



DEVELOPMENT OF A CLAY BIODIGESTER

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ABSTRACT

The quest for sustainable waste management, reduction of greenhouse gas emission and the increasing demand of energy has led researchers to seek for alternative solution in meeting both demands. Anaerobic digestion technology is used for digesting wastes and producing biogas, which is a source of renewable energy in return. This research work examines the use of clay as an alternative construction material of the anaerobic biodigesters. The biodigesters were carefully designed to ensure airtightness and to attain an anaerobic environment inside the digesters. Clay in its nature tends to retain heat received, abundance in nature and is of low cost. The ability of clay material to retain heat makes it viable for biodigester, as temperature is one of the key parameters in the production of biogas. It employed the prototype and evaluated the rate at which clay biodigester produced biogas as compared to other construction materials. Five (5) different biodigesters containing different sample compositions were used for the experiment. The first biodigester is the control containing 8kg of cow dung mixed with 16kg of water. The second biodigester contains 4kg of cow dung, 4kg of beans chaff mixed with 16kg of water. The third biodigester contains 2kg of cow dung, 2kg of vegetables mixed with 16kg of water. The fourth biodigester contains 3kg of cow dung, 3kg of beans chaff, 3kg of vegetables mixed with 16kg of water. The fifth biodigester contains 4kg of cow dung, 4kg of goat excreta mixed with 16 kg of water. The biodigesters were evaluated under the same anaerobic condition. It was observed that the biodigester with the cow dung and beans chaff combination produced the highest biogas with an average daily production of 0.41 litre/day. The biodigester with cow dung, and vegetables gave an average daily production of 0.35litre/day. The biodigester with cow dung and beans chaff gave an average daily production of 0.384litres/day. The biodigester with cow dung and goat excreta gave an average daily production of 0.352litre/day. The biodigester with cow dung only gave an average daily production of 0.36litres/day. All the experiments were carried out on an average daily temperature of 29°C. Each one of the biodigesters have an uptrend line i.e. the higher the retention period, the more the biogas produced. It was also observed that biogas production depends greatly on the temperature of the environment. This is to make biodigesters and green energy easily accessible to the local communities.

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1.0 Introduction

Increasing Population has greatly increased the amount of waste generated with poor waste management practices. This poor waste management practices leads to high exposure to outbreak of different kinds of diseases such as malaria, pest multiplication and water-borne diseases (Adoum et al., 2023). Sustainable waste management: prevention and the reduction of the volume of wastes consumed has become the highest important political priorities in many countries, thereby making it a share effort of the prevention and reduction of pollution, reducing the greenhouse gas emission and also limiting the global climate change (Guimarães and Rodrigues, 2023; Kasinath et al., 2021; Jyothilakshmi and Prakash, 2016). About 2.01 billion

tons of municipal solid waste are being generated in the world annually (Syed *et al.*, 2020), and the world energy council (WEC) has estimated that over 6 million tonnes of wastes will be generated per day by the year 2025 (Mahmudul *et al.*, 2021). When these volumes are not properly disposed, they can either be abandoned or disposed as the landfill which produces greenhouse gases and these gases when not properly collected contribute significantly to air pollution and global warming. The increase in energy demand tends to pull pressure on energy generation, and also on the over dependency on the use of fossil fuels which in turn contribute to air pollution and greenhouse gas emission due to the combustion of fossil fuels (Barinyima *et al.*, 2018). The increasing use of fossil fuels has increased rapidly with a daily use of oil gas and coal reserve to about 600 million barrels, 400 billion cubic feet (BCF), and 14.2 giga tons of oil equivalent (GTOE) per year (Mullo *et al.*, 2018). By the year 2025, it was estimated that the world energy consumption rate will be increased by 30%, according to the U.S. energy information administration (Urso *et al.*, 2015), with fossil fuel being the leading source of energy and a non-renewable and limited natural resource.

