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Fabrication of a Bio-Digester using Fresh Cow Dung as Energy Source

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Abstract

Energy is a fundamental factor for economic development; the global energy consumption is on geometric increase annually. Hence, in many developing countries there is a serious energy crisis and the shortage of fuel is a reality for most families and societies daily. Cooking is one of the most energy-consuming activities, yet is often inefficient. The open fire is still very common. This paper focus on the fabrication of an anaerobic biodigester using fresh cow dung as fed. The volume of the digester composed of fresh cow dung and clean water at a temperature 37℃. Slurry fed into the digester was prepared by thoroughly mixing fresh cow dung with water in a ratio of approximately 1:1 by mass. After a retention time of thirty four (34) days, the biogas generation rate was 0.215lit/hr. The gas produced by the biodigester gave characteristics blue flame during combustion test, indicating very high percentage of Methane.

Keywords: Biodigester, Methane, dung, fabrication, retention time, anaerobic. Etc.

INTRODUCTION

The problem of energy in many developing countries (including Nigeria) has not changed in the last 20 – 30 years and millions of people still lack enough energy inputs to sustain economic development (Stout and Best, 2001). The sudden and unexpected fall in the price of crude oil in the world market over the past five years up till date has been having devastating socio-economic effect on mono product (specifically crude oil) dependent economies like Nigeria. This calls for an urgent need to prioritize diversification of the energy sector of Nigeria economy through optimal and effective use of available and abundance “energy based raw materials/resources” such as animal waste, biomass and renewable resources. Furthermore, the under-utilization of readily available large quantity and “gasify” animal waste produced annually in Nigeria (Jekayinfa and Omisakin, 2005), may also increase incidences of exposure and risk associated to fuel wood pollution among vulnerable populations, particularly rural dwellers in Nigeria. In fact the World Energy Council as well as Food and Agricultural Organization of the United Nation strongly recommend that government should promote renewable and sustainable technologies that will adequately and substantially address energy crisis and its’ associated socio-economic effects peculiar to their respective countries.

Generally, waste generations are inevitable in domestic, agricultural and industrial operation. Taking into cognizant the environmental and hazardous health implication of these wastes; there has been increasing call and trend towards achieving cleaner energy production (in which higher percentage of waste materials are converted to product) or conversion of the waste generated to alternative economic uses. Biological gasification of waste or Biogas technology (biomass) is one of the effective and affordable technologies of alleviating environmental-health consequences of waste by converting them to useable energy (biogas). Biogas technology is used to mitigate the problem of waste. It employs anaerobic digestion of waste to produce methane rich gas known as biogas. Nigeria, an agrarian country produces large quantity of agricultural residues and waste annually which can play a significant role in meeting her energy demand (Oladeji, et al, 2009. But the implied potentials of these agricultural wastes (cow dung, poultry dung, pig dung etc.) and feed stock are yet to be fully tapped, specifically in converting them to energy using biogas technology. Pioneer biogas plants in Nigeria are 10m^3 biogas plant constructed in 1995 by the

Sokoto energy research Center (SERC) in Sokoto, the 18m^3 biodigester constructed in 1996 at Ojokoro Ife and another in Lagos by the federal institute of Industrial Research Oshodi (FIIRO) Lagos (Zuru et.al., 1998).

An investigation carried out on biogas production potential of cow dung using a laboratory scale of 10L bio-digester, It was found that cow dung stands a promising feedstock for biogas production (Abubakar and Ismail, 2012). Ukpai and Nnabuch (2012) have also reported significant volume of methane gas produced from cow dung using anaerobic digestion. Okoro Igwe et. al., 2013, has also reported that biogas generated from cow dung using bio-digester is capable of producing energy requirement of a household for continuous cooking. Over the years, research carried out on Biogas technology in the department of Mechanical Engineering, Delta State University, Oleh Campus has produces little or no result due to some identifiable constraints. The insufficient quantities of biogas produced in previous researches by some of these researchers may be due to improper design of the biogas digester. Some of the identifiable limitations are improper air tightening of the digester, biogas pressure were not considered, no bio-digester lagging and no basis for choosing the volume of the digester thus, the need for this research.

