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Development of a mini biogas digester for household use

Tanko Bako[1], Larry Orobome Agberegha[2], Abubakar Said Aliyu[1]

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Author Affiliation:
[1]Department of Agricultural and Bio-Resources Engineering, Faculty of Engineering, Taraba State University, Jalingo, Nigeria
[2]Department of Mechanical Engineering, College of Engineering and Technology, Federal University of Petroleum Resources, Effurun, Delta State, Nigeria

***Corresponding author:**
Email: engbako@gmail.com

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ABSTRACT

A mini biogas digester was designed, developed and evaluated at the Department of Agricultural and Bio-Resources Engineering, Taraba State University, Jalingo. Biogas was generated by co-digesting cow dung and vegetable waste at 25 days retention time. The cow dung was collected from the university farm, while the vegetable waste was collected from the residential settlement around the University campus. The substrate was mixed in the ratio 1:1:1.5 of cow dung, vegetable waste and water. The generated gas was collected in a tire tube using a motorized compressor. The biogas was burnt using a burner to observe the features of the flame produced. The mini biogas digester has a total production cost of thirty one thousands and thirty naira (₦30,030.00) only. The designed biogas digester had a 0.230 m^3 PVC tank as the combined digester volume and gas holder volume, 4 inches pipe as inlet for substrate delivery into the digester and 1 inch pipe as outlet for exiting effluents. The design analysis showed the digester size as 0.173 m^3 and gas holder size as 0.058 m^3. The biogas produced from the experiment showed the good quality combustible biogas yield of 8508.8327 cm^3 (0.008509 m^3). The gas produced gave a brilliant coloured flame on burning. The results also showed that the residue organic waste from the digester can be used as manures for fertilizing the farm.

Keywords: substrate; cow dung; vegetable waste; gas

1. INTRODUCTION

Energy is one of the key components required to reduce poverty, improve the standard of life, and facilitate socio-economic development. The current and continued rapid economic growth of Nigeria leads to high energy demand with associated challenges and negative impacts. The country has been experiencing a severe energy crisis (lack of electricity and gas supply network), especially in rural areas. Rural and remote areas of the country have often faced severe crises and have inadequate or no public energy supply. These areas are characterized by their often inefficient use of woody biomass, mainly for cooking purposes. To avoid the resulting environmental degradation and achieve sustainable development, access to clean and affordable energy is essential. Upgrading existing biomass resources (i.e., animal manure, crop residues, kitchen waste and green wastes) to biogas shows significant promise in this respect.

The combination of growing energy demand, inadequate natural resource availability, and lack of renewable energy alternatives has led to a burgeoning interest in biogas technology in Nigeria and other countries. Anaerobic digestion (AD) is a biological process that is used for the efficient conversion of livestock manure and agriculture residues into clean renewable energy and organic fertilizer. Methane rich biogas (typically 50-70% methane, 30-50% CO_2, with traces of H_2S and other gases) is a clean, efficient, and renewable source of energy, which offers a multipurpose carrier of energy, and can be used as a substitute for other fuels (like firewood and cattle dung) currently used in rural areas (Yu et al., 2008; Bond and Templeton, 2011). Typical calorific values of biogas are 21-24 MJ/m^3 or around 6 kWh/m^3. The digestate is highly enriched in ammonium and other nourishment and can be used as an organic compost in the field or as fish feed (Bond and Templeton, 2011).

Tremendous amounts of biomass resources - agriculture residues (crop/tree residue, rice husk, wheat, jute stick etc.), animal dung, woody biomass, tree leaves, municipal solid waste, kitchen waste, vegetation, sugarcane bagasse, poultry droppings, garbage, etc. - have the potential to meet the energy needs of households and small industries. Today, especially in South-east Asia millions of rural families uses small-scale digesters to produce biogas for multi purposes such as cooking, heating, cooling, lighting and vehicle fuel (Yu et al., 2008). Biogas has definite advantages as compared to other renewable energy alternatives: it can be produced when needed, can be easily stored in reasonable quantities, and can be distributed through existing natural gas networks as a natural gas substitute (Holm-Nielsen et al., 2009).

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 (Christian et al., 2018). 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 (Ghaffar and Fan, 2015; Lei et al., 2015; Dai et al., 2016; Shuzhen et al., 2016; Christian et al., 2018).