Various waste-to-energy technologies, such as anaerobic digestion, incineration, liquefaction, pyrolysis, fermentation, gasification, etc. have been developed in order to account for the challenges of poor waste management practice, to reduce the environmental burden and to proffer solution to the ever-increasing energy demand, as an alternative and affordable source of energy (renewable energy) (Arijeet *et al.*, 2023). Biogas is a renewable energy resource that is gotten from the digestion of biomass under anaerobic condition and has a calorific value of 6 kWh/m³ (Miettinen, 2023) ranging between 25.9 to 30 kJ/kg depending on the percentage composition of methane present in the gas (Okwu *et al.*, 2019). Biogas is produced in the absence of oxygen through the process known as anaerobic digestion, and it is an odorless gas that burns with clear blue flames (Nwankwo *et al.*, 2017). Biogas is an odorless gas which can be obtained from various feed stocks such as piggery, cattle dung, poultry waste and cabbage from kitchen wastes. Biogas produces blue flame and can be suitable for cooking, heating of ovens or crucible and lighting. It has a heating value of 22 MJ/m³ (Soliu and Onunka, 2019). The biogas has variety of applications from domestic to industrial use.

Anaerobic digestion is the process of converting biomass, the residue of plant and animal, manure, sewage, municipal waste, green waste, plant materials and crops into biogas and was first introduced in the year 1870 by Jean Louis Mouras (Abubakar, 2022); (Cristiane *et al.*, 2021). Anaerobic digestion is a microbial process whereby organic carbon are converted by subsequent oxidation and reductions to its most oxidized state (CO₂) and reduced form (CH₄) (KeChrist *et al.*, 2020). Dig estates is also the end product of the bio digestion which is rich in both macro and micronutrients suitable for plant fertilizers (Bastabak and Kocar, 2020), (Mucha *et al.*, 2019). Anaerobic digestion process is dependent and can be affected by factors, such as; operating temperature, pH, the concentration of the substrates, the loading rate, moisture content, carbon to nitrogen ratio, stirring, co digestion, pretreatment and additives, mixing and reactor design etc. anaerobic digestion can best be suited between 3 temperature ranges; the psychrophilic temperature (15-25°C), mesophilic (30-40°C) and the thermophilic (50-60°C) temperature ranges (Mahmudul *et al.*, 2021; Oladoye *et al.*, 2017). Anaerobic digestion (AD) technology (also known as biodigester, bioreactor, anaerobic reactor) is a simple biotechnological commercial route to transform organic waste or biodegradable material to useful energies by consortium of microorganisms living symbiotically. This biological process is carried out purposely to produce biogas and digestate. It is often called biogas plant, where various chemical and microbiological reactions take place. It serves the purpose of providing an anaerobic environment for the proper biodegradation of the organic wastes. It is a structure that should be air and watertight (Obileke *et al.*, 2021; Atelge *et al.*, 2020). Mullo *et al.*, (2018) defined biodigester as a closed vessel/ container that contains the mixture of water and organic matter-manure, for a period of time and maintained at an average temperature of 30°C to allow for anaerobic degradation, and to produce methane gas and biofertilizers, thereby reducing the polluting potential of the excrements. The development of biodigester makes the management of waste possible, mitigating the organic waste and sewage disposal in the community and also as an alternative energy source which serves as national technology for the production of biogas. The project introduces clay as an alternative construction material to the conventional materials used for the construction of a biodigester. The biodigester will utilize organic waste materials as feedstock to produce biogas, a renewable energy source that can be used for cooking, heating, and electricity generation

Biogas digester has been constructed using different kind of materials from concrete, steel plastic, aluminium, mild steel, zinc, rubber (Soliu & Onunka, 2019); Oladoye *et al.* (2017) reported that the color of the constructing material has greater impact on biogas production, as well as the manure color. Most bio digesters have been constructed using concrete in cast form to build the digester walls. Adoum *et al.* (2022) designed a biogas digester with high density polyethylene (HDPE) to digest biodegradable waste. Aderibigbe (2015) reported the use of 'storex' tank has the reactor and also a non-corroding metal and the use of 4 co-substrates.

Another bioreactor was developed by Guimarães and Rodrigues (2023) using glass jacket to construct the digester, together with a heating and agitation system. The aim of the research is to design, construct and evaluate the performance of a clay anaerobic biodigester for biogas production.

