

FABRICATION OF BIOGAS DIGESTER AND PRODUCTION OF FUEL FROM ANIMAL DROPPINGS USING HIGH-DENSITY POLYETHYLENE AND POLYVINYL CHLORIDE

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Abstract: A portable biogas digester was fabricated to obtain combustible methane gas from livestock waste using HDPE plastics and PVC pipes. The structure was made airtight, and fitted with an inlet channel, gas outlet channel, waste outlet channel, and emergency pressure outlet channel. A domestic water purification filter with filtration elements of activated charcoal, iron filings, and local potash was modified for biogas upgrading. All filter composite materials were dried, and mixed with charcoal, potash, and iron filings in the ratio of 4:3:1. Leak proofing was done using PVC gum, silicon bonds, and rubber gaskets to ensure gas-tight seals. HDPE thread tape was also used as screw-able elements. Upon fabrication completion, a leak test was carried out using one (1) liter of water, and no leakages were observed. The animal droppings of poultry (three bags of 50 kg) were - filled into the digester, mixed, and allowed to generate uniform mass for appropriate environmental conditions for microbial processes of anaerobic digestion, involving the breakdown of microorganisms in the absence of oxygen, for the emission of the gas (methane). Gas collection was achieved through the outlet pipe (connected from the filter) which is the flexible hose connected to the gas cylinder valve, allowing direct capture of upgraded methane in the metal cylinder. The bill of engineering measurement and evaluation (BEME) for the fabrication was made. The obtained methane gas produced was purified - able to biomethane, which is burnable to obtain electricity and heat using combined heat and power (CHP) plants, usable as fuel, and inject - able to the natural gas.

Keywords: Biogas; Digester; Anaerobic Digestion; Digestion System Designs; Biogas Applications; Biomethane; etc.

1. INTRODUCTION

The world population is on the increase even with a declining growth rate (Okolotu and Oluka, 2021; Okolotu et al, 2024). The need for the conservation of the environment as well as proper management of natural resources is vital for future sustenance. Currently around 3.5 Mton of biomethane are produced worldwide

(IEA, 2024). Europe, Asia, and the United States are the major producers. Europe, the people's republic of china (hereafter "China"), and the United States account for 90 % of the global production (IEA, 2024).

1.1 Biogas: Biogas is the mixture of gases produced by the breakdown of organic matter in the absence of oxygen (anaerobic), primarily consisting of methane and carbon dioxide. Biogas is a mixture of methane, CO₂ and small quantities of other gases produced by anaerobic digestion of organic matter in an oxygen free environment (IEA, 2024). Biogas can be produced from raw materials such as agricultural waste, manure, municipal waste, plant material - sewage, green waste or food waste. Biogas is a renewable energy source. Biogas is produced by anaerobic digestion during which digestion (fermentation) of organic (biodegradable) material occurs inside a closed system (Appels et al., 2008). This closed system is called an anaerobic digester, biodigester or a bioreactor. Biogas is primarily composed of methane (CH₄) and carbon dioxide (CO₂), and usually contains small amounts of hydrogen sulfide (HS), moisture and siloxanes. Methane gas in particular is combustible, and this energy release allows biogas to be used as a fuel. It can be used for any heating purpose, such as cooking. It can also be used in a gas engine to convert the energy in the gas into electricity and heat. Biogas can be compressed after removal of carbon-dioxide, the same way as natural gas is compressed and used to power motor vehicles (Abatzoglou & Boivin, 2009). Biogas is considered to be a renewable resource because its production and use cycle is continuous. As organic material grows, it is converted and used. It then re - grows in a continually repeating cycle. For future energy security and improvement in the use of natural resources, the depletion of conventional energy resources such as fossil fuel can be solved by the use of renewable energy sources. Generation of biogas through anaerobic digestion technology is a renewable energy source. The agriculture chain (from production through processing to use) results in several byproducts. Many of which are disposed of as waste.