The development of new methods of production and use of renewable energy sources that suit the economic and the geographical conditions of the developing countries will be required in order to solve the problems of energy crisis and climate change. To this end, this research examines the generation of energy from an organic waste known as Biogas. The interest in such renewable energy is driven by the rapidly shrinking reserve of fossil fuel due to increasing demand for primary energy, rise in fuel prices, global warming-from flaring and greenhouse gas emission; and most importantly the availability of organic waste. The main objective of this study is to develop a biogas system that will generate clean energy as an alternative source of energy in the villages. This will help build body of knowledge in biogas energy generation and further create awareness of the need for sustainable energy sources in the country.

2. MATERIALS AND METHODS

Materials

The materials used for construction of the biodigester are; PVC drum, ball valve, brass hose, gas pipe, hose clamp, PVC pipe 4" and 1", brace tee barb and adhesives. The materials used for performance test are; Continuous flow biodigester, substrates (cow dung and vegetable wastes), plastic buckets, head pan, shovel, water, gas storage tube, motorize compressor, storage tube and gas stove.

Design selection

The factors considered in selecting the design of the mini biogas plant are; availability of construction materials and skills, cost of materials and feed materials to be used. Since vegetable matter and cow dung is to be used as feed stock, a continuous system and a fixed dome digester type was selected. In order to avoid gas leaks, a good insulating and airtight material must be used. The design of the mini biogas digester employs the principle of both the fixed dome digester system and balloon digester system that is entirely made of PVC which has the advantage of being light, airtight, easy to maintain and low cost. The mini digester consists of a heat-sealed plastic drum, combining digester and gas-holder. The gas is stored in the upper part of the digester. The inlet and outlet are attached directly to the skin of the drum.

Gas plant size selection

Size selection of biogas plants depend on the amount of gas required and the amount of feed stock available. For 2 m^3 gas productions per day, the corresponding size of the fixed dome digester is about 10 m^3 and for 10 m^3 gas productions per day, the corresponding size of the fixed dome digester is about 50 m^3 (Yasmine, 2017). In this design, a small capacity plastic drum was used for the mini biogas plant construction. The total surface area of the drum (A_d) was calculated from Equation 1.

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$$A_d = 2\pi rh + 2\pi r^2 \quad (1)$$

Where; r = Radius of the drum (0.285 m), h = Height of the drum (0.90 m).

$A_d = 2\times\pi\times0.285\times0.90 + 2\times\pi\times0.285^2$ $A_d = 1.61+1.79 = 3.40$ m^2

The total volume of the drum (V_d) was calculated from Equation 2.

$$V_d = \pi r^2 h \quad (2)$$

$V_d = \pi\times0.285^2\times0.90 = 0.230$ m^3

Digester size selection

The digester capable of fermenting such a mixture of input materials, including plant waste, is the fixed dome digester, which usually operates on a continuous basis (Yasmine, 2017). The size of the digester was taken to be three-quarter of the total volume of the drum.

$$\text{Digester size} = \frac{3}{4} \times 0.230 = 0.173 \text{ m}^3$$

Gas holder size selection

The gas holder collects and stores the gas when it is not in use. The volume of the gas holder depends on the relative rates of gas production and consumption. Most plants are used to provide gas for cooking and lighting. At the other extreme, if all the gas is used to run an engine for 3 hours a day, then the gas holder must be able to store 88 per cent of the daily gas production (Yasmine, 2017). In the fixed dome digesters, the gas accumulates in the space under the dome, which should never become less than 20 percent of the total volume of the digester (Yasmine, 2017). The size of the gas holder of the mini biogas plant was taken to be 25 % of the total volume of the drum.

$$\text{Gas holder size} = \frac{25}{100} \times 0.230 = 0.058 \text{ m}^3$$

Volume of biomass required. The volume of the biomass required per day was computed from Equation 3.

$$V_B = \frac{V_D}{R_T} \quad (3)$$

Where; V_B= Volume of biomass added per day (m^3/day), V_D= Volume of the digester (m^3), R_T= Retention time required (25 days).

$$V_B = \frac{0.230}{25} = 0.010 \text{ m}^3/\text{day}$$

Gas yield. The gas yield or gas production rate of the digester was obtained from Equation 4.

$$G = V_B \times G_Y \quad (4)$$

Where; G = Daily gas production rate (m^3/day), V_B = Volume of biomass added per day (0.010m^3/day), Gy = Gas yield per kg of feedstock per day (m^3/kg/day).

$G = 0.010\times0.5 = 0.005$m^3/day

Construction process

The construction process involves cutting, fixing and sealing of plastic pipes to the digester drum. Plate 1 is the construction process of the developed biogas digester.