2. Materials and Methods

2.1 Material Selection

2.1.1 Clay

The used clay was obtained from the *Dlamdi Manna* village in Biu, Borno State it has properties that makes it suitable for the construction of Biodigester. The properties of the clay are its impermeability, plasticity, coherence, thermal insulation, compatibility with liners and environmentally friendly (Ayyub, 2024).

2.1.2 Black Cotton Soil

This is the binder that was used for binding the clay particles together. It was mixed with water in the ratio of 2:1. The binder has good strength properties: plasticity, good adhesion, water retention, shrinkage control and compatibility with the firing process of the clay. The black cotton soil is a mineral-based binder that is used to bind clay particles together, the picture of the black cotton soil is shown in plate 1. Plate 2 shows the clay binder (black cotton soil) ready to be mixed with clay for the construction of the biodigester (Ayyub, 2024).



Plate 1: Black cotton soil



Plate 2: Clay-binder

2.1.3 Rubber Tube Collector

The rubber tube collector serves as the gas storage chamber. It is connected to the Biodigester with the aid of a pressure hose for gas collection. The tube collector selected is compatible and resistant to the corrosive nature of the biogas. It does not allow the permeability of the gas, it is flexible and ease to install, resistance to weathering, chemical resistance, and low maintenance requirements (Ayyub, 2024).

2.1.4 PVC Pipes

The PVC pipes serve as the medium through which wastes are introduced and evacuated from the Biodigester. The inlet and outlet pipes are 7.5cm by 50cm and 4cm by 24cm respectively.

2.1.5 Pressure Hose

The pressure hose is used to evacuate the gas generated from the Biodigester and stored in the rubber tube collector. The pressure hose used is 0.5 inches for effective gas transport.

2.1.6 Organic Waste

The organic wastes used are cow dung, goat excreta and agricultural wastes. The animal wastes that were used in this experiment are cow dung shown on plate 3 and the goat excreta shown on plate 5 which are sourced from the slaughterhouse located in BCG area of Biu Local Government Area. Plate 4 shows the vegetable waste sourced from Biu market which is used for the experiment.



Plate 3: Cow dung



Plate 4: Vegetables



Plate 5: Goat excreta

2.2 Design Method

2.2.1 Design Parameter

The biodigester developed is 30L as can be seen in figure 3, it has both spherical and cylindrical shape which allows easy mixing of the slurry and effective design of the gas chamber respectively. Water is added in the ratio of 1:2. The hydraulic retention time is 15-20 days. The inlet and outlet pipes are 8cm and 6cm respectively. The gas collection opening was design to be 0.5inches. Figure 1 shows the diagram of the biodigester, and its dimensions used in the experiment. Figure 2 shows the exploded view of the biodigester showing the individual components of the system, separated together. Figure 3 shows the front view of the biodigester, it is usually a 2D representation of the biodigester components as seen from front direction. Figure 4 shows the isometric view of the biodigester which is a 2D representation of the biodigesters components, shown in 3D- like perspective. Figure 5 shows the full labelled diagram of the biodigester used in the experiment.

