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Research Article

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Comparative Analysis of Gases Obtained From A Bio-Digester Using Different Waste Media

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Abstract The development of a technological devices and equipment for biogas production from different energy plants and organic wastes has made biogas a renewable source of energy generation. The interest in the use of the biogas as a renewable source of energy is increasing and also the scope of substrates for the anaerobic digestion process is on the increase. With the mini digester it is possible to observe the amount of biogas (methane gas) production and thus the most suitable plant, giving the maximum methane yield, can be determined. The mini digester made of galvanized steel was built, some measurements with energy plants were performed and then parameters such as biogas composition from animal wastes and crop residues were measured (in the laboratory) and compared. The highest biogas and methane yield was recorded in the animal waste. Probable recommendations were later made.

Keywords Technological devices and equipment, Mini digester, Biogas, Wastes

Introduction

Energy (renewable or non-renewable) plays important roles in diverse processes and activities in the society. It is complex and could be converted into different forms. It could be transported, stored and used in numerous forms or places. As a result of this, the usefulness of energy can never be taken slightly because it moves as the world moves which means it is dynamic in use and it measures the rate of development among the countries of the world. However, past research had shown that population has a serious effect on energy use. 60 percent of the world's population live in rural areas of developing countries and rely on agriculture for their livelihood [1]. About one billion people rely on residue as their principal cooking fuel. In many areas, particularly in Asia, the commercialization of bio-residues is a source of modest income but at the same time, it is a burden for poor people [2, 3]. Bio-fuels after present a good opportunity for energy production as both the production and consumption of energy can be located in the same area unlike with fossil fuel. For heat and electricity, a wide range of technologies utilizing biogas already exists [4].

Thus, biomass, a source of energy has been used since ancient times [5], is the collective name for renewable materials which includes: (a) energy crops grown specifically to be used as fuel, such as wood or various grasses, (b) agricultural residues and by-products, such as straw, sugarcane fiber, rice hulls animal waste, and (c) residues from forestry, construction, and other wood-processing industries [6-8]. However, bio-gas is produced in different environments e.g. in landfills, waste water treatment plants (WWTP) and bio-waste digesters during anaerobic degradation of organic material (of plant, animal and human origin which can profitably be used to generate valuable energy and fertilizer). It usually contains 45% to 70% methane and 30% to 45% carbon-dioxide [1]. Depending on the source, biogas can also contain nitrogen, hydrogen sulphide, and organic silicon compounds. In biogas plant, the gases produced are generally used for energy production. Biogas is widely used in some countries and there is still a great potential to be tapped.

Thus, the over dependence on fixed/limited fossil fuels for large scale electricity generation is very alarming. Hence, exploitation of renewable sources of energy is imperative to mitigate energy crisis and eventually to subsidize environmental degradation (due to burning of fossil fuels) in foreseeable future. In remote areas of the developing countries, petroleum products are not easily available and even when they are available; they are not affordable to poor people who are the main users of wood-fuels. On the other hand, wood burning in an-in-efficient traditional stove built by the households themselves emit harmful gas like carbon mono-oxide (CO) which is hazardous for health. It leads to Acute Respiratory Infections (ARI) and Chronic Obstructive Lung Diseases (COLD). Women are the most common victims of these conditions not only do they suffer physically but their expenditure on health increases due to illness. However, this work is aimed at comparing and analyzing the composition of gases obtained from a biogas plant using different media. This is achieved through construction of an improvised plant for gas collection, measuring and analyzing the quality of gases obtained in the plant and deducing the best waste medium based on the result obtained.

Materials and Methods

Materials and Equipment

The following materials were used in this study:

a) **Animal Wastes:** Pig dung, water, poultry dung, sheep dung and cow dung. Availability of animal dungs makes it the easiest feedstock to use for a biogas production as they already contain the right types of bacteria. Animal dung has also been broken down chemically by acids and enzymes in the animal's gut. The animal dung used was obtained from University of Ibadan Research farm, in Ibadan-North Local Government of Oyo State. The variation of their mixture i.e. cow dung, pig dung and poultry dung were of the same proportion.

b) **Crop Residues:** Cassava peels, corn cob, corn stock, vegetables, and wastes from food. Availability of crop residues, make it the easiest feedstock to use for a biogas production as it already contains the right types of bacteria. Crop residues have also been broken down chemically by acids and enzymes. The waste used was obtained from our homes and research farms. The variations of their mixture i.e. crop residues used were of the same proportion. The variations of their mixture were of the same proportion.

