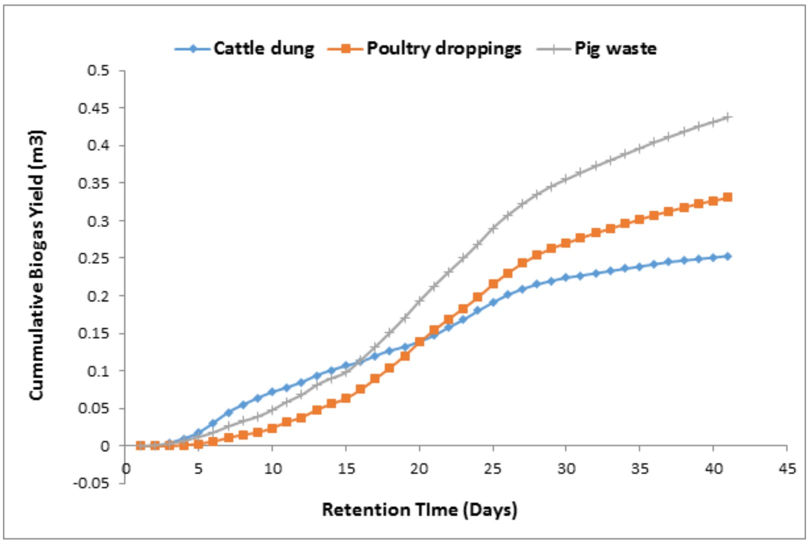

Figure 4 Cumulative biogas yield from cattle dung, poultry droppings and pig waste

4. CONCLUSION

The research showed the generation of biogas from pig waste, poultry droppings and cattle dung. The variation of biogas production from the different substrate was attributed to spontaneous change in metabolism of the bacteria in response to the variations in the pH and temperature of the digestion medium. The cumulative biogas yield for pig waste (PD), poultry droppings (PD) and cattle dung (CD) were 0.438, 0.331 and 0.253m^3 respectively.

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