The aim of this study is to design and fabricating of bio-digester with an improved to produce sufficient gas for cooking. Furthermore, test for its efficiency, i.e. how perfect it can sustain a family of four on daily use. In this study, cow dung and a quality storage tank was the key component used for the fabrication the mproved (anaerobic) bio-digester suitable for a family of four. One of the major limitations is that Analysis and purification of the biogas generated is not considered in this research work. Considering previous work done in this aspect of energy source it will be interesting to know that tremendous achievement has been reached.

Anaerobic digestion is a natural process that happens in conditions of absence of oxygen, it is referred to as bio-methanization,. In this microbiological process, the organic matter is fermented by transforming the digesters (bacterial) action in biogas (composed of CH_4 and CO_2 mainly) and producing a fertilizer rich in mineralized nutrients and therefore for immediate disposition for the plants. Bio-digesters are closed reactors that facilitate anaerobic digestion by providing an anaerobic atmosphere for the organisms responsible for this process (Balasubramanya, 1988; Chanakya 2009).

The fermentation can occur conditionally in natural environments such as in lakes sediments and in gastrointestinal tracts of animals or can be created in industrial, semi-industrial and rural processes (Khalid et al., 2011). Anaerobic digestion is a multi-stage process and parallel reactions where different types of bacteria degrade organic matter successively. Large bacterial populations are identified, which are developed catalyzing three consecutive processes: hydrolysis, acidogénesis (formation of acids) and methanogenesis (formation of methane) (Bouallagui, 2005; Elías et al., 2012; Yaw et al., 2016). There are several factors that can affect, improve or inhibit the functioning of the anaerobic digestion process. These factors are; pH, temperature, nutrients, organic load, concentration of solids in the tributary, available nutrients, retention time and organic loading speed, agitation and inhibitory substances (Khalid et al., 2011).

The pH value is an important indicator of the operation of the process within the biodigestor. According to Elías et al. (2012), in each phase, microorganisms show maximum activity in a differentiated pH range (Table 1). The biggest problem is generally to maintain the ph above 6.6, since the organic acids produced as intermediates in the early stages due to an overload or any other imbalance can cause a rapid decrease of the pH and the consequent cessation of methane production. Alkalinity and pH in anaerobic digestion can be adjusted by adding different chemicals to the mixture (sodium and potassium bicarbonate, calcium carbonate, etc.) and also by mixing different residues to be treated in the reactor (codigestion). (Diaz de Basurto, 2013)

Table 1: *Optimum pH ranges for different micro-organisms*

Stage	**Types of Bateria**	**Optimum pH Range**
Hydrolysis and Acidogenesis	Hydrolytic Acidogenic	7.2 – 7.4
Acetogenesis	Acetogenic and homoacetogenis	7.0 – 7.2
Methanogenesis	Methanogenesis and Acetogenesis	6.5 – 7.5

Source: *Elías et al., 2012*

Temperature is very important parameters in anaerobic digestion, since it determines the degradation rate of the anaerobic process, mainly those of the hydrolysis and methanogenesis stages. There are three temperature ranges in which anaerobic digestion can be carried out, they include; Psychrophilic: Below 25ºC, Mesophyll: between 30 and 40ºC, Thermophilic: between 50 and 60ºC. By increasing the temperature range, increase the hydrolysis rate, the speed of growth and thus the speed in the production of biogas. (Elías et al., 2012; Fernández et al., 2008)

The hydraulic retention time describes the measure of average time a substance resides in the reactor. By increasing this time, it increases the degree of degraded organic matter, as well as the production of methane. The organic loading speed is defined as the amount of organic matter fed by volume of biodigestor over a certain period of time. In the absence of inhibitors, high organic loads provides high methane production, but also increases the risk of point overloads that lead to acidification of the reactor causing a decrease in pH and possible failure of the system.

Family-scale bio-digestion has been widely disseminated in countries like China or India since the last quarter of the last century and more recently in Nepal (Biogas Support programme), typically in fixed-dome (Chinese type) or floating-dome digesters (type Indian). However, the complexity of its construction and a relatively high cost may be limiting to its implementation. The plastic tubular bio-digesters, of simple and economical construction, allow for a greater expansion of this technology (Preston, 2002). Possible materials for its construction are polyethylene and PVC (Geo-membrane), being the last more resistant but also more expensive (Pedraza et al., 2002).

