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Original Research Article

ANAEROBIC DIGESTION OF FOOD SUBSTRATES FOR BIOGAS PRODUCTION

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ABSTRACT

This study focused on the evaluation of biogas production from digestion of food substrates. Three materials (steel, brick and plastic) were considered for the bio-digester Plastic was selected based on cost, weight, availability and assembly. Incorporated within the setup was a biogas scrubbing unit consisting of steel wool for (H_2S) removal, distilled water for (CO_2) absorption and Type B silica gel for water absorption/drying of purified biogas (CH_4) before storage. The digestion process was carried out using multiple food waste and water at different masses of 10 kg, 15 kg, 20 kg and 25kg in a mix ratio of 1:1. The mixture of 10 kg of multiple food waste and water in the same ratio produced raw biogas of 151 g and purified biogas (CH_4) of 115 g while 15 kg of the same feedstock combination produced raw biogas of 255 g and purified biogas of 204 g. Furthermore, 20 kg of the same feedstock combination produced raw biogas of 354 g and purified biogas of 303 g, whereas, 25 kg of the same feedstock combination produced raw biogas of 425 g and purified biogas of 383 g. A trend was established where the biogas productivity curve started from a minimum point but later rose to a constant peak point where substrates was observed to have stabilized, followed by gradual decline until a minimum point was attained when the food substrate was no longer active in terms of biogas production.

1. INTRODUCTION

Energy is the bedrock of technological advancements in any economy, and its immense benefits to man's existence is gradually increasing the world energy demand and consumption (Sunday, 2012). Therefore, the higher the population density of a given country, the higher the energy demand and consumption and the higher the need for renewable form of energies to offset the upsurge in energy crises and minimise the acute pressure on fossil fuels which are non-renewable form of energy (Halil and Onurlubas, 2010; Asikong et al., 2013; Otun et al., 2015). According to Alemayehu and Abile (2015), the vast depletion of the world petroleum reserves and increasing threat of oil and gas activities on the ecosystem has necessitated the need for alternative fuel sources. However, the search for cleaner, greener, renewable, and economically feasible source of energy has presented biogas which is a renewable energy resource obtained from the breakdown of organic materials by microorganisms in the absence of oxygen, a process known as anaerobic digestion (Han and Shin, 2004; Holm-Nielsen et al., 2009).

Anaerobic digestion process can either take place naturally such as marshes, dumpsites, septic tanks etc. or in a controlled environment such as a biogas plant where optimum digestion may be achieved for biogas recovery due to the presence of water and limited amount of air to facilitate the decomposition processes of biodegradable materials within the feed substrates (Al Seadi et al., 2008; Ukpabi et al., 2017). In other words, decomposition is quickly achieved with wet materials compared to materials with little or no moisture which sometimes dry up without decomposing (Verma, 2002; Faisal et al., 2015). Example of organic waste known for its energy potential is food wastes which are generally biodegraded under anaerobic condition to give off biogas which is composed primarily of methane (CH_4) and carbon dioxide (CO_2) and trace amounts of other gases and water vapour (Yang et al., 2004).

Biogas has a calorific value of 450-550 Btu/ft^3 and can be used as a substitute for kerosene, charcoal and fire wood for cooking and electricity for lighting (Othuman et al., 2014). This saves time and money and above all preserves our natural reserves (forest) from the felling of trees for firewood. The utilization of biogas as a potential energy resource depends highly on its methane concentration. Therefore, biogas purification is very essential for recovery of substantial amount of energy per unit volume of compressed biogas and to eliminate the corrosive effect of (H_2S) found as trace gas in biogas (Nallamothu et al., 2013). Biogas purification increases the concentration of methane in biogas and increases the calorific value of recoverable methane from biogas by decreasing the concentration of carbon dioxide which as a greenhouse gas (GHG) that contributes immensely to global warming and its effects on our environment (Ebunilo et al., 2015).