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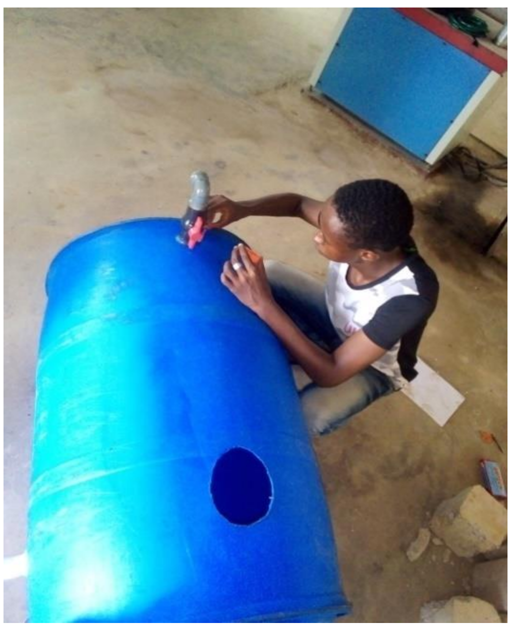
Description of the biogas digester

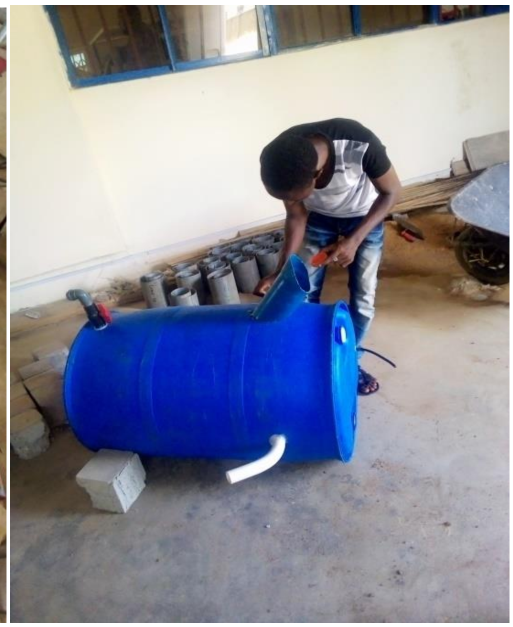
The developed bio-digester consists of a 0.230 m^3 capacity PVC drum having inlet and out let pipes, with a gas pipe which was connected to a storage tube. The PVC drum was designed to store (hold) the substrate for the digestion process, the inlet pipe was designed for feeding substrate into the digester and the outlet pipe drains the substrate during overflow. The storage tube was used for storing the gas obtained from the digestion process. Plate 2 is photograph of the developed biogas digester.

Preparation of the substrate for performance evaluation

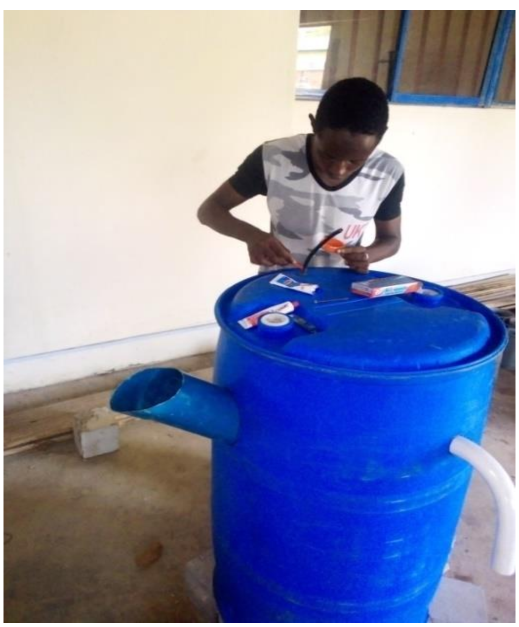
The cow dung was measured using a plastic bucket of 0.151 m^3, and was mixed with grinded vegetable waste 46 Liters together with 115 Liters of water. The combination was mixed using stick and hand to give a homogeneous substrate.