A continuous-flow reactor is one that has a continuous tributary and effluent. In the continuous-flow reactor there is a mass exchange throughout the operating time. Where was sought to reach the stationary state by controlling the operating conditions that are the concentration of substrate, pH and temperature. The load of all the material to be fermented is done at the beginning of the process and the discharge of the effluent is done at the end of the process; usually they require more labour and a space to store the raw material if it is produced continuously and a gas tank (due to the large variation in the amount of gas produced during the process, having its peak in the middle phase of this) or was sources alternatives to supply it. The load of the material to be fermented and the discharge of the effluent is carried out in a continuous way or by small potholes (eg once a day, every 12 hours) during the process, which extends indefinitely over time; they usually require less labour, but a more fluid or mechanically mobilized mixture and a gas tank (if this is not fully used continuously). The continuous biodigesters are used to purify water contaminated by different pits.

According to Kim Oanh et al. (2013) in the laboratory-scale study, they used 45-litre cylindrical reactors located inside. These were insulated with polyurethane foam to minimize reactor temperature variations that could affect the anaerobic digestion process. Each reactor was hermetically sealed with rubber tape and a screw cap to ensure anaerobic conditions. The recycled liquid was obtained by filtering the effluent from the digester through a screen to prevent clogging of the pipes and then distributed over the top of the solid waste in the reactor by means of a pump and a sprinkling system of taps. The detailed design of the laboratory-scale bio-digester is shown in Figure 1. This was loaded a mixture of various types of solid organic waste.

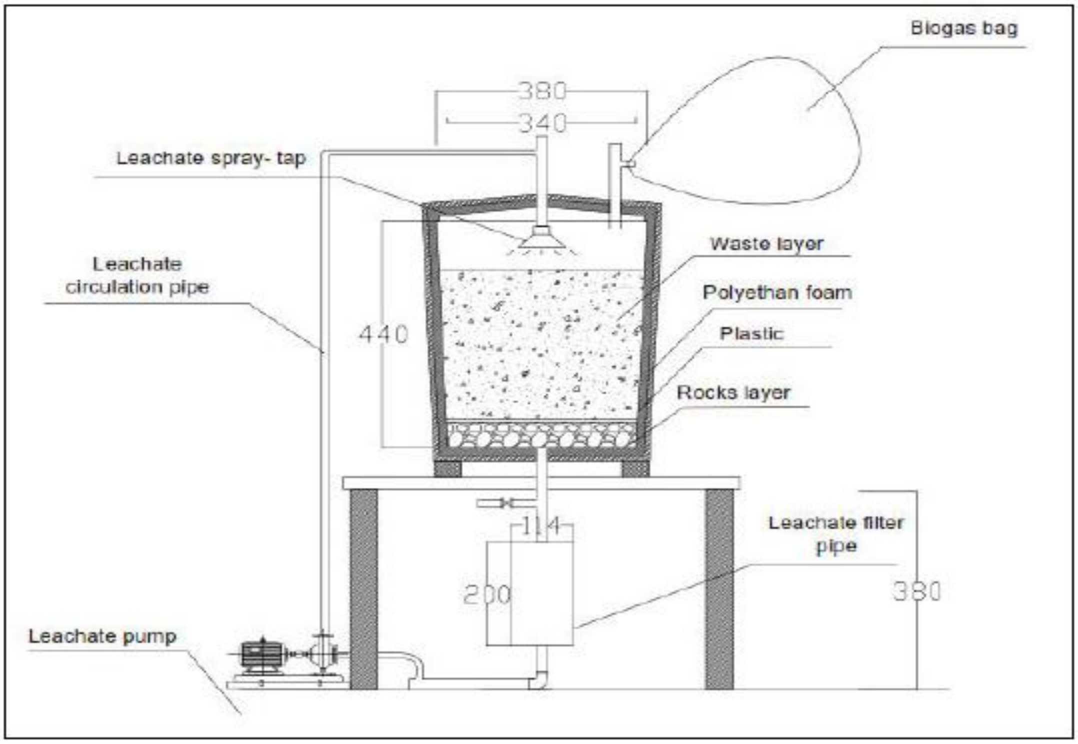

Fig. 1: *Laboratory-scale anaerobic digestion biodigester*
Source: Le Thi, Ko et al., 2013

The mixture of the best results with respect to the production of biogas and the methane content in the laboratoryscale test was selected for experiments with pilot-scale reactors (Le Thi, K. O. et al., 2013). As a basis of our prototype conceptualization, the design and scaling from the laboratory type will be carried out, as a departure for the pilot scale design. This will be carried out according to estimations of residues quantification and previous characterization studies in the area, for the conceptualization and development of the biodigestor. In contrast to the design proposed by Le Thi, K. O. et al. (2013) calculations will be made for sizing, considering the quantity of waste generated and the energy potential to produce biogas to be obtained. Having an accuracy of the laboratory-scale generation, there will be a period of settlement of waste use to determine the methane production potential generated, as well as the dimensions of each part and component of the prototype to design.

