Original Research Article

Utilization of Plantain (Musa species) Leaves for Biogas Production

Abstract

Aim: To determine the relationship between the volumes of biogas that can be produced using different biomass/water ratios.

Study design: Biogas was produced by the anaerobic digestion or fermentation of plantain leaves. A practical laboratory scale experimental design was used to find out the effect of biomass/water ratio and retention time on the volume of biogas generated using sun-dried and ground plantain leaves as the feed stock.

Place and duration of study: The research was carried out in Chemistry Department, University of Benin City, Nigeria. Study was done between March and June, 2012.

Methodology: Five (5) biodigesters were used for the biogas production with different biomass/water ratios (1:1, 1:2, 1:3, 1:4 and 1:5) and for a 10-day retention period. The average pH and temperature of the biodigesters were 7.8±0.5 and 30±20C respectively. The biogas produced was characterized using a gas chromatography system 6890 series (and 6890 plus)

Result: Certain amounts of methane, Nitrogen, Oxygen were detected in the gas produced. Proximate analysis of the plantain leaves gave the percentage composition by mass of Nitrogen(0.139%), Crude protein(0.906%), Potassium(1.146%), Sodium(0.063%), Phosphorus(0.085), Calcium(2.003%), Magnessium(0.690%), Sulphate(0.076%), Organic carbon(12.520%), Organic matter(28.002%) and ash content(5.300%).

Conclusion: Using plantain leaves as feed stock, optimum biogas production can be attained using a biomas/water ratio of 1:4. But there is need for further work to validate reliability and also reduce the volume of nitrogen in the biogas produced.

1.0 Introduction

The use and availability of energy for domestic and industrial purposes is a major concern for most people these days. Both developed and developing nations of the world now spend a large proportion of their earnings on gas and oil [1, 2]. These fossil fuels are being continuously used to a large extent. However, since these forms of energy are non-renewable, their availability will continue to decrease and costs will continue be on the rise. [3].
The predicted continuous increase in oil price is due to the limited nature of fossil resources. The turbulence in the Nigerian oil and gas industry as a nation and recent global increase in the price of fuels worldwide proves that the above is true. Although Nigeria is an oil and gas producing nation, the country faces a severe energy crisis due to continuous disruptions in the supply of petroleum products. Vandals, rebels, energy hackers and criminals find Nigeria's centralized oil and gas distribution networks are easy targets [4].

A more serious issue of international concern is climate change. There has been a global movement toward reduced use of fossil resources though energy is a very fundamental tool for development. Nigeria and other developing countries of the world are bedeviled by additional challenges regarding environmental protection due to their heavy dependency on biomass and fossil fuel. According to the study by Adaramola and Oyewola, Nigeria is endowed with enormous amounts of conventional energy resources such as crude oil, tar sands, natural gas and coal, as well as a good number of renewable energy resources such as hydro, solar, wind and biomass. It has been reported that most developing nations of the world are facing serious shortage of fuels, the most commonly used fuel being wood fuel [5]. For this reason, the search for new and renewable energy sources has received worldwide attention. One excellent source of renewable energy is biogas.

Biogas originates from biogenic material and is a type of biofuel. It is normally produced by the anaerobic digestion or fermentation of biodegradable materials such as biomass, manure, sewage, municipal wastes, green wastes, plant materials and crops [6]. In the absence of oxygen, anaerobic bacteria decompose or digest organic matter and produce a gas mainly composed of methane (CH_4) and carbon dioxide (CO_2) called biogas.

Anaerobic digestion is a natural process and there are digesters that are designed and managed to accomplish this decomposition. As a result of the digestion, organic material is stabilized and gaseous by-products, primarily methane (CH_4) and carbon dioxide (CO_2) are released [7]. The process of biogas production takes place under different temperature regimes. Typically, anaerobic digesters are designed to operate in either the mesophilic (20-45°C) or thermophilic (45-60°C) temperature ranges. However, methanogenesis is also possible under low temperature (< 20°C), this referred to as psychrophilic digestion [8]. Anaerobic digestion at psychrophilic temperatures has not been as extensively explored as either mesophilic or thermophilic digestion, probably due to little anticipation of the development of economically attractive systems using this technology [9]. Generally, the production of methane from anaerobic digestion depends on the temperature, the kind of material added to the digester, the solids loading, the pH and the hydraulic retention time (HRT) [10,11].