Anaerobic digestion provides a means of reducing the hazards associated with the byproducts of agricultural production and processing. The concentration of hazardous gases is reduced, and the resultant sludge is an excellent addition to soil organic matter. This work provides technical details on the fabrication of portable biogas digesters. Data generated from this work will be useful in making decisions that will aid the efficient fabrication of larger portable biogas digesters. Bio gas collection for anaerobic digestion for production is vital for resource management. A typical example of biogas recovery is presented in figure below;

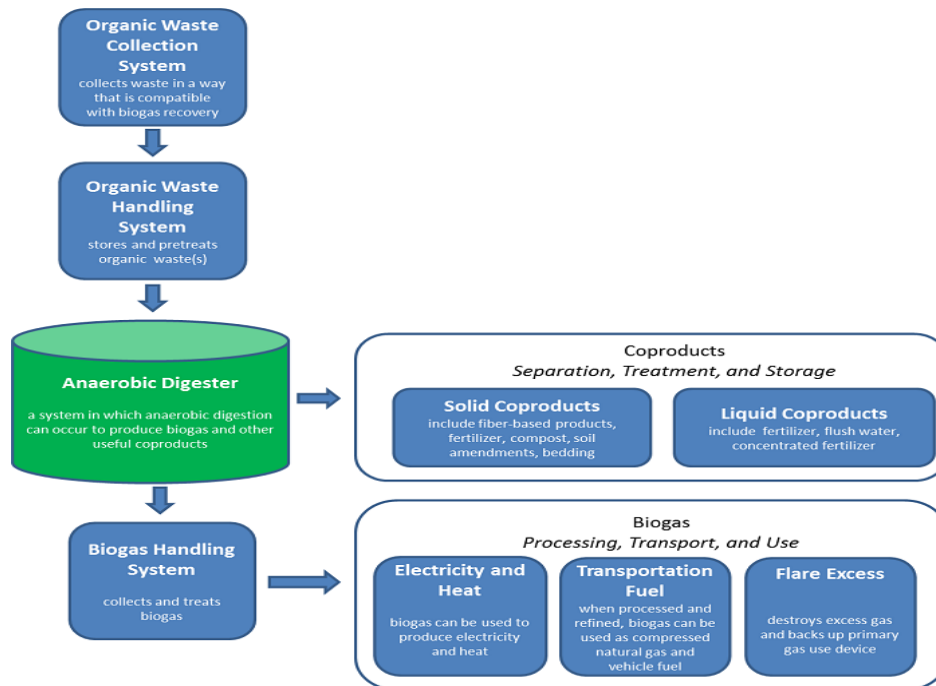


Figure 1: Details of the elements of a biogas recovery system (EPA, 2024)

1.2 Anaerobic Digestion: Anaerobic digestion is a process involving the breakdown of organic matter by micro-organisms in the absence of oxygen. Much of the fermentation used industrially to produce food and drink products, as well as home fermentation, uses anaerobic digestion (Wikipedia, 2024). A typical digester is a closed system where a certain temperature is maintained and where the released gas is captured, stored and used. An anaerobic digester is a sealed, heated tank which provides a suitable environment for naturally – occurring anaerobic bacteria to grow, multiply, and convert manure to biogas and a low – odor effluent (PSU, 2023). The main component of this biogas is methane gas, which is a fuel. Methane is also one of the greenhouse gases implicated in global warming. Capturing and using the gas therefore help reduce the emission of greenhouse gases to the atmosphere. Biogas could be burned directly or used to run an engine that powers an electrical generator, thus producing electricity and heat. The main stages in the anaerobic digestion process are presented below, and each relies on a specific group of micro-organisms.

Stage I - Hydrolysis and Fermentation: Large, insoluble organic molecules are broken down by extra-cellular enzymes through hydrolysis. High amounts of cellulose, or other material that is hydrolyzed slowly, can limit the performance of the entire system (Poulsen, 2003). Short - chain fatty acids (acetic acid, formic acid, etc.) are formed by the enzymes while by - products undergo fermentation to produce alcohols, CO₂. and H₂. In this stage, certain bacteria breakdown organic polymers like carbohydrates into simple sugars so that the next group of bacteria can further process the material (TNDEC, 2024).

Stage II - Acidogenesis: Any short-chain fatty acids longer than acetic acid are oxidized by the acidogenic bacteria to produce formic acid, acetic acid, and H₂. Valdez - Vazquez et al., (2004) conducted research on means of promoting the H₂ - producing feature of acidogenic bacteria for use as an alternative fuel source.

Stage III -Acetogenesis: This is the third step of biogas production from conversion of organic materials. TNDEC, (2024) noted that, in this stage, certain bacteria called acetogenic bacteria convert the organic acids into acetic, carbon, and hydrogen.

Stage IV – Methanogenesis: Methanogenic bacteria convert the acetic acid and H₂ to methane and carbon dioxide. In this stage, certain single cell – called organisms called methanogens convert the intermediate products produced in the preceding stages into biogas (primarily methane and carbon dioxide) (TNDEC, 2024).The methanogenic are the most unstable among these primary groups of bacteria.