Fruit and vegetable residues present an energetic potential if they become biologically converted into methane (Gunaseelan, 2004). These residues, and in general all organic, can be characterized by their potential biochemical methane (PBM). The PBM test provides a measure of anaerobic degradability of a given residue, in addition, it is a fast and economical method. Due to the worldwide increase in the application of anaerobic digestion technology, a large number of studies and research has been carried out in recent years to determine the potential for the production of methane from organic solid waste. The different protocols raised differ according to the purpose of the measurement, the type of samples, the complexity of the equipment proposed in each work and even the units of the variables presented, making the comparison of the data of biodegradability in literature is very difficult (Angelidaki et al., 2009).

Hansen et al. (2004) propose a more comprehensive and easy-to-operate protocol for the determination of the methane production potential of organic solid waste and is expressed in terms of volume of methane (mL) under standard conditions of pressure and temperature per gram of organic residue. Biomass has to be a waste to take into account in anaerobic digestion technology, since the potential of methane production of this, is at least, double than animal excrement, or plants (Jagadish et al., 2008). Qiao et al. (2011) evaluate, in their study, the potential for methane production of cow and pork excrement, mud and remnants of fruit, vegetables and food.

MATERIALS AND METHODS

The Context of the Study

Due to availability of cow dung in Abraka, the digester was fed with cow dung. The biogas digester was installed at a livestock farm along police station road, Abraka, Ethiope east local government area of Delta state, Nigeria. The exact geographical coordinates of the location site are as follows: latitude 5°46′52″ North and longitude 6°7′20″East, with an elevation of 1000 feet. as shown in Figure 2.

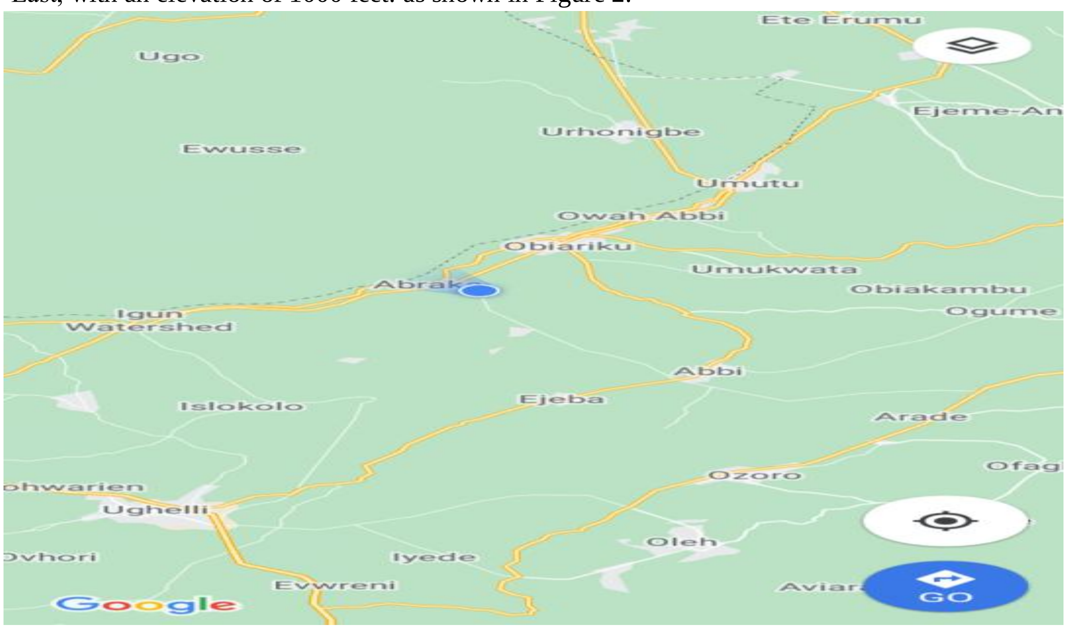

Fig. 2: Location site for the biodigester site

Description and design parameter of the Biogas Digester System

The biogas digester of the present study was made from a high-density polyethylene (HDPE) plastic. It has the following parts:

- the inlet chamber (feed entrance),
- outlet chamber (removal of digested waste),
- and the gas storage chamber.