There are four metabolic stages involved in the production of methane using anaerobic digestion process. First, polymers from particulate organic matters are converted into monomers by extra cellular enzymes through the process of hydrolysis. Then the soluble organic matter and the products of hydrolysis are converted into organic acids, alcohols, hydrogen and carbon dioxide by acidogenic bacteria. The third stage involves the conversion of the products of acidiogens into acetic acid, hydrogen and carbon dioxide by acetogenic bacteria. Lasty, methanogenic bacteria effect the production of methane from acetogen products. [12]

The main advantage in using anaerobic digestion is that while the biogas produced, can be used for steam heating; cooking and generation of electricity [13,14,15], the effluent produced can be used as a biofertiliser or soil conditioner [16].

Each year some millions tons of methane are released worldwide into the atmosphere through microbial activities [17]. About 90% of the emitted methane comes from biogenic sources (decomposition of biomass). The remainder is of fossil origin such as through petrochemical processes. In the northern hemisphere, the present methane concentration amounts to about 1.65ppm [18]. Unlike fossil fuel combustion, biogas production from biomass is considered CO_2 neutral and therefore does not emit additional greenhouse gases into the atmosphere. However, if biogas is not recovered properly, it will contribute a greenhouse effect twenty times worse than if methane is simply combusted [19]. Therefore, there is a real incentive to transfer biogas combustion energy into heat and/or electricity. Biogas production from anaerobic digestion also helps in treating the organic wastes and reducing the environmental impact of these wastes. It contributes to a better image of the farming community while reducing odour, pathogens and weeds from the manure and producing an enhanced fertilizer easily assimilated by plants [20]. So, unlike the situation where when biomass is totally burnt,

it is possible to return much of the original material to the land and thereby improve the soil quality and displace the use of chemical fertilizer.
Other advantages of anaerobic production biogas include revenue from possible reuse of digested solids as livestock bedding, reduction of work for firewood collection and cooking, high quality solids for soil amendment and reduced groundwater and surface water contamination potential [21,22].
Production of methane-rich biogas through anaerobic digestion of organic materials provides a versatile carrier of renewable energy, as methane can be used in replacement for fossil fuels in both heat and power generation and as a vehicle fuel, thus contributing to cutting down the emissions of greenhouse gases and slowing down climate change. Methane production through anaerobic digestion has been evaluated as one of the most energy-efficient and environmentally benign ways of producing vehicle biofuel [2]. The European Union (EU) had set a target of increasing the utilisation of biofuels in vehicles to 5.75% by year 2010 in each member state [3], while in 2005 the market share of biofuels in Finland was 0.1% [23]. Methane production from energy crops and crop residues could be an interesting option for increasing the domestic biofuel production, as it has been estimated that within the agricultural sector in the EU, 1500 million tons of biomass could be anaerobically digested each year, half of this potential accounted for by energy crops [24].

Many researchers have studied the production of biogas from sources ranging from crops, human and animal wastes, municipal waste water and sludge [20,24-26], to non-conventional crops [27-29].

Plantains (*Musa spp*., AAB genome) are plants producing fruits that remain starchy at maturity [30] and need processing before consumption. Plantain production in Africa is estimated at more than 50% of worldwide production. West and Central Africa contribute 61 and 21%, respectively. Nigeria is one of the largest plantain producing countries in the world [31]. The dried leaves, sheath and petioles are used as tying materials, sponges and roofing material. Plantain leaves are also used for wrapping, packaging, marketing and serving of food [32].
Bogas has been produced from plantain fruit and the peels thereof [20,22,33].
However, in this study, the biogas potentials of plantain leaves was examined on a laboratory scale.

2.0 Materials and Methods

2.10 Sample Collection

Plantain leaves were collected from Ugbowo axis of Benin City ($6^0$19’N $5^0$36’E), Nigeria. The leaves were sun dried for two weeks and then milled to powder using a dry grinding machine.