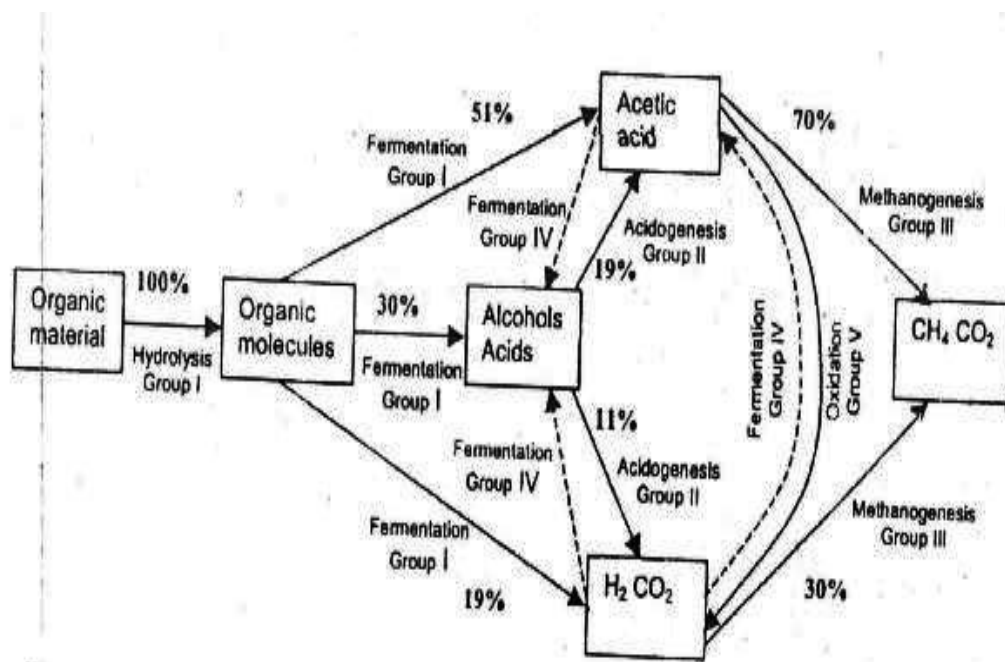


Figure 2: Processing and micro - organisms involved in converting organic material to methane and carbon - dioxide under anaerobic conditions (Poulsen, 2003).

Figure two (2) indicates the groups in the anaerobic process. Group IV can either produce acetic acid or break it down if the concentration of acetate is too high. Group V oxidizes acetic acid to H₂ and CO₂ (neither group is central to the basic understanding of anaerobic digestion). Figure three (3) below, summarizes the main processes in a simplified flowchart.

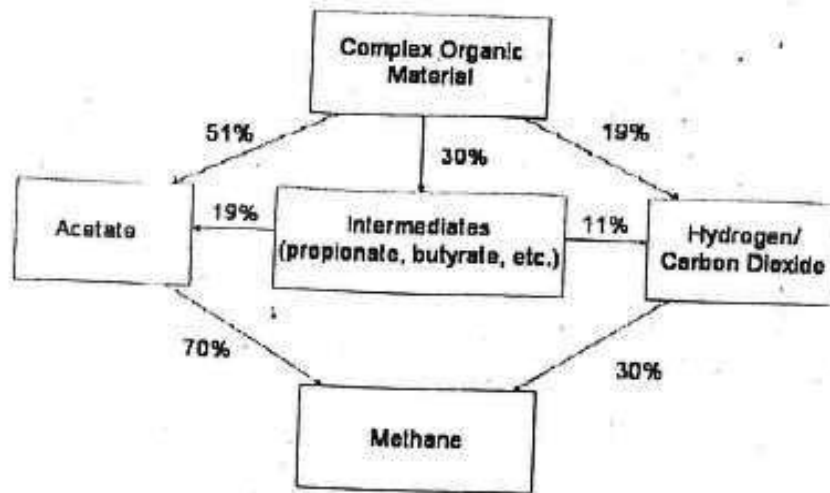


Figure 3: Carbon flow in anaerobic environments with active methanogens (Ahring, 2003)

It is important to note that these processes must be in balance with each other. For example, Poulsen, (2003) noted that, if the methanogenic bacteria do not use the hydrogen produced by the acidogenic bacteria almost immediately, the higher hydrogen concentration will increase the production of alcohols and fatty acids, causing the system to collapse. The following are important parameters which must be considered in the design of an anaerobic digestion system;