The aim of this study is to evaluate the potentials of biogas production from relative masses of food waste.

2. MATERIALS AND METHODS

2.1. Materials

The materials used in this study include the following: plastic digester, food waste, pressure gauge, distilled water, type B silica gel, and LPG cylinder.

2.2. Methods

Three different concepts of bio-digester designs made of bricks, metal and plastic were considered for anaerobic digestion of food waste for biogas production, but plastic bio-digester was selected on the basis of cost, performance, safety, assembly and mass. Variable food waste substrates such as Rice, Beans, Yam, Plantain, Fufu, Garri, Banana, Potatoes etc. were mixed together with water. The digestion processes were carried out for equal proportion of 25 kg, 20 kg, 15 kg and 10 kg of food substrates mixed with water at the ratio of 1:1. The experimental setup comprised a bio-digester equipped with control valves at the inlet and outlet, biogas gas extraction hose and pressure gauge of 5 bar. The experimental setup also consisted of biogas scrubbing units interconnected with plastic hoses in which gases produced as a result of substrate decomposition passes through prior to entering the gas storage vessel. As shown in Figure 1, the first scrubbing chamber is composed of steel wool for removal of hydrogen sulfide (H_2S) and siloxane. This is followed by another scrubbing chamber containing distilled water (H_2O) to absorb (CO_2) which is the primary impurity present in biogas. The last scrubbing unit contains Type B silica gel which absorbs moisture present in the biogas. Incorporated within the setup was a hermetic reciprocating type compressor with hydrocarbon refrigerant to increase the biogas pressure from the bio-digester to storage cylinder. The biogas temperature and pressure was monitored throughout the compression process with the help of temperature and pressure gauges. For storing the gas after compression, a 4 kg LPG cylinder was used.

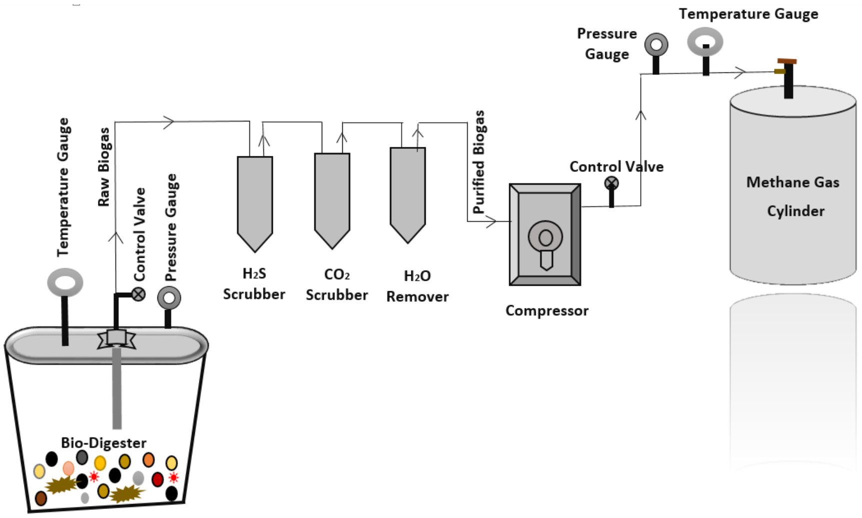

Figure 1: Flow diagram showing the experimental set-up for biogas production

2.3. Design Concepts

In this study, three (3) bio-digester concept designs were proposed to experimentally determine the trend of biogas production, and the most suitable design was considered based on a number of design conditions.