2.20 Gas Production and Measurement

50.00g of the powdered plantain leaves was charged into a Buckner flask (that acts as biodigester) and mixed with appropriate amount of water to give various biomass/water ratios of 1:1, 1:2, 1:3, 1:4 and 1:5. The pH of the slurry was taken. The Buckner flask was tightly covered with rubber bungs to avoid gas linkage. The flask was connected to a measuring cylinder which had been filled with water and inverted into a trough resting on a beehive shelve. The experiment was carried out at ambient temperature for 10 days.
The volume of biogas produced was measured by water displacement in the inverted cylinder. This measurement was carried out daily for the retention period of 10days.

2.30 Gas Collection and Analysis

The same set up used for the measurement of the gas produced was repeated with some modifications. The measuring cylinder was omitted with the Buckner flask directly connected to an improvised gas storing medium. The gas collected was analyzed using gas chromatograph (GC-6890 model) equipped with a thermal conductivity detector.

2.40 Proximate Analysis of Plantain Leaves

Proximate analysis of the plantain leaves was carried out using the methods described by AOAC [34]. The parameters determined include: Nitrogen, Crude protein, Potassium, Sodium, Phosphorus, Calcium, Magnessium, Sulphate, Organic carbon, Organic matter and ash content.

3.0 Results and Discussion

The result of proximate analysis of plantain leaves is shown in Table 1. The result shows that plantain leaves have a high concentration of organic matter and organic carbon which is indicative of high biogas yield. The result however shows relatively low contents of phosphorus, nitrogen, potassium, calcium, magnesium and ash. The trend of the various parameters determined is in the order: Organic matter > organic carbon > ash > calcium > Potassium > crude protein > Magnesium > Nitrogen > Phosphorus > Sulphate > sodium.

Table 1: Percentage Composition of the Plantain Leaves

Parameters	% Composition
Ash	5.300
Nitrogen	0.139
Crude Protein	0.906
Potassium	1.146
Sodium	0.063
Phosphorus	0.085
Calcium	2.003
Magnesium	0.690
Sulphate	0.076
Organic carbon	12.520
Organic matter	28.002

Parameters	Value, mol %	Agip Standard, mol %
Methane (C_1)	15.40	96.93
Ethane (C_2)	0.14	2.55
Propane (C_3)	0.00	0.40
Isobutene (i C_4)	0.00	0.00
n-butane (n C_4)	0.00	0.00
Iso-pentane (i C_5)	0.00	0.00
n-pentane (n C_5)	0.00	0.00
Hexane plus (C_6^+)	0.00	0.00
H_2S	0.01	0.00

O_2	8.01	0.00
CO_2	1.35	0.00
Nitrogen	75.10	0.13
TOTAL	**100.01**	**100.00**

Table 2: Quality of biogas from Plantain Leaves

The results of the chromatographic analysis of the biogas produced are presented in table 2 above. It shows that the yield of methane gas (15.40%) was considerably higher than that of other components like CO_2 (1.35%) and O_2 (8.01%). However the high yield nitrogen gas (75.10%) is undesirable as the Agip standard is 0.13%. The high nitrogen content may be due to contamination by atmospheric nitrogen as a result of the crude method of using surgical hand gloves for the gas collection.

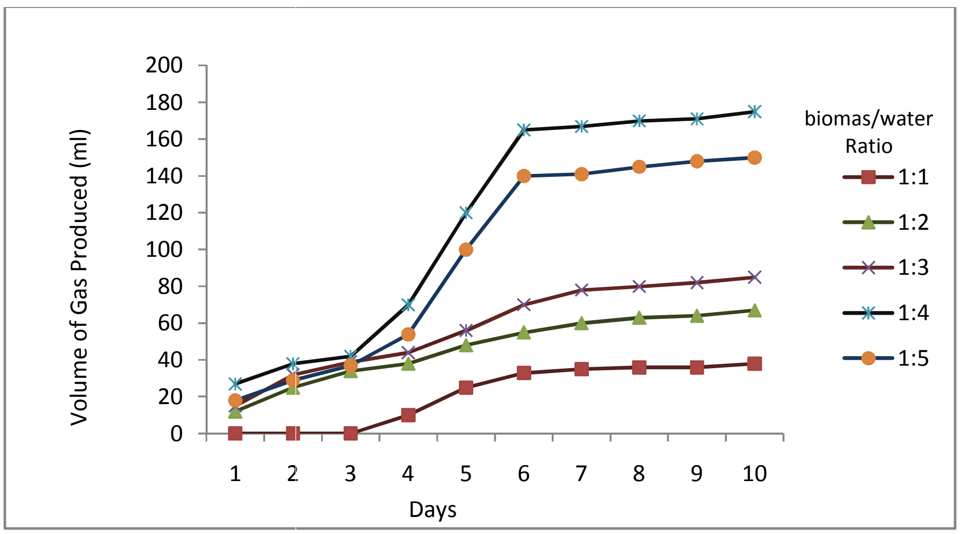

Fig.1: Daily volume of biogas produced for the different biomas/water ratio regimes