I. Temperature: Three temperature ranges exist for anaerobic digestion: (i) Psychrophilic range between 5° and 25 °C, character sized by slower methane production and longer retention times. (ii) Mesophilic range between 30 ° and 40 °C, is the most widely used of the three, and this range balances heating costs with methane production. (iii) Thermophilic range from 50 ° to 60° C, produces the most methane but is also the most sensitive, due to fewer bacterial species in existence. Once a stable temperature is reached, fluctuations should be kept within 5 °C to avoid killing the desired bacteria. Thermophilic tolerance is generally less than that of lower temperatures. Each temperature ranges at which the digester can be operated have its own advantages. The thermophilic process has been found to be superior to the mesophilic process from an energy balance and, thus, "profit point of view (Ahring, 2003). Thermophilic digesters usually achieve better degradation of long-chain fatty acids, have a shorter retention time, and require less biomass compared to the quantity of methane produced. The thermophilic process also achieves higher pathogen and weed seed destruction than the mesophilic process alone (El - Mashad et al., 2004). However, the risk of ammonia inhibition is greater and more energy is required to operate a thermophilic digester. Thermophilic processes are considered to be more prone to instability than mesophilic due to fluctuations in input quality. The start - up time of thermophilic digesters is however longer than that of mesophilic reactor due to the low numbers of thermophilic bacteria in

organic waste. Most of the agricultural digesters in the United States are mesophilic (Kramer, 2009). The lower heating requirements of mesophilic temperatures translate into lower costs. Psychrophilic digesters require a solids retention time approximately twice as long as mesophilic. These digesters require the least amount of energy input. Biogas production is slow but gas quality and other parameters indicate favourable process stability. These systems are commonly found in the form of a covered lagoon and, as such, they are usually subject to fluctuations in temperature.

ii Loading Rate: This is expressed as the weight of volatile solids (VS) per unit of volume of digester capacity per unit of time. High loading rates use the digester volume more efficiently. They also increase solids concentration, retention time and alkalinity, which are taken into consideration.

iii Retention Time: The Hydraulic Retention Time (HRT) and Solids Retention Time (SRT) are the average lengths of time the liquid or solid portion of manure remains in the digester. Generally, the lower the operating temperature (e.g. psychrophilic digestion) the higher the retention time needed.

iv Solids Concentration: This is normally reported as the percentage dry matter and the volatile solid percentage of that dry matter. The solids concentration is necessary to determine the loading rate. The solids concentration also helps to determine the most suitable type of digester.

v Alkalinity And pH: The methanogenic bacteria have optimum pH conditions ranging between 6.4 to 7.6 (average), while other bacterial species are more tolerant to pH levels outside of this range.

1.3 Digestion System Designs: Different systems have been designed for anaerobic digestion. The following are basic descriptions of the popular systems used on farms.

i Plug Flow System: The plug flow digesters are primarily used at dairy operations that collect manure by scraping (EPA, 2024). The plug flow system usually takes the form of a long concrete tank with a slight grade over the length. They are often designed as long, narrow concrete tanks with rigid or flexible cover (ABC, 2022). Influent is either continuously or intermittently added to one end and flows by gravity to the opposite end. The contents are not mixed mechanically. The retention time is thus a function of channel length, channel grade, and the loading rate. Mixed plug flow systems have been used at a wider variety of operations because they can tolerate a broader range of solid concentrations (EPA, 2024).

ii Complete Mixed System: This is also known as a completely stirred tank reactor (CSTR). The complete mixed system is most commonly a circular tank with a mechanical agitator. The mixing prevents settling and maintains contact between bacteria and the manure. Electricity input costs are higher due to the intermittent mixing of the systems. However, the mixing can cause foaming in the tank, which is undesirable because it occupies digester volume and can clog gas lines. Complete mix digesters often dilute the mix of feedstock to aid mixing, like the consistency of a thick 'soup' (ABC, 2022). Influent is often added to the digester as effluent is excreted in small quantities at regular intervals. Therefore the retention period of manure in a complete mix digester is not necessarily uniform.

iii Fixed Film System: The fixed film system contains structures like corrugated plastic drainage pipe inside the vessel to help retain more anaerobic bacteria. The structures increase the surface area available for the bacteria to adhere to, thereby reducing the numbers of bacteria washed out in the effluent. The anaerobic process begins faster and stronger compared to a plug - flow or completely mixed system. The advantage of the fixed film system is the shorter retention time - a retention time of 20 days in a conventional completely mixed system can be shortened to 4 days with fixed film system.