c) **Water:** This is a chemical substance with the chemical formula H_2O. Its molecule contains one oxygen and two hydrogen atoms. It was used to mix the biodegradable waste to speed up the anaerobic process.

d) **The equipment used:** These include: wastes digester, temperature dial gauge (*Rototherm temperature dial gauge)*, bucket, stirrer, holes, motorcycle tyre tube, clips valve, galvanized steel of 1.5mm thickness, Iron rods, Steel pipes, Tap valve, Rollers, Bolts and Nuts, Bearing, Rubber nut, Gasket, Hose, Paint (Black), Steel (To build platform), Welding Machine, Electrodes, Steel tape (for measurement), cutter (for cutting iron sheet), Spanner, Grinding Machine, Hammer, Saw and Pipe wrench.

Design Consideration

The following considerations were made:

i. **Stirrer:** This is a mechanical device inside the digester used to stir the fermenting slurry to stimulate gas production and to break the "scum" layer forming at the surface of the slurry. The newly incorporated stirring mechanism is direct and efficient. It was designed in such a way that the force needed to drive the paddle is direct. The form of motion is "rotational" which is fixed to the paddle directly, so as, to break the hard scum formed on the surface, middle or beneath the slurry inside the waste digester. This will enhance maximum yield of biogas produced. The stirrer was rotated in ***25 complete oscillations twice a week***.

ii. **Inlet pipe:** The inlet pipe was designed for the introduction of feed materials into the digester (charging the digester). It is situated at the side of the drum. It has a cover to close the inlet mouth and keep air away from getting into plant as the digestion and breaking down of waste materials inside the plant is anaerobic (in the absence of air).

iii. **Slurry outlet:** This is a small pipe outlet of about 300mm diameter, situated at the bottom part of the plant. It was designed for the passing out of used slurry at the end of the digestion process. The slurry outlet has a screw fitted around its mouth to close it and prevent air from entering into the digester when it is not being used.

iv. **Gas outlet:** This is also a small diameter pipe protruding out in front of the waste digester part at the top part. It was designed for the collection of gas that was produced from the plant. Flexible rubber hose could be fitted to the gas outlet to collect the gas and convey it to the tube. The gas outlet also has a tap fitted to it to close the outlet and prevent produced biogas from getting out of the tank before collection is needed.

v. **Cover:** This is regarded as the digester outlet. It is situated above the plant. It is circular and 200mm in diameter. The cover was built in such a way as to conform to the air-tightness of the whole set-up, and therefore when the cover is closed, there is no way air can be introduced into the plant. The cover was designed to hold the stirrer. Two bevel gears rest on the cover with one attached to the long paddle of the stirrer and the other attached to the rotating handle which rest on a length of angle iron that is welded to the top part of the digester.

vi. **Available Residues for Biogas production:** The agricultural residues that are available in Nigeria can be broadly categorized into two; animal and crop residues (waste). The available animal residues are, Poultry dung, Human excreta or feces, Goat dung, Sheep dung, Cow dung, Buffalo dung and Pig dung, while the available crop residues, cassava peels, corn cob, corn stock, saw dust, rice straw and wheat straw.

Design Calculations

The waste digester consists of the upper part, middle and the lower part. The upper part is designed to have a cylindrical shape while the lower part takes the shape of a perfect cylinder. The middle part takes the shape of a cone.

Calculation details

Volume of waste digester V_B = volume of upper part + volume of lower part + volume of middle part

$$V_B = V_U + V_M + V_L \quad (1)$$

Where; V_B = Volume of waste digester, V_u = volume of upper part, V_L = volume of lower part

V_m = Volume of middle part

H_L = height of the lower part, H_U = height of the upper part, H_M = height of the cone/middle part

Therefore, Volume of the digester is $V_B = \pi R_U^2 H_U + \frac{1}{3}\pi(R_L^2[H_M + H_U] - R_U^2 H_U) + \pi R_L^2 H_L$ (2)

Table 1: Design Calculation Details

S/N	Parameters	Upper Part	Middle Part	Lower Part	Total Volume (V_B)
1	Diameter (m)	0.2	0.45	0.45	0.1435 m^3 or 143.5 Litres
2	Height (m)	0.15	0.05	0.55	
3	Parts' Volume (m^3)	0.047	0.009033	0.0875	