The inlet and outlet chambers were built with PVC pipe. The inlet chamber was connected to the digester chamber via an inlet pipe made of Ø 2 inches PVC pipe, inclined at an angle of 90° to the digester cover, while the outlet chamber was connected using the same 2 inches PVC pipe. The dimension of the inlet chamber is 895mm for the height while that of the outlet chamber is 1290mm for the height. The fabricated biogas digester was installed as shown in Figure 3.2. The digester cover was also made of the same HDPE plastic material that could withstand harsh environmental conditions and still maintain anaerobic condition. The slurry and gas temperature were monitored using a K-type thermocouple inserted into the digester through the cover of the digester

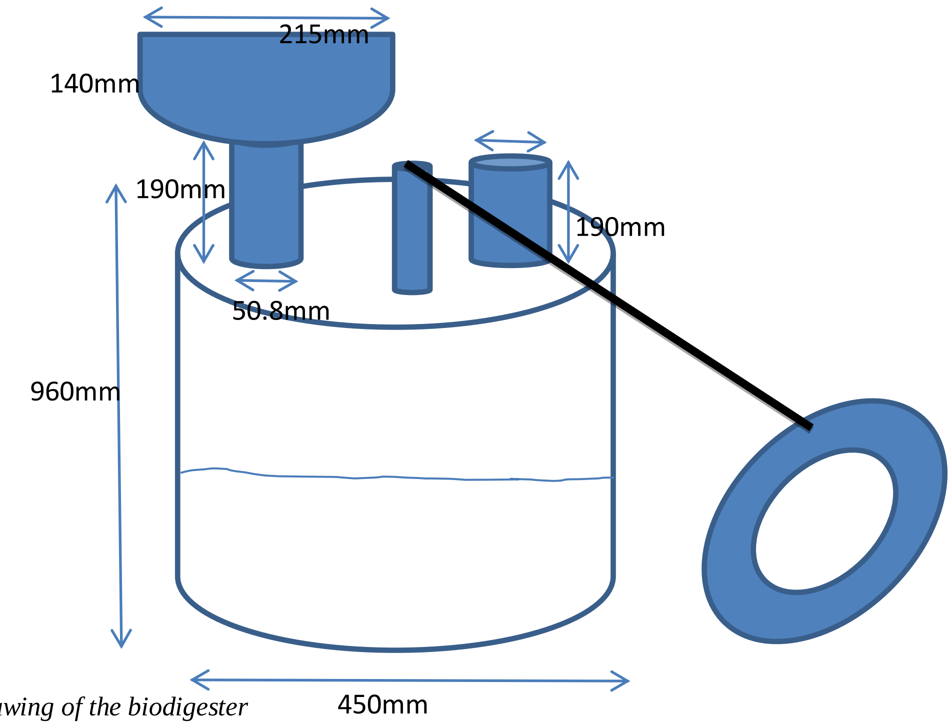

Fig. 3: Section drawing of the biodigester

Material Preparation

The cow dung was collected from Fulani camp and weighed to know to its total weight. This measurement was done using analogue scale. Prior to the digestion process, the slurry was obtained by diluting solid waste (cow dung) measuring 54kg with water measuring 40kg to ensure that the percentage of the total solids was less than 10%.