iv Covered Lagoon: The covered lagoons are typically not heated, so their use is restricted to areas with a relatively warm climate. The hydraulic retention times for covered lagoons range from 40 to 60 days, depending on regional climate. Electricity generation is not usually practical with a covered lagoon because biogas production varies with temperature. The covered lagoon systems produce less biogas in colder temperatures and little or no gas below 4 °C. Most covered lagoons used to be open manure lagoon on a farm that have added an engineering flexible cover added to capture biogas (ABC, 2022).

v Centralized Systems: The centralized systems are much larger anaerobic systems than the typical on - farm installation. A number of farms within a designated geographical area are usually required for the economical operation of a centralized anaerobic system. The advantages of a centralized system include less individual risk, favourable economies of scale, and less individual farmer involvement. The disadvantages include the typically high-level costs required to haul inputs and outputs, higher capital costs, and the need for daily management of the system by a trained operator.

1.5 Biogas Applications: There are many uses for the gas produced by anaerobic digestion. Biogas can be substituted for any application designed for natural gas. A boiler will convert the methane to heat. Micro turbines, gas turbines, internal combustion engines and fuel cells convert biogas into both electricity and heat.

i Heat Boiler: The heat boilers represent the simplest use of anaerobic produced gas. Biogas can be used in heat boilers to directly produce high quality hot water or steam. The hot water or steam may be used to heat the digester and be used in secondary systems such as absorption chillers or space heaters. The gas could also be used directly in any natural gas fired appliance

ii Flare: There are two basic types of flares available: open and enclosed. The open flares usually consist of a burner with a small windshield. The open flares are usually constructed several metres off the ground in order to protect both workers and supply pipes from the radiated heat. The open flares are mostly suited for temporary or test uses. The enclosed flares are usually ground - based permanent structures. The burner is kept in an enclosed cylinder lined with refractory material. The insulation and control of air mixture contribute to a more uniform burn as well as lower emissions.

iii Internal Combustion Engines: The use of internal combustion (IC) engines with biogas is long established. IC engines are sub - divided into two categories: compression engines, and spark ignition engines. Both types of engines may be converted to run using the biogas produced by anaerobic digestion. The biogas operation of compression engines is known as "dual fuel" operation, because a small amount of diesel fuel is combined with

the gas for ignition purposes. The spark ignition engines are operated on a mixture of biogas and air, as ignition is caused by a spark plug. In a dual fuel engine, a mixture of biogas and air, mixed in an external device is sucked into the engine chamber and ignited with a small amount of diesel fuel.

1.6 Biomethane: Biomethane (also known as “renewable natural gas”) is a near – pure source of methane produced either by “upgrading” biogas (a process that removes any CO₂ and other contaminants present in the biogas) or through the gasification of solid biomass followed by methanation (IEA, 2024). Biogas can be cleaned and upgraded to natural gas standard when it becomes biomethane. Bio methanation is the chemical process of creating methane by combining gaseous carbon oxides with hydrogen (EBA, 2024).

II MATERIALS

The materials used in actualization of this work are presented below;

The major materials used are the research study areas: Agricultural engineering departmental processing laboratory, and Agricultural engineering departmental demonstration site, both located in Engineering faculty, Delta state university of science and technology, Ozoro, Nigeria.

Other materials include: HDPE drum, water purification filter, Potash, iron sponge, charcoal, HDPE tape, rubber gaskets, PVC gum, silicon bond, Socket joints, elbows, tees, valves, PVC and rubber pipes of various size, 25 liters - plastic gallon, funnel, gas cylinders, multipurpose thermometer with sensing probe, Poultry droppings, water, etc.

III METHODS

A portable biogas digester was produced in the processing laboratory of the Department of Agricultural Engineering, Delta State University of Science and Technology, Ozoro. The holding tank was a HDPE drum. A water purification filter was modified as a biogas filter and packed with local potash, activated charcoal and iron filings in order to remove unwanted gases. Four openings were provided: a substrate inlet (the coverable PVC pipe on the drum seal for pouring in solvents and solutions after corking the seal), substrate outlet (the PVC pump below the tank for removal of wastes), gas outlet (the PVC plastic pipe attached to the rubber tube, connected to the drum through the seal for the collection of produced gas from fermentation process for appropriate transmission of gas to the cylinder), and emergency pressure valve (the PVC pipe with tap connected, on the drum seal to regulate internal reaction within the gas production unit). Upon mixing, at ratio of 1:1 water to Poultry droppings, fermentation was allowed for thirty - two (32) days in the air tight vessel, and within the period, gas collection was carried out.