2.3.1. Concept 1 (Bricks Bio-digester)

The brick designed bio-digester is a replicated prototype of a septic tank with little modifications. More like a moderately sized manhole, it is a dug hole on the subsoil surface and lined with bricks along it perimeters and floor with thin layer of cement plaster to give the internal walls and floor a smooth but hard surface impenetrable by biogas or leachate from the waste substrate. The brick bio-digester design which is covered with concrete slab measures about 640 mm in length by 640 mm in width by 640 mm in height. Biogas extraction pipes is installed from the top cover such that one end of the pipe is connected to surface tank while the other end projects downwards into the digester. The receiving tank is equipped with appropriate pressure gauge and measuring devices to determine the pressure of the incoming gas at pre-determined times. Figure 2 represents a schematic diagram of the set up.

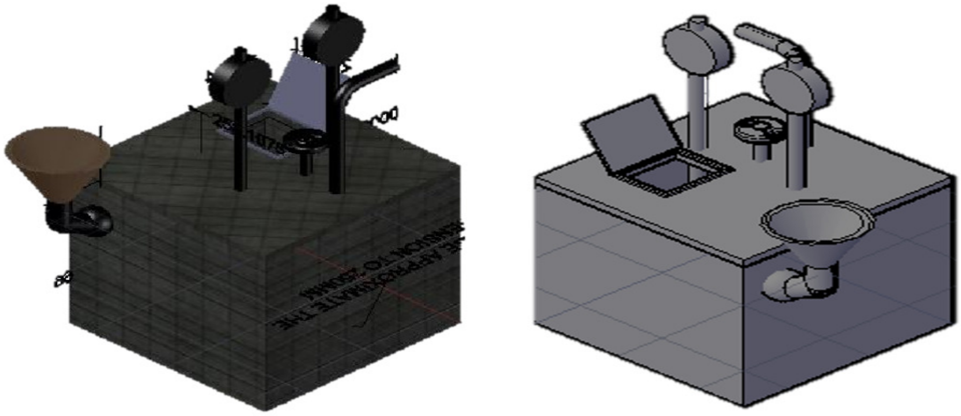

Figure 2: Concrete made bio-digester

2.3.2. Concept 2 (Metallic bio-digester)

Figure 3 represent a metallic bio-digester with dimension of 536 mm height, 159 mm radius and 318 mm diameter respectively.

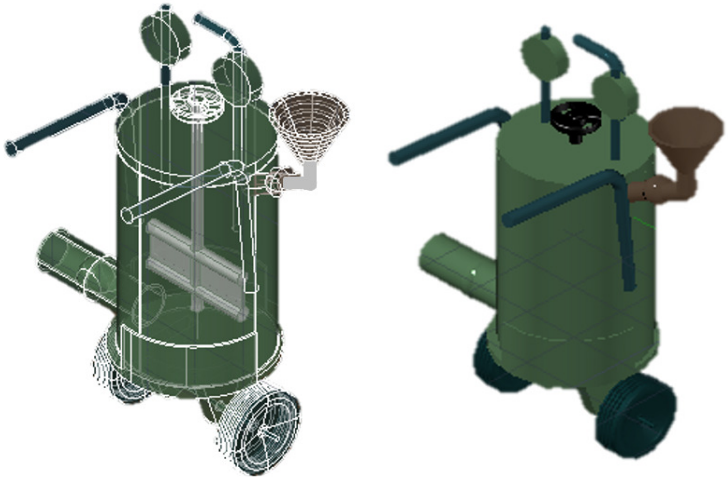

Figure 3: Metallic biodigester

The bio-digester consist of inner metal jacket enclosed in another metal jacket of specific diametric difference. A waste loading Shute from where waste materials are introduced into the tank is attached to the inner cylinder via the external cylinder. Another outlet pipe connected to a receiving vessel and projecting downwards the metallic bio-digester is installed through the cover to serve as biogas extraction pipe. Mixing blade is attached to one end of the waste mixer which extends from the top center of the digester cover downwards to enable proper mixing of food waste deposited in the digester.