(a) Sealing of Drain Valve



(b) Sealing of Inlet Pipe



(c) Sealing of Gas Outlet

(d) Connection of Hoses

Plate 1: Construction Process of the Developed Biogas Digester

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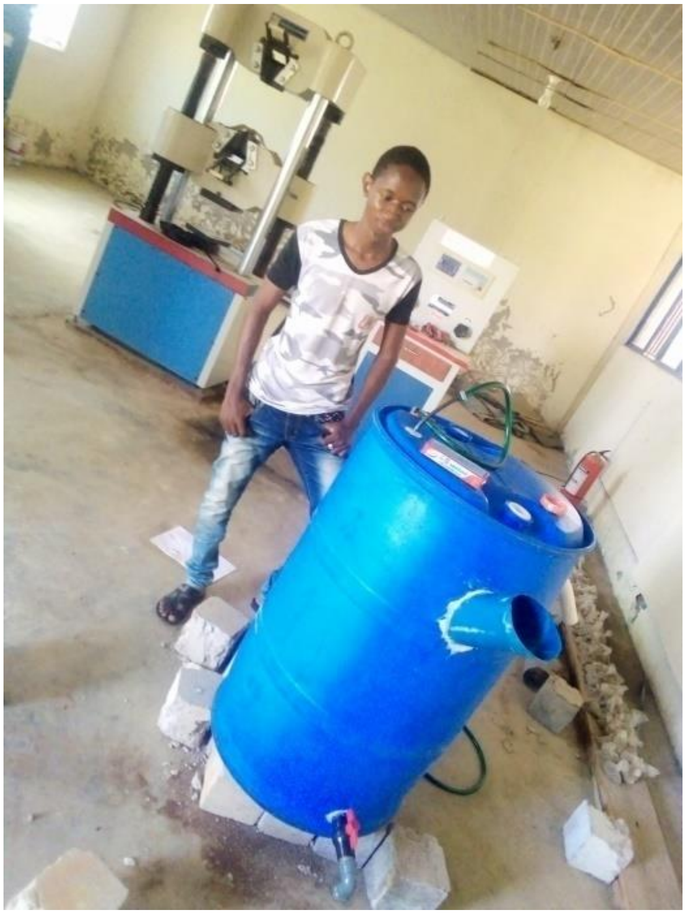

Plate 1: continuous loaded digester

Loading of substrate

The substrate was loaded into the digester through the inlet pipe. And the inlet was covered to prevent air into the digester. The system was left for 25 days before collecting the gas. The gas collected was weighed using a metric balance.

Gas collection

After the retention time (25 days), the gas was collected and stored in a tricycle tube using a motorized compressor.

Determination of volume of biogas in the storage device

The gas in the storage device is regarded as incompressible because the pressure in it is less than 1 bar (maximum is 0.28 bar), as such perfect gas equation cannot be employed here for impressed gas. Therefore, the volume of the gas in the storage tube is taken to be equivalent to the volume of the inflated tube (Nyifi *et al*., 2018) which is a hollow circular cylinder and was computed using Equation 5.

$$V = 2\pi RA \qquad (5)$$

Where; A = Area of a circle (m^2), R= Radius of circular tube to center cross section.

But the area of a circle was calculated from Equation 6.

$$A = \pi r^2 \qquad (6)$$

Where; r = cross section radius.

$A = \pi \times (5.5)^2 = 95.033$

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Therefore; $V = 2\pi RA = 2\times\pi\times14.25\times95.033 = 0.008509\ m^3$

The Volume equal to 0.008509 m^3 of biogas was obtained in 25 days retention time.