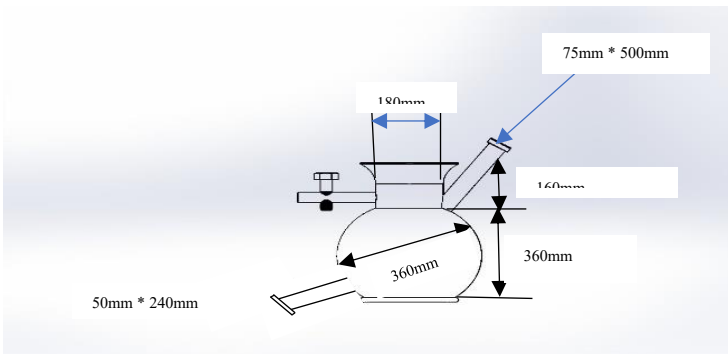


Figure 1: Clay biodigester

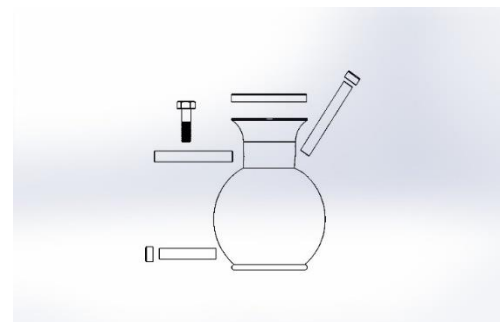


Figure 2: Exploded view of the biodigester

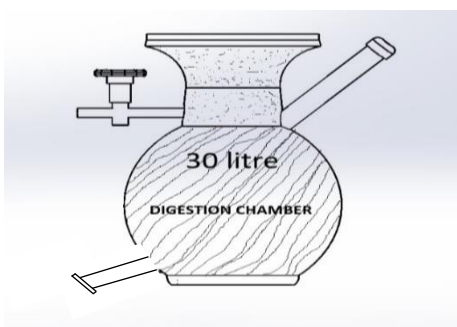


Figure 3: Front view of the biodigester

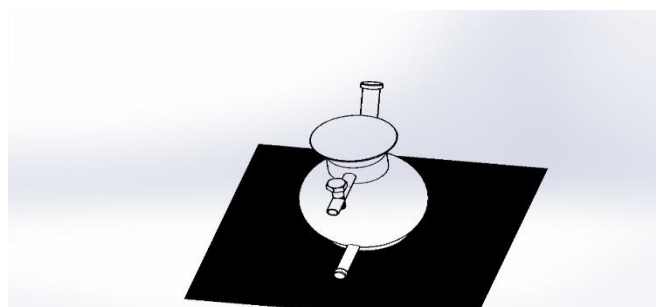
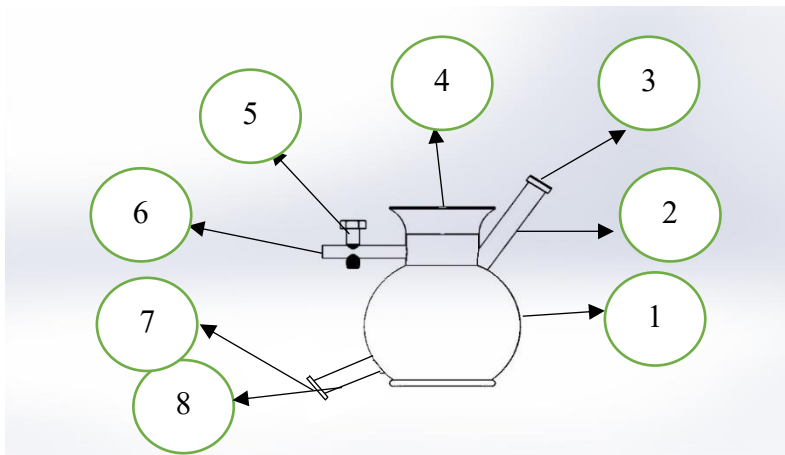


Figure 4: Isometric view of the biodigester



S/N	Name of component
1	Clay biodigester
2	Inlet pipe
3	Inlet cap
4	Cover
5	Outlet valve
6	Gas outlet valve
7	Outlet cap
8	Outlet pipe

Figure 1: Fully labelled diagram of the Biodigester

2.2.2 Procedure for the Development of the Biodigester

The binder was soaked with water in the ratio of 2:1. After a uniform mixture was obtained, the binder mixture was then poured in the fine particle clay and mixed to form lumps as can be seen on plate 6. The clay and the binder mixture were wedged by kneading and pressing to ensure consistency and to remove air bubbles in the clay materials as can be seen on plate 7. The clay material was centered to a prototype pot to get the base and to ensure a symmetrical pot as can be seen on plate 8. It was followed by shaping and throwing of the pot by using hand and shaping tools. After which, trimming of the excess clay was done when it was partially dry. After the clay pot was air dried and its leather hardened, two openings were created on the clay anaerobic digester. The two openings were designed to allow for the insertion of the 2.5 inches and 1.5 inches diameter pipes for the inlet and outlet. The first opening was located at the top of the digester which serves as the feeder for the digester. The second was located at the bottom of the digester and serves as the medium for the removal of the digested wastes. The openings are made to be directly opposite to each other. Another opening was made at the top of the digester, for the collection of the produced gas in its chamber. This opening is 0.5 inches, for the ease of gas collection. Rubber hose was inserted in this opening, and it was connected to an external rubber tube for gas storage. After the drying stage and the various openings were obtained, bisque was done on the pot in the kiln, at a lower temperature of around 1000°C to harden it. It then subjected to a higher temperature of about 1200-1300°C to ensure further hardness of the clay pot. The pot was then allowed to cool slowly in the kiln to prevent cracking. Air-tight cover was provided for the clay anaerobic digester for complete fermentation of the organic waste in the digester.