2.3.3. Concept 3 (Plastic Bio-digester)

The plastic bio-digester is not quite different from the metal bio-digester, except that it is single walled cylindrical plastic container of known volume with inlet and outlet pipes attached at the appropriate positions for effective loading of the waste substrate and extraction of biogas respectively. Mixing blade is also attached to one end of the waste mixer which extends from the top center of the digester cover downwards to enable proper mixing of food waste deposited in the digester. Figure 4 shows the plastic digester used in this study.

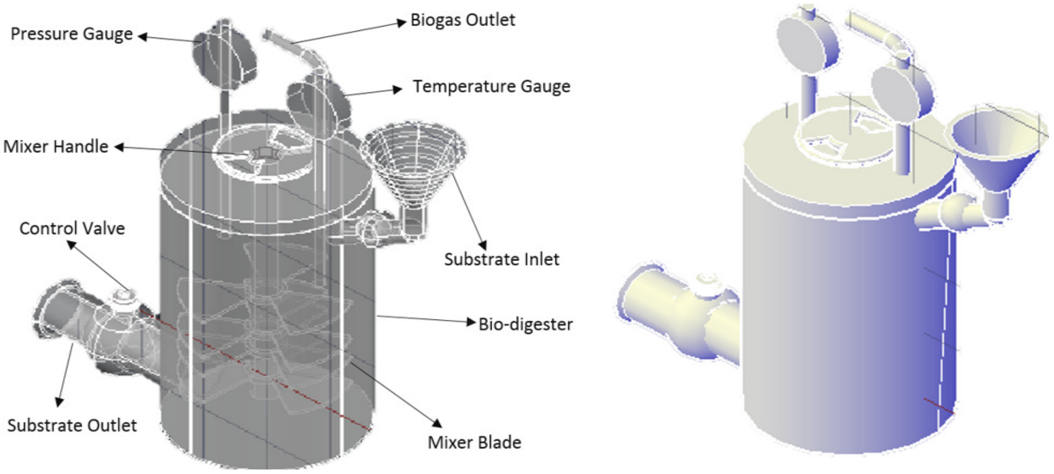

Figure 4: plastic biodigester

Table 1: Decision matrix

Criteria	Weight	Design Concepts					
		Design concept 1		Design concept 2		Design concept 3	
		Rating	Point (%)	Rating	Point (%)	Rating	Point (%)
Functionality	5	3	15	4	20	7	35
Cost (₦)	4	7	28	7	28	5	20
Safety	3	7	21	6	18	3	9
Assembly	2	2	4	4	8	5	10
Mass (kg)	1	2	2	3	3	7	7
Total			70		77		81

Point = Rating x Weight

2.4. Selection of Concept

The decision matrix analysis of five selected criteria was based on the KISS design philosophy “Keep It Simple Stupid”, which states that most systems work best if they are designed in a simple way rather than convoluted. Considering the weight factor, ratings and points (shown in Table 1) allocated to each of the three design concepts, the third concept (concept 3) was selected for the experimental setup because it had the highest point of 81% compared to other concepts. Each criterion was assigned a weighing factor that measures its relative importance with respect to the functionality of each design concept. Considering the aim of this study, functionality was ranked highest in the chart while cost was ranked second. Safety of personnel came into play based on the principles of ergonomics whereas, the ease in parts assembly was not left out considering the time and energy required. Mass of the equipment was also considered in selection of the final design in terms of mobility and space.

2.5. Material Selection

The choice of material considered for the bio-digester was driven by the following factors;

1. Cost: The cost of purchasing readymade plastic vessel for the bio-digester is relatively cheaper than fabrication with metal or construction with bricks.
2. Availability: depending on the amount of biogas required, different sizes of plastic tanks are readily available in the market for purchase and installation of gas extraction probes and hoses.
3. Assembly: Considering the three design concepts, it will obviously take less time and relatively low cost to assemble design concept three (3).
4. Mass (kg): Light weight of the plastic material makes it less cumbersome to carry and transport the bio-digester from one place another for installation and fittings unlike metals and bricks.