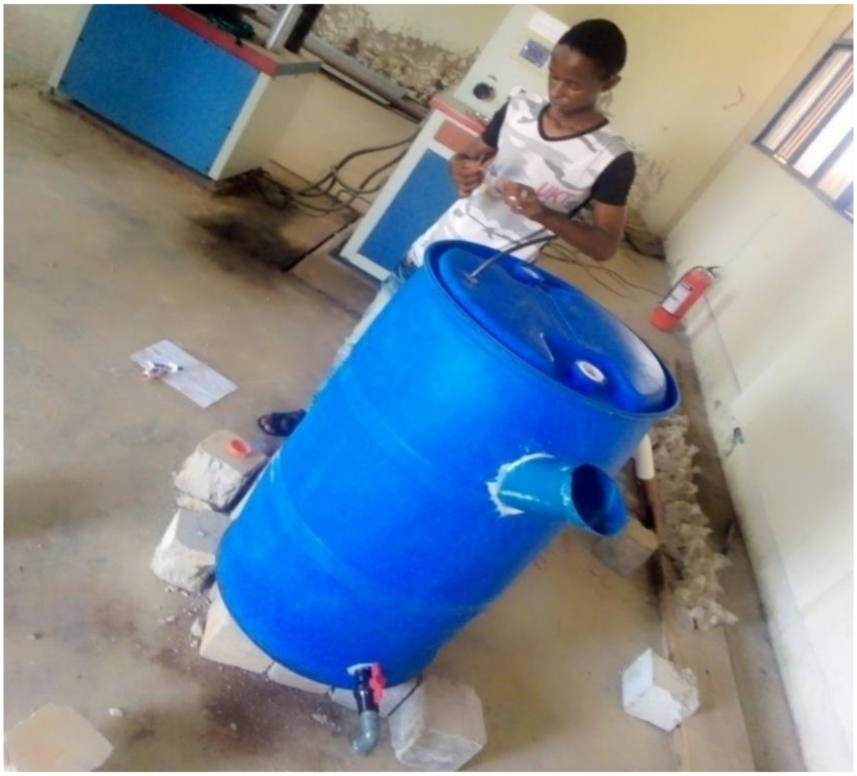

Plate 2: The Developed Biogas Digester

3. RESULTS

The result of the design of the digester was based on two parameters: the size of the digester and the methane production rate. The size of the digester was important to determine its ability to be used in portable application, while the methane gas production rate was important to determine how efficient the digester was to cover the cooking gas requirement of a family. Cow dung and vegetable wastes were used as substrates for biogas generation using the developed biogas digester. Table 1 shows the parameters obtain from the design analysis.

Table 1: Results of the Design Analysis

Parameters	Specifications
Type of digester	Continuous loaded digester
Total volume of the tank	0.230 m^3
Digester size	0.604 m^3
Gas holder size	0.210 m^3
Retention time	25days
Substrate used	Cow dung and vegetable waste
Ratio of water, cow dung and vegetable waste	1.5:1:1
Volume of cow dung	0.151 m^3
Volume of vegetable waste	0.151 m^3
Volume of water	0.302 m^3
Expected biogas yield per day	0.016 m^3 per day
Volume of biomass mass required per day	0.032 m^3/day

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4. DISCUSSION

A mini biogas plant was designed, developed and tested for cooking gas production at family level. The developed digester was tested using cow dung and vegetable wastes as substrates at a hydraulic retention time of 25 days. The biogas produced was collected in a tire tube using a motorized compressor. The gas collected burned using a burner to analyze the characteristics of the flame produced. The mini biogas digester has a total production cost of thirty thousands and thirty naira (₦30,030.00) only. The results obtained from design analysis and construction of the biodigester showed that the system is affective in waste to energy conversion for use in energy generation and for cooking in household. The biogas produced from the experiment showed the good quality combustible biogas yield of 8508.8327 cm^3 (0.008509 m^3). The gas produced gave a brilliant coloured flame. The results also showed that the mini biodigester is capable of providing a residue organic waste, after its anaerobic digestion that has superior nutrient qualities over normal organic fertilizer, as it is in the form of ammonia and can be used as manure. The biogas systems are those that take organic material as feedstock into an air-tight tank, where bacteria break down the material anaerobically, and release biogas, a mixture of mainly methane with some carbon dioxide. The biogas can be burned as a fuel, for cooking, electricity generation, lightning, or other purposes, and the solid residue can be used as organic compost fertilizer. Through this compact system, it has been demonstrated that by using feedstock having high calorific and nutritive value to microbes, the efficiency of methane generation can be increased by several orders of magnitude. It is an extremely environmental friendly system. Considering the environmental impacts, the system will be able to reduce the amount of waste going to the sanitary landfill, convert all methane emissions to carbon dioxide which has a lower global warming potential. The society will also benefit economically and socially from the pride of a reliable solid waste management process for the country, since all degradable waste can be used as a substrate, and the sale of viable electricity from a biogenic carbon source, instead of depending on conventional electricity along that cannot reach many villages.

5. CONCLUSION

In this study, a mini biogas plant has been successfully designed, constructed and operated under continuous feeding mode. Cow dung and vegetable wastes were used as substrates for biogas production. The conclusions drawn based on results from this study are the following:

a. The biogas plant has a simple design which can easily be applied in other areas; where the raw materials and the feeding substrate of the plant is available. The biogas plants also can easily constructed using local materials and skills. And it is environmentally sound with 100 % recyclable inputs and zero waste emissions.
b. Cow dung and vegetable wastes were suitable substrates for biogas system.
c. The energy results showed that the quantity of biogas was utilized, where it produced enough heat to meet up household energy needs, and the biogas is of high quality which leads to a cleaner environment and possibly would aid in reducing maintenance costs for the plant.
d. The effluent released from the biogas is also an excellent bio-fertilizer. The anaerobic digester of the slurry was able to destroy most of pathogens that may be present.
e. The biogas system proved to be economically feasible for the farmers to save money by providing them with another source of energy to heat their farm and biofertilizers to use for agricultural purposes making biogas investment more worthwhile to farmers, since the substrate available.

Ethical issues
Not applicable.

Informed consent
Not applicable.

Funding
This study has not received any external funding.

Conflicts of interests
The authors declare that there are no conflicts of interests.

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Data and materials availability

All data associated with this study are present in the paper.

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