Basis of biogas production

Biogas is produced when bacteria convert organic matter to methane gas. This process is similar to what takes place in the rumen of a cow, so we often hear waste digester referred to as anaerobic digesters or anaerobic fermenters. Four ingredients are used for biogas production:

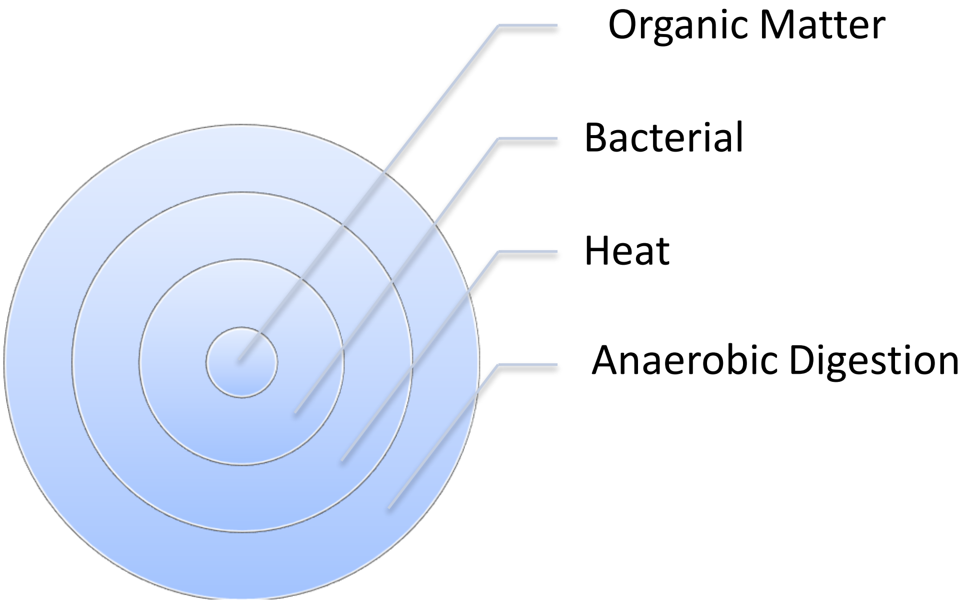

Figure 1: Biogas Processes

Wastes Digester

The name BIO- means the biological process or stages (fermentation, forming of bacteria that the feedstock undergone during the production of methane which is also known as biogas. Digester is a container or tank in which an anaerobic process takes place for the production of gases. Anaerobic digestion is an energy conversion process that converts volatile solids into digested gas. This conversion of solids to gas through a biological process is called bio-energy conversion.

The digester tank is a cylindrical tank that is made of *galvanized steel because of its corrosion resistance property*. The diameter of the lower part of the waste digester is 45cm, while the upper part of the waste digester has a diameter of 20cm. The lower part has a height of 55cm, while the upper part has a height of 15cm. The waste digester was designed to hold an average of 0.1435m^3 (143.5 Litres) of slurries and gas production of 0.0756m^3 (75.6 litres).