Experimental Procedure and Measurement

Volume of the Digester

For the fabrication of the biodigester, the design calculation of the digester volume, inlet and outlet section were considered. After the fabrication of the digester chamber, the actual digester volume was determined by measuring the dimension of other components using the builder's meter. Figure 3.2 shows the drawing of the biodigester. The volume of each of these shapes contributed to the total volume of the biogas digester. The following parameters were used in the calculation:

- Height of the digester = 0.96m
- Diameter of the digester = 0.45m
- Diameter of the inlet pipe = 0.05m, r = 0.025m
- Height of the inlet pipe = 0.19m
- Diameter of the outlet pipe = 0.05m, r = 0.025m
- Height of the outlet pipe = 0.19

- Diameter of the inlet cone = 0.215m, r = 0.108m
- Height of the inlet cone 0.14m

First, considering the biogas digester, the volume is determined as

$V = \pi r2h,$

Where $r = 0.225\ m$, the radius of the biodigester, an $h = 0.96\ m$, the height of the cylindrical shape.

$$V = 3.143\ X\ 0.225^2\ X\ 0.96$$

$$V = 0.153\ m^3$$

Therefore, the volume of the digester was obtained to be 0.153m^3. Second, for the inlet pipe section, the volume of the inlet is determined as

$$V_i = volume\ of\ inlet\ pipe + volume\ of\ the\ inlet\ cone$$

$$V_i = V_p + V_c$$

$$V_i = \pi r^2 h + \frac{1}{3}(\pi r^2 h)$$

$$V_i = (3.143\ X\ 0.0252\ X\ 0.19) + \frac{1}{3}(3.143\ X\ 0.1082\ X\ 0.14)$$

$$V_i = 0.00039 + 0.0017$$

$$V_i = 0.00209\ m^3$$

Therefore, the volume of the inlet section was obtained to be 0.00209m^3. Third, for the outlet pipe section, the volume of the outlet is determined as

$$V_0 = \pi r^2 h$$

$$V_0 = (3.143\ X\ 0.025^2 X\ 0.19)$$

$$V_0 = 0.00039\ m^3$$

Construction of digester

The bio-digester was constructed using high-density polyethylene (HDPE) drum bought from obiaruko main market, PVC pipe, PVC ball valve, PVC back-nut, PVC adaptor, flexible connector, gas hose and PVC gum. Figure 3 below shows the drum and the PVC materials used in the bio-digester construction.

Fig. 3: *High-density polyethylene (HDPE) drum*

Several holes were drilled on top of the drum for easing mounting of the inlet pipe, outlet pipe and gas collector pipe, Inlet, outlet and gas collecting pipes were screwed to the drum cover and gummed with a PVC gum to prevent leakages and to prevent air from entering the digester chamber.

Digester loading and biogas production

The cow dung was weighed using measuring scale and a weight of 54kg was recorded as shown in Figure 4. The cow dung was prepared with water (49kg) into slurry and introduced into the constructed bio-digester at the construction site. The digester loading rate was increased progressively by adding greater volumes of water and cow dung content to eventually reach the maximum nominal loading.

Fig. 4: *weighing and loading of cow dung*

The slurry was allowed to occupy three quarter of the digester space leaving a clear height as space for the gas production. Before feeding the bio-digester, the flexible hose connecting the gas outlet from the digester to the gas holder was disconnected, such that the gas outlets from the digester were left open. This was done to prevent negative pressure build up in the digester. The gas was collected from the digesters through a 10 mm diameter flexible hose connected from the digesters to the bottom of the gas collection systems.

RESULTS AND ANALYSIS/DISCUSSION

Experimental Results

The following experiments was carried out after the digester was loaded with cow dung; temperature, biogas production rate,

Temperature behaviour

The constructed bio-digester was observed to have a temperature lower than the ambient temperature twelve (12) days after the slurry was fed into the digester at a temperature of $43°C$, this necessitated the monitoring of the temperature behaviour of the slurry in the digester which was obtained from the digester wall. The results are tabulated below.

Table.1: *Ambient and Digester Wall Temperature*

DAY	AVERAGE TEMPERATURE OF DIGESTER (^{O}C)				AMBIENT TEMPERATURE ^{O}C			
	M	A	E	Average	M	A	E	Average
1	24.2	33.9	29	29.03	19.8	36	28	27.94
2	26.33	36	30	30.5	21	43	29	31
3	26.33	30.5	28.33	28.31	23.5	35	27	28.5
4	25.83	31.21	29	28.68	23	37	28	29.33
5	26	31.33	29	28.75	21	36	28	28.33
6	26.83	31	29	28.94	25	35	28	29.33
7	26.83	31	29	28.94	24.5	35	28	29.11

Where: M=Morning, A=Afternoon, E=Evening

Plotting these values in table 1 against number of days resulted into the graph in Fig. 4. It was observed that the temperature of the digester before the retention time, is on the average lower than the ambient temperature by a range of 2-3^{o}C for both morning and evening. This implies that the methanogenic bacteria were growing in population during this period. When the retention time elapsed, the temperature of the digester was observed to be greater than the ambient temperature particularly in the morning and evening, an indication that the methanogenic process has increased hence biogas production has begun.