Plate 6: Lump formation



Plate 7: Kneading



Plate 8: Base finishing of the pot

2.2.3 Characterization of the Waste

The total volume of the biodigester used for the project is 30 liters. The wastes used for the experiment include cow dung, goat excreta, beans chaff and vegetables. Each of these wastes were digested in the pots in the ratio of 1:2.

- 8kg of cow dung was used with 16kg of water in the first pot, this serves as the control pot. This ratio constitutes about 80% of the digester volume as can be seen on plate 9.

- 4 kg of cow dung and 4kg of beans chaff were mixed with 16kg of water in the second pot as can be seen on plate 10.
- 2kg of cow dung and 2kg of vegetable waste were mixed with 16kg of water in the third pot as can be seen on plate 11.
- 3kg of cow dung, 3 kg of beans chaff and 3 kg of vegetable were mixed with 16kg of water in the fourth pot as can be seen on plate 12.
- 4kg of cow dung and 4kg of goat excreta were mixed with 16kg of water in the fifth pot as can be seen on plate 13.

Plates 9 to 13 show the composition mixtures used in the five (5) different clay pots.



Plate 9: Cow dung mixture



Plate 10: Cow dung + beans chaff



Plate 11: Cow dung + vegetable waste



Plate 12: Cow dung + beans shaft + vegetables waste



Plate 13: Cow dung + goat excreta

2.3 Data Collection

The mean atmospheric temperature under which the Biodigester operates was recorded daily. The biogas production data was taken on two days' interval for a period of 15-20 days. The volume of the biogas was obtained after weighing an empty tube collector using F-METTLER USA weighing balance with a precision of 0.1g, and then reweighing it when the gas was collected in the tube. The difference in this value gives us the mass of the biogas. The volume was obtained using the relationship below:

$$\rho = \frac{m}{V} \quad (1)$$

The biogas was collected into the tube collector and taken to the lab for analysis of the composition of the various gases present in it, at a daily interval.

2.3.1 Data Analysis

The biogas produced was analyzed by observing the variation of the volume of the biogas across the retention period. The composition of the methane and carbon dioxide gas present in the biogas was analyzed using a gas analyzer instrument. Data generated were subjected to Microsoft excel software to compare the variations of temperature on the various pots and on the wastes type and the biogas yield.

2.4 Design Theory and Calculations

- Total volume: the total volume designed for the project is 30L
- Operating volume: the operating volume is about 80% of the total volume.

$$V_O = 80\%V_T = 24L \quad (2)$$

- Hydraulic retention time: a hydraulic retention period of 20days is selected for the digestion of the wastes.
- The organic flow rate: it is the rate of daily input of organic wastes into the digester. It can be gotten from the formula

$$HRT = \frac{V_O}{Q} \quad (3)$$

The organic flow rate is calculated to be $0.0012m^3/day$, equivalent to about 1.992kg of the wastes to be loaded into the digester per day

3. Results and Discussion

The daily biogas production of each individual clay Biodigester was collected for a period of 18 days under the same ambient conditions. Observable differences of physical and chemical characteristics of the digesters were seen during the production of the biogas.

Figure 6 shows the graph of the daily biogas production using cow dung. It can be seen from the graph that at days 1 and 2 no gas was produced; the microorganisms take time to adapt and break down the complex organic matter. The microorganisms start to digest the cow dung, biogas production gradually increases. The highest volume of the biogas gas produced was collected in day 13 with the value of 0.5 liter. The rapid increase in biogas production is because of the microorganisms multiplying and become efficient in breaking the organic matter leading to increase in biogas production. The average volume of biogas calculated was found to be 0.36liters/day.