Digester Fabrication: The biogas digester was made from high-density polyethylene (HDPE) plastic, chosen for durability reasons. The drum was fitted with four openings (substrate inlet, gas outlet; emergency gas release point, and substrate outlet) of circular holes drilled. Socket joints were attached with gaskets to the holes to ensure air tight fit. These can be seen in figure four (4) below;



Figure 4: Socket joints and drilled holes.

In section I, hole boring was achieved using hot metallic material. This was followed by filing and fitting in (section ii) which gave a resultant functional fitted three openings (section iii) in figure four (4) above.

Details of the various openings are presented in table one (1) below;

Table 1: Digester openings size and placement

S/N	Type of opening	Diameter (cm)	Location
1	Substrate inlet	6	Top (cover)
2	Emergency gas release	4.5	Top (cover)
3	Gas outlet	4.2	Top (cover)
4	Substrate outlet	6	Base

Filter Fabrication: A domestic water purification filter was modified for upgrading of the biogas. The filtration elements used are activated charcoal, iron filings and local potash, according to Orhorhoro et al. (2018). All filter composite materials were dry, and were mixed with the charcoal, potash and iron filings in the ratio of 4:3:1.

Leak Proofing: Upon fabrication completion, a leak test was carried out using approximately 1 litre of water to ensure that no leakages were made.

The digester was loaded to approximately 60% capacity (about 0.074m³) with poultry droppings in slurry form.



Figure 5: Mixing of the droppings

The mixed droppings were further balance by adding more solvent through the inlet unit using the funnel after corking the digester seal.

The bill of engineering measurement and evaluation (BEME) for the fabrication of the digester was made.

IV RESULTS

The produced digester is presented below;



Figure 6: Biogas digester

The result of the filter element produced is presented in figure seven (7) below;



Figure 7: Filter element

Leak proofing experiment result indicated a gas tight seals. Methane gas was produce.

The result of the bill of engineering measurement and evaluation (BEME) for the fabrication of the digester is presented in table two (2) below;

Table 2: Bill of Engineering Measurement and Evaluation (BEME) for fabrication of the digester

S/N	Item	Description	Quantity	Unit Cost (₦)	Total Cost Naira (₦)	Cost in Dollar (\$)
1.	Receptacle	HDPE drum	1	35,000	35,000	26.92
2.	Pressure gauge	Analog (kPa)	1	19,000	19,000	14.62
3.	Pipes	PVC and rubber pipes of various sizes	As reqd.	11,500	11,500	8.85
4.	Fittings	Socket joints, elbows, tees, valves, etc.	As reqd.	11,550	11,550	8.88
5.	Glue	PVC gum, silicon bond, etc.	As reqd.	7,500	7,500	5.77
6.	Labour	Specialized labour (plumbing)	1	22,000	22,000	16.92
7.	Miscellaneous	HDPE tape, rubber for gaskets, etc.	As reqd.	8,200	8,200	6.31
8.	Transport expenses	Purchase, movement of waste etc.	As reqd.	15,000	15,000	11.54
9.	Filter	Water purification filter	1	4,000	4,000	3.08
10.	Filter components	Potash, iron sponge, charcoal	As reqd.	7,000	7,000	5.38
TOTAL					140,750	108.27

V DISCUSSIONS

In the gas collection, the outlet pipe from the filter which is the flexible hose with a valve at the end, allow for direct capture of upgraded methane in a metal cylinder. Retention time affected gas pressure built up in the digester. The gas produced at the beginning of harnessing was low relative to fermentation rate which increased with respect to time. The system produced combustible methane gas at the end of the retention time. Gas production was low in the first few days and increases with time.

The PVC pipes and fittings connected to the drum served as controls to excessive fermentation products (to avoid explosion from unbalance internal reaction within the tank gas storage). This emergency release valve was fitted with a short length of polyvinyl chloride (PVC) pipe and a valve, in order to make room for emergency release of the pressurized contents. In leak proofing, PVC gum, silicon bond, and rubber gaskets were used to ensure air tight seals. HDPE thread tape was also used as screw able elements.

VI CONCLUSION

Methane gas was produced (from the portable digester) and purify – able to biomethane, which is burnable to obtain electricity and heat using combined heat and power (CHP) plants, usable as fuel, and inject – able to the natural gas.

RECOMENDATION

The usage of biogas especially in Africa is minimal though it is on the increase, it should be encourage for future sustenance.

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