Four basic factors are to be considered while selecting the materials are: availability, cost, mechanical properties, manufacturability. The rate of biogas (R_b) equation was determined by using Equation (1)

$$R_b = \frac{N_e}{P_p} \tag{1}$$

Where, R_b is the rate of biogas evacuation, N_e is the number of evacuation and P_p is the period of biogas production.

3. RESULTS AND DISCUSSION

Known mass of food waste ranging from 10 kg, 15 kg, 20 kg and 25 kg was introduced into the plastic digester and a periodical measurement of the gas produced during the organic waste decomposition was recorded accordingly. Peak production volume and total production time of biogas was noted in order to determine the amount of gas in volume produced from a given known mass of waste introduced into the plastic digester as well as the time of peak production and time taken to produce gas (hydraulic retention time). The results obtained from the relative masses of food waste anaerobically digested are presented in Tables 2-5.

Tables 2-5 represents biogas yield from relative masses of food waste intermixed with water in the same ratio. As shown in Table 2, biogas yield from 25 kg of food waste yielded raw biogas of 425g and purified biogas of 383g in mesophilic temperature range of 22-33^{o}C with initial substrate pH of 7.1 before digestion and pH of 6.4 after digestion. As presented in Table 3, biogas yield from of 20 kg yielded raw biogas of 354 g and purified biogas of 303 g in mesophilic temperature range of 22-32^{o}C with initial substrate pH of 7.0 before digestion and pH of 6.5 after digestion. Furthermore, Table 4 represents results of biogas yield from 15 kg of food waste with raw biogas yield of 255g and purified biogas yield of 204g in mesophilic temperature range of 22-31^{o}C and initial substrate pH of 6.9 and pH of 6.6 after digestion.

Table 2: Biogas yield from 25 kg of food waste

HRT	Raw Biogas (g)	Pressure (Bar)	pH before Digestion	Purified Biogas (g)	Pressure (Bar)	pH after Digestion	Temperature (°C)
14	10	0.2	7.1	30	0.4	6.4	22
15	20	0.3		25	0.36		23
16	25	0.34		25	0.35		24
17	30	0.4		35	0.45		29
18	30	0.4		23	0.32		29
19	30	0.4		20	0.3		29
20	40	0.5		20	0.3		32
21	45	0.55		25	0.34		33
22	35	0.46		30	0.4		32
23	30	0.39		25	0.35		31
24	30	0.4		25	0.35		31
25	25	0.34		20	0.3		24
26	25	0.35		20	0.3		24
27	15	0.24		20	0.3		22
28	15	0.24		15	0.25		22
29	10	0.2		15	0.25		22
30	10	0.2		10	0.2		22
Total	425	5.91		383	5.52		

Table 3: Biogas yield from 20 kg of food waste

HRT	Raw Biogas (g)	Pressure (Bar)	pH before Digestion	Purified Biogas (g)	Pressure (Bar)	pH after Digestion	Temperature (°C)
14	10	0.2	7.0	10	0.2	6.5	22
15	20	0.3		14	0.24		23
16	30	0.4		20	0.3		29
17	40	0.5		30	0.4		32
18	35	0.45		34	0.45		31
19	35	0.45		33	0.42		31
20	33	0.42		32	0.43		31
21	31	0.41		25	0.34		31
22	30	0.4		25	0.34		30
23	26	0.36		23	0.33		26
24	20	0.3		18	0.29		23
25	19	0.28		15	0.25		22
26	15	0.25		14	0.24		22
27	10	0.2		10	0.2		22
Total	354	4.82		303	4.43		