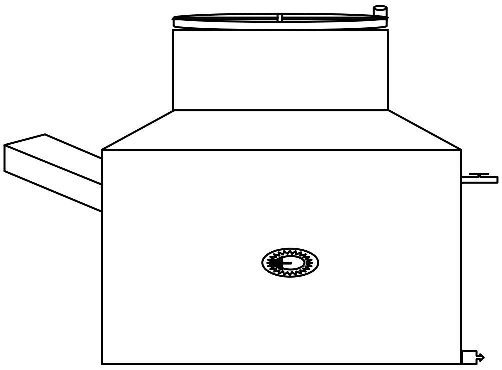

Figure 2: Schematic diagram of the side view digester

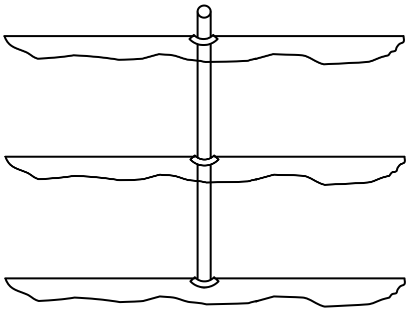

Figure 3: Schematic diagram of the Stirrer of a Wastes mechanism

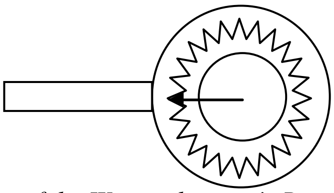

Figure 4: Schematic diagram of the Wastes digester's Rototherm temperature gauge

Specimen /Sample Preparations

A fresh cow-dung of 4.8700 kg, 1.3700 kg of poultry dung, 0.4800 kg of pig dung and 1.9067 kg of sheep dung were mixed together with 12 litres of sterile distilled water in the ratio 3 to 4 approximately i.e. 8.6267 kg of animal wastes and 12 liters of sterile distilled water) to form a slurry on one hand, which was then fed into the digester at room temperature. On the other hand, 3.5 kg of fresh cassava peels, 2.4 kg of corn cob, 0.127 kg of corn stock, 1.6 kg of vegetables, and 1.0 kg of wastes from food, were mixed together with 12 litres of sterile distilled water in the ratio 3 to 4 approximately i.e. 8.627 kg of crop residues and 12 liters of sterile distilled water) to form a slurry which was then fed into the digester at room temperature. The mixing and feeding of wastes into the digester are shown in plate 1 to plate 4.

Operation of the Wastes digester

i. **Condition of Operating the Digester:** The waste digester was placed in an open air, where it was exposed to ambient temperature. The internal temperature of the waste digester ranges between 28^{o}C-37^{o}C.
ii. **Hydraulic Retention Time (HRT)**: This is the average time spent by the input slurry inside the digester before it comes out. Hydraulic retention time for this experimental work was 23 days. The HRT was long as a result of the unfavourable weather condition, which affected the total volume of biogas generated within the period (75.6 litres).
iii. **Biogas Collection:** After a considerable calculated hydraulic retention time of the feed materials undergoing anaerobic digestion in a digester plant, the gas outlet will be turned on to collect the gas produced. Tyre-tube was used in the collection of the biogas [9]. The biogas produced from the digester passed through the gas outlet, then through the holes and finally in to the tyre-tube shown in plate 5. During the collection, some precautions were ensured in order to prevent the gas from escaping.
iv. **Precautions:** Having carried out the experiment, the following precautions were ensured:
   a. Air tightness of the waste digester since the process is under anaerobic condition (i.e. in the absence of air).
   b. Proper mixing of the waste materials, before being put into the waste digester.
   c. The waste digester was coated black to enhance the absorption of heat.
   d. Proper stirring of the slurry to avoid scum formation.

Results And Discussion

Test/Experimental Results

Table 2: Temperature variation of the environment during digestion of the mixture

Days (Week 1)	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Digester Temp. ^{0}C	28	28	28	28	29	27	28
Ambient Temp. ^{0}C	28	33	31	27	32	32	32
Days (Week 2)	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Digester Temp. ^{0}C	27	28	28	28	27	28	28
Ambient Temp. ^{0}C	33	32	32	32	31	31	31
Days (Week 3)	1	2	3	4	5	6	7
Digester Temp. ^{0}C	28	28	29	29	27	29	28
Ambient Temp. ^{0}C	33	28	33	32	33	33	33

The Table below shows the results of the gas composition obtained from the waste digester.

Table 3: Results of the biogas analysis

Parameters determined	**Sample A Animal Wastes**		**Sample B Crop Residues**	
	1st	2nd	1st	2nd
Methane (%)	46.70	46.50	42.65	42.60
Carbon dioxide (%)	32.80	32.90	29.55	29.50
Hydrogen sulphide (%)	6.60	6.61	4.60	4.61
Sulphur (%)	2.20	2.20	1.44	1.44
Water vapour (%)	5.00	5.04	4.96	4.98
Oxygen (%)	6.70	6.05	5.65	5.78