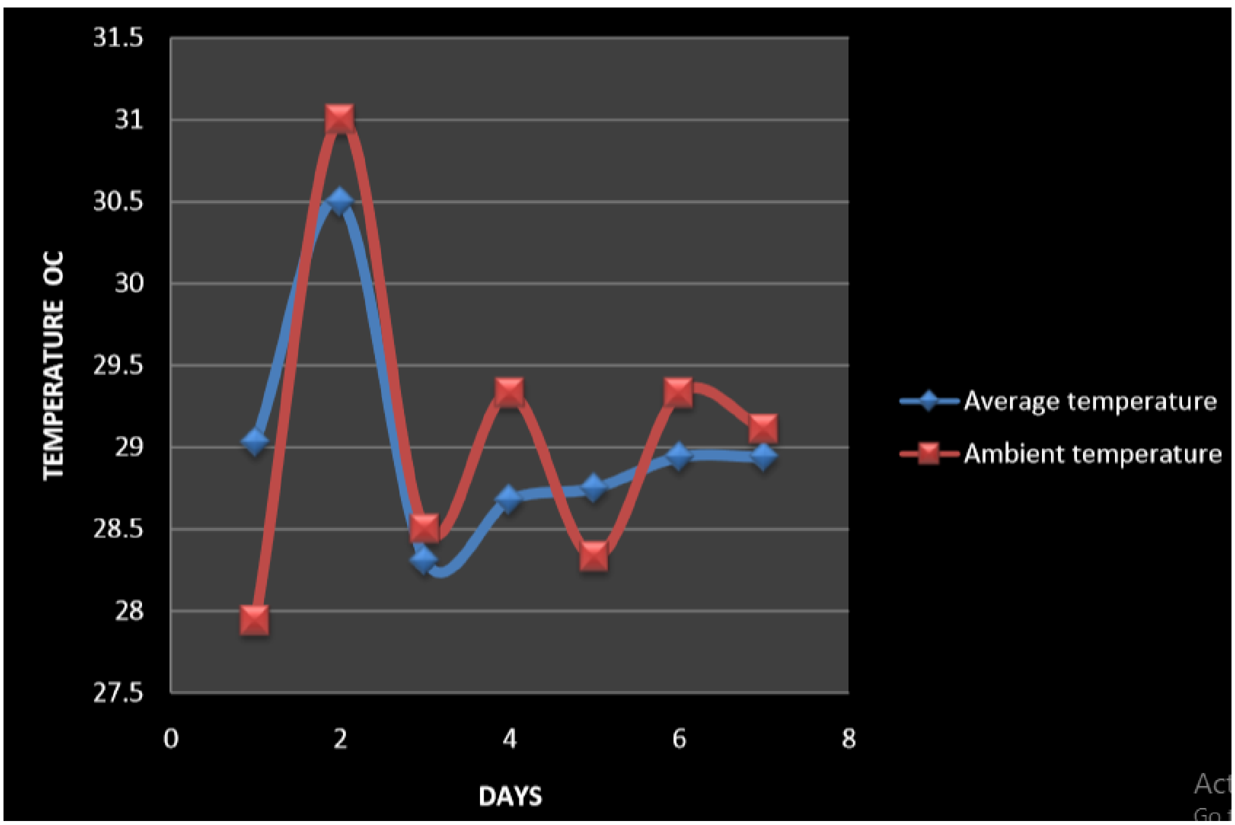

Fig. 5: *Fluctuation of Digester Temperature*

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Biogas production rate

During the retention time the biogas production was obtained by measuring the volume of the biogas produced in every twenty four (24) hours. The setup is shown in Figure 5

Fig. 6: *Setup for gas collection*

This analysis was carried out after the first production of the biogas was expelled from the digester due to large amount of air present. Twenty four (24) hours after the expulsion, the following results were obtained as shown in Table 4.2. A plot of plot of retention time and accumulated gas is also shown in Figure 4.3.