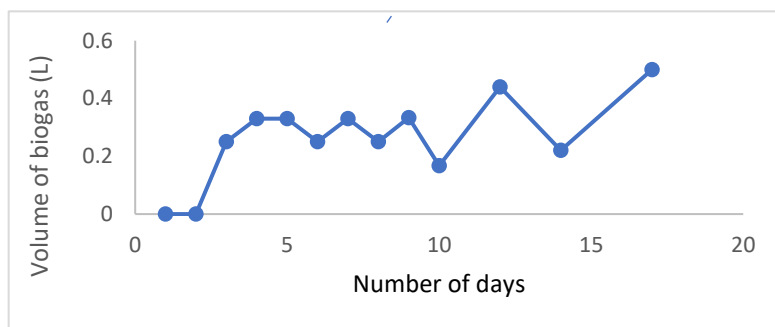


Figure 6: Graph of Biogas Production using cow dung

Figure 7 shows the graph of biogas production using cow dung and beans chaff. It can be seen from the graph that no biogas was produced in days 1 and 2. The microorganisms take time to adapt and break down the complex organic matter. The microorganisms gradually start to digest the cow dung and beans chaff, biogas production gradually increases. The highest volume of the gas produced was collected in day 3 with the value of 1.3 liters. The rapid increase in biogas production is as a result of the microorganisms multiplying and become efficient in breaking the organic matter leading to increase in biogas production. The average volume of biogas calculated was found to be 0.41liters/day. The gradual decline in biogas production is, as the easily digestible organic matter is depleted, the organisms start to slow down, leading to decrease in biogas production.

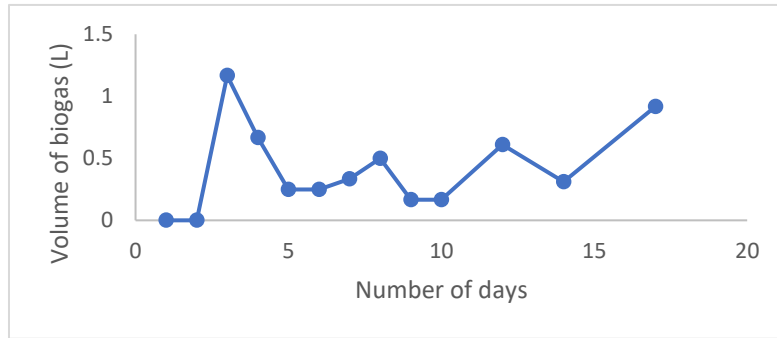


Figure 7: Graph of Cow dung and Beans chaff

Figure 8 shows the graph of daily biogas production using cow dungs and vegetables, it can be seen from the graph that at day 1 and day 2 no biogas was produced. The microorganisms take time to adapt and break down the complex organic matter. The microorganisms gradually start to digest the cow dung and vegetables which gradually increase the production of biogas. The highest volume of the biogas produced was collected in day 7 and day 12 with the values of 0.7 litres in each of the two days. The rapid increase in biogas production is as a result of the microorganisms multiplying and become efficient in breaking the organic matter leading to increase in biogas production. The average volume of biogas calculated was found to be 0.35liters/day. The gradual decline in biogas production is, as the easily digestible organic matter is depleted, the organisms start to slow down, leading to decrease in biogas production.