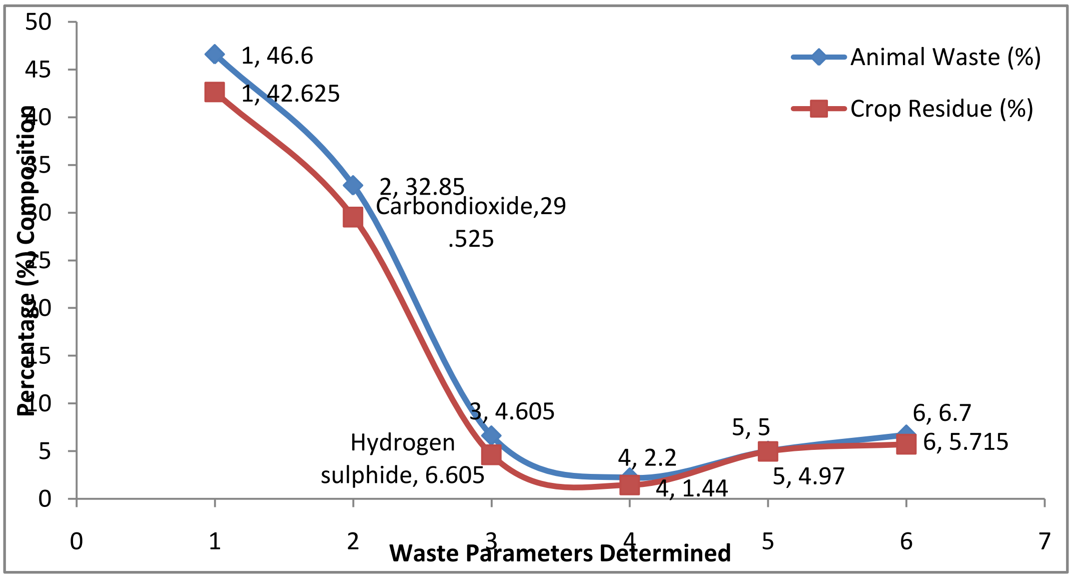

Figure 5: plot of percentage composition against parameters (biogas constituents)

Discussion

It was discovered in table 2 that the digester temperature is between 27 and 29^{0}C while the ambient temperature is between 28 and 33^{0}C. This shows that fermentation would only occur between the digester and ambient temperatures stated above. Gases would also be generated at the above temperature ranges. The fermentation in each of the samples takes 23 days before the slurry was taken to the laboratory for the result-analysis. Table 3 shows the result of the animal and crop (residue) wastes obtained in the laboratory. It was discovered that animal wastes has the highest percentage composition of gases compare to crop residues, this is substantiated in figure 5. It was also observed that methane gas remains the highest in the biogas composition compare to others. This has support the proposition that methane gas remains the major or sole constituents in biogas production. Also from figure 5, the two lines intercept at parameter 5, which means that the result obtained shows equal amount of water vapour. The improvised waste digester is effective, because the percentage composition of the biogas generated is almost the same compared to the percentage composition of the biogas in the standard case. For instance, methane composition generated in the improvised wastes digester is 42.60-46.60% while that of standard case is between (45-75%).

Conclusion

As a renewable source of energy, biogas production from agricultural biomass is of growing importance as it offers considerable environmental benefits and is an additional source of income to farmers. The research was patiently carried out leaving no stones unturned; the design and construction of the biogas plant; the fermentation of the wastes, the laboratory analysis and evaluation of the gases took 23 days. The mini digester used for the experimental tests, was built to produce the biogas from various energy plants and other organic waste materials. Two tests simultaneously were performed. Animal wastes and crop residues in certain ratio were anaerobically digested; biogas yields and biogas composition were measured and compared. Biogas qualities (CH_4, CO_2, and O_2 etc.) were measured in the Moore Plantation Laboratory, Ibadan, Nigeria. The highest biogas and methane yield was recorded in the animal waste. Also, the presence of low sulphur content is as a result of the means of collecting the gas. It is advisable to use a gas cylinder instead of tyre tube for the collection of gases, because of its (tyre tube) reaction with the gas. The production of gases generated has positive effect on the environment. The need to sanitize the environment, energy saving and reservation for the future, cost reduction and monopoly on one lesser source of energy is worth looking into. Therefore, the study is highly recommended for:

i. Production of alternative source of energy generation which tends to reduce pressure on the use of present fossil fuel.
ii. Reduction in environmental pollution because large amount of total waste are being put into use in the process of generating bio-gas. Some advantages of biomass over conventional fossil fuels are the low sulfur content and highly reactive char. In addition, biomass materials do not cake and can therefore be easily handled in both fluidized and moving bed reactors. Finally, catalyst poisons are not present in biomass in significant concentrations. This can be important for the initial thermal processing as well as for subsequent upgrading operations.
iii. The study which would turn waste to wealth. What some people described as waste when re-cycled is the source of wealth to some other people.
iv. Creating an alternative to power generation. The gas produced by bio-degradable waste could be used as an alternative to power generation such as fuel in a gas engine for heat and electricity generations.
v. Assisting in determining the effect of these gases in our environment. The Biogas production from agricultural biomass is of growing importance as it offers considerable environmental benefits.

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APPENDIX

Plate 1: mixing operation

Plate 2: An improvised waste digester

Plate 3: pouring operation

Plate 4: Stirring Operation

Plate 5: Tyre tube method of collecting biogas