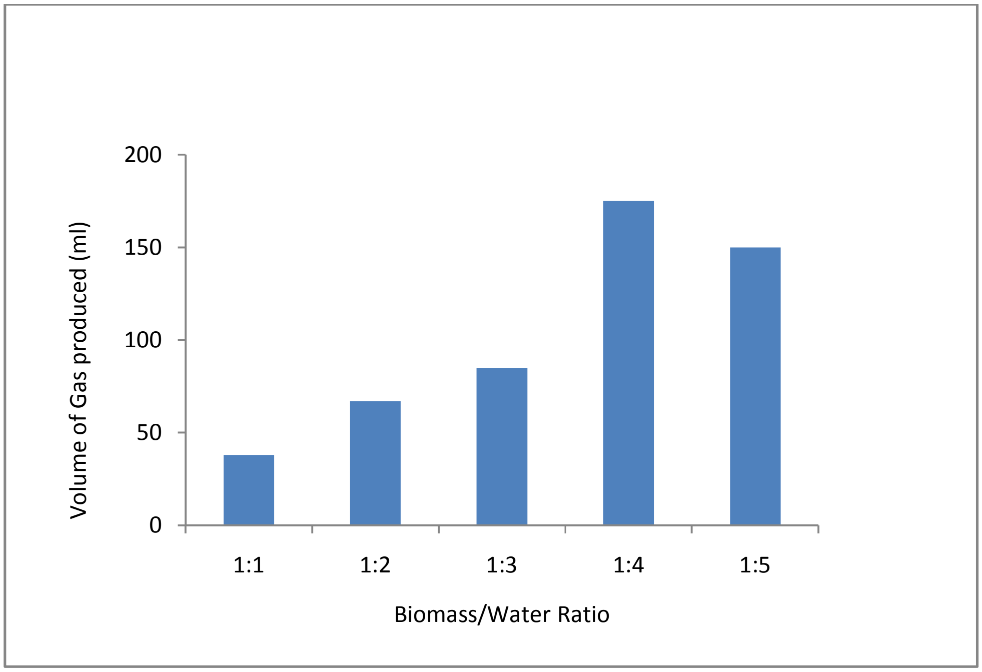

Fig. 2: Cumulative biogas yield from Plantain Leaves

Figures 1 and 2 show the daily biogas production and the cumulative volumes, respectively, for a period of 10 days in five different biodigesters with biomass/water ratios of 1:1, 1:2, 1:3, 1:4 and 1:5, corresponding to A, B, C, D and E respectively. Gas production started in all the biodigesters after the first day except for digester A that had a lag phase of 3 days. This may be due to the limited quantity of water in this biodigester.

Fig. 1 shows that optimum biogas production was achieved on the sixth day. This is because the marginal volume of biogas produced daily was in incremental amounts up to the sixth day. Therefore, the marginal increase in the volume of biogas produced, with respect to days, became very minimal. This is expected since the population of the microbes responsible for the digestion decreases with time.

Fig. 2 shows that the highest cumulative volume of biogas occurred in digester D, with dilution ratio of 1:4, while lowest volume was observed in biodigester A (1:5). This shows that the daily and cumulative volumes of biogas produced was substrate dependent, with a maximum at a dilution ratio of 1:4. This is consistent with previous work on Elephant grass [35], in which the dilution regime of 1:4 produced the highest volume of biogas. Generally the order of biogas production with respect to dilution ratio was 1:4 >1:5 >1:3 >1:2 >1:1.

5.0 Conclusion

Using plantain leaves as feed stock, optimum biogas production can be attained using a biomas/water ratio of 1:4. But there is need for further work to validate reliability and also reduce the volume of nitrogen in the biogas produced.

6.0 References

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