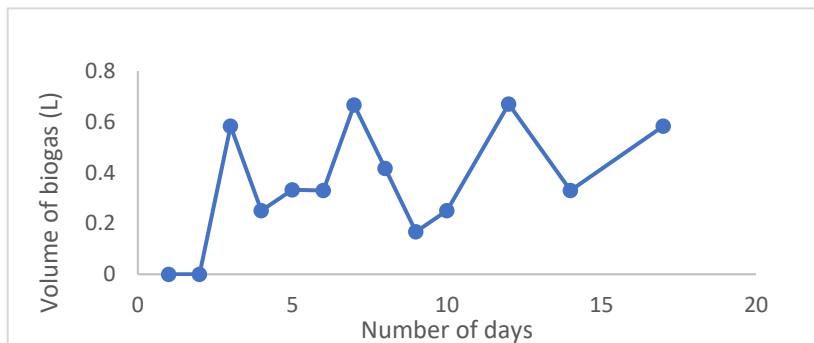


Figure 8: Graph of Cow dung and Vegetables

Figure 9 shows the graph of daily biogas production using cow dung, beans chaff and vegetables. It can be seen from the graph that at day 1 and day 2 no biogas was produced. The microorganisms take time to adapt and break down the complex organic matter. The microorganisms gradually start to digest the cow dung and vegetables which gradually increase the production of biogas. The highest volume of the biogas produced was collected in day 8 with the value of 1.2 liters. The rapid increase in biogas production is as a result of the microorganisms multiplying and become efficient in breaking the organic matter leading to increase in biogas production. The average volume of biogas calculated was found to be 0.384liters/day. The gradual decline in biogas production is, as the easily digestible organic matter is depleted the organisms start to slow down which leads to decrease in biogas production as can be seen from the graph.

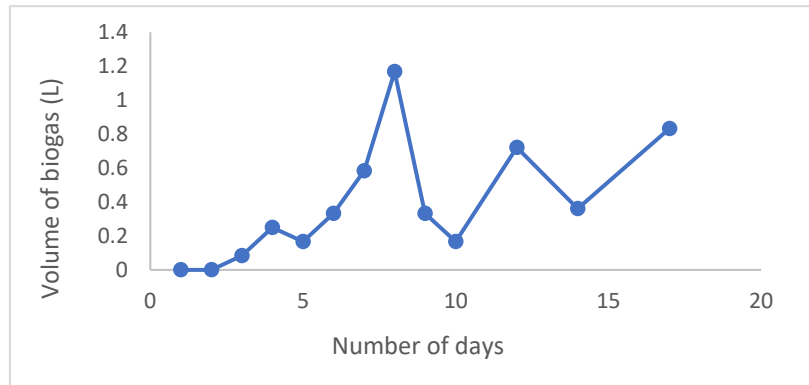


Figure 9: Graph of Cow dung, Beans chaff and Vegetables

Figure 10 shows the graph of daily biogas production using cow dung and goat excreta. It can be seen from the graph that at day 1 and day 2 no biogas was produced. The microorganisms take time to adapt and break down the complex organic matter. The microorganisms gradually start to digest the cow dung and goat excreta which gradually increase the production of biogas. The highest volume of the biogas produced was 1 liter which was collected in day 17. The rapid increase in biogas production is as a result of the microorganisms multiplying and become efficient in breaking the organic matter leading to increase in biogas production. The average volume of biogas calculated was found to be 0.352liters/day. The gradual decline in biogas production is, as the easily digestible organic matter is depleted the organisms start to slow down which leads to decrease in biogas production.

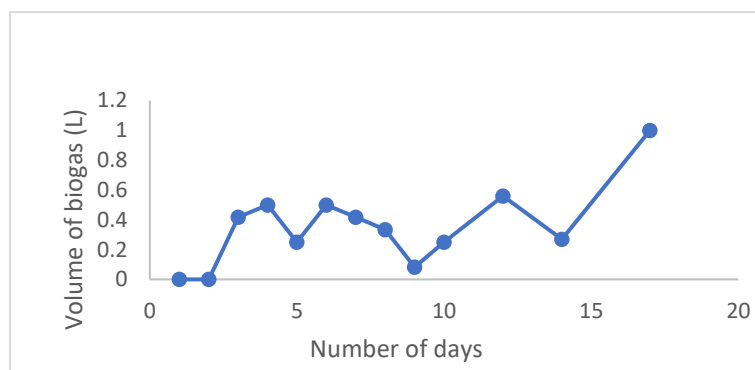


Figure 10: Graph of Cow dung and Goat Excreta

4. Conclusion

A local biodigester was developed using a pulverized clay and a black cotton soil as the binder. The five different biodigesters used were filled with organic waste of different proportions and further evaluated for biogas production under the same anaerobic condition using different proportions of waste in each of the digesters. The digester with the cow dung and beans chaff produces more biogas than other combinations. It can be deduced that using more than one substrate in the digester tends to produce more biogas than using a single substrate. It was finally recommended that polypropylene fiber should be added to the clay to improve its strength, reduce cracking and increase the durability of the biodigester.

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