Table 4.2: *Volume of Biogas Generated (With a Production Rate of 0.215litres/Hour)*

S/N	Time collection after first production was expelled from the digester (hours)	Volume of biogas collected (Litres)	Accumulated volume (Litres)
1	0	0	0
2	24	3.5	3.5
3	48	5.0	8.5
4	72	7.0	15.5

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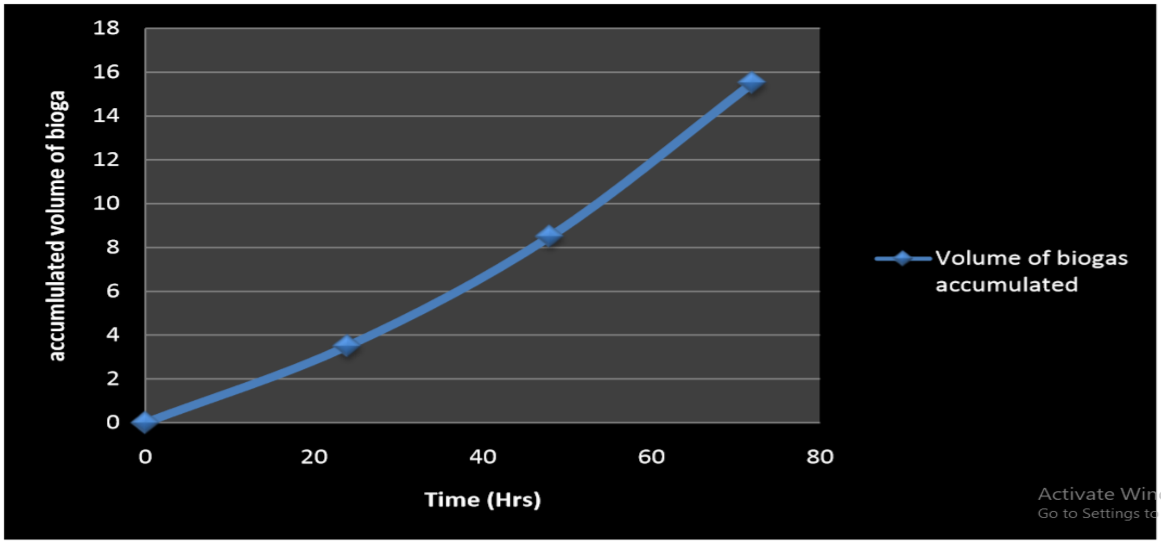

Fig. 7: *Volume of biogas accumulated against time (hrs)*

Combustion Test

The combustion test carried out on the generated biogas for different days revealed that the methane content in the biogas improved on daily bases. A week after the first sample of the biogas was generated it was observed that it burnt satisfactory with a blue flame as shown in Figure 7.

Figure 7: Carrying out combustion test

Data obtained from the combustion test process are as shown in Table 3.

Table 3: *Combustion results*

No. of days after the slurry was loaded into the digester	Volume of biogas (Litres)	Remark
14	0.3	Supported combustion
16	1.0	Slightly combusted
17	2.1	Improved combustion
19	3.3	Combustion satisfactory

Cost Analysis

Cost is a major factor taking into consideration not only in the selection of the material employed, but also in the processing of the selected materials. The material selected and processes employed are such that the cost is reduced to possible minimum. The cost of materials employed in the construction is shown in table 4.4

Table 4: *Cost analysis*

s/n	Component description	Qty	Unit Cost N	Total cost
1	Drum	1	14000	14000
2	PVC ball valve	2	1500	3000
3	PVC backnut	3	900	2700
4	PCV gum	1	1800	1800
5	Gas hose	3	500	1500
6	PVC pipe	1	1200	1200
7	Gas valve	2	1000	2000
	Total			26,200

Conclusion

A bio-digester was designed, constructed and tested. The biogas generation rate was 0.215litre/hr after a retention time of thirty four (34) days. Although the combustion of the initial biogas generated was unsatisfactory during combustion test probably due to large amount of incombustible gases, subsequent biogas generated was combusted for 10mintues to boil 1 litre of clean water. The biogas generated from this research was not analyzed due to time constrain but gives a characteristic blue flame of methane during combustion suggesting a high percentage of methane in the composition.

Acknowledgement

Appreciation goes to all that contributed this study a success especially Engineer Okwuejemine Charles Ufuoma and Ubaezuonu Chukwuejemine who devoted time and space for this research

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