Table 5 represents results of biogas yield from 10kg of food waste with raw biogas yield of 151g and purified biogas yield of 115g in mesophilic temperature range of 22-31°C with initial substrate pH of 7.0 before digestion and pH of 6.5 after digestion. The above results presented for biogas yield from relative masses of food waste revealed that increase in temperature has a positive effect on biogas yield, and this is in line with the observation of Latinwo and Agarry, (2015); Ebunilo et al. (2015) in similar studies. It was also noted in this study that the higher the hydraulic retention time, the higher the rate of biogas production and this conformed with the findings from investigation conducted by Asikong et al. (2013). The growth of anaerobic bacteria is hampered by oxygen, and with the limited availability of oxygen in the bio-digester, aerobic microbes were displaced rapidly for anaerobic digestion to occur. At this stage, further breakdown of the waste substrates by anaerobic bacteria occurs as a form of fermentation in which the end products of hydrolysis are converted by acidogenic (fermentative) bacteria into carbon dioxide carbonic acid, ammonia, water vapour, hydrogen, alcohol, volatile fatty acids (VFA) etc.

Table 4: Biogas yield from 15 kg of food waste

HRT (Days)	Raw Biogas (g)	Pressure (Bar)	pH before Digestion	Purified Biogas (g)	Pressure (Bar)	pH after Digestion	Temperature (°C)
14	10	0.2	6.9	10	0.2	6.6	22
15	26	0.36		20	0.3		25
16	30	0.4		24	0.35		29
17	40	0.49		30	0.4		32
18	37	0.46		30	0.4		31
19	35	0.45		25	0.34		30
20	29	0.4		23	0.33		28
21	24	0.35		20	0.3		25
22	14	0.24		14	0.24		23
23	10	0.2		10	0.18		22
Total	255	3.45		204	3.04		

Table 5: Biogas yield from 10 kg of food waste

HRT	Raw Biogas (g)	Pressure (Bar)	pH before Digestion	Purified Biogas (g)	Pressure (Bar)	pH after Digestion	Temperature (°C)
13	12	0.22	7.0	10	0.2	6.5	22
14	23	0.33		18	0.28		24
15	27	0.38		24	0.35		26
16	30	0.4		25	0.36		31
17	28	0.38		20	0.3		27
18	19	0.30		10	0.2		23
19	12	0.21		8	0.18		22
Sum	151	2.22		115	1.87		

Al Seadi et al. (2008) noted that 70% of the methane formed originates from acetate reaction, while the remaining 30% is produced from conversion of hydrogen (H_2) and carbon dioxide (CO_2) as shown in the following biochemical reactions. Methane is produced by methanogenic bacteria (*methanobacterium, methanobacillus, methanococcus and methanosarcina*) known as methanogens by two methods: either by means of cleavage of acetic acid molecules to generate carbon dioxide and methane, or by reduction of carbon dioxide with hydrogen. Methanogenesis is largely influenced by operating conditions such as composition of feedstock, feeding rate, temperature, and pH while large entry of oxygen and the population of methanogenic archaea can also affect methane production process (Tabatabaei et al., 2010; Nnadi, 2014).

4. CONCLUSION

The daily consumption of food by humans all over the world has led to a tremendous increase in the availability of food waste which can be used for energy recovery rather than disposing it indiscriminately in our environment. The anaerobic digestion of food waste in this study has shown the derivable energy potential of food waste in terms of biogas generation. This study has revealed that the higher the mass of food substrates digested anaerobically, the higher the rate at which biogas generation occurs provided the digester operating parameters such as temperature, pH, ratio of substrate to water, particle size of substrates etc. are controlled for optimal biogas yielding rate. The temperature condition in this study was in the mesophilic range, varying between 22°C and 33°C, whereas, the pH of each mass of substrates before digestion varied between 6.9 and 7.1 and after digestion varied between 6.2 and 6.4, indicating that the substrates removed from the digester after digestion can be used as organic manure for plant growth. Finally, it was also observed that the pH decreases as the retention period increases hence the decrease in the pH defined the gradual change in the biogas production rate from hydrolysis to acidogenesis.

5. ACKNOWLEDGMENT

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6. CONFLICT OF INTEREST

There is no conflict of interest associated with this work.

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