Biogas generation from Watermelon peels, Pineapple peels and Food wastes

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***Abstract*—the anaerobic digestion process for biogas production was investigated using locally available waste materials (watermelon peels, pineapple peels and food wastes). Watermelon peels and pineapple peels each was co-digested with food wastes in ratio 1:1 while using rumen contents of cattle as inoculum. The physical, chemical and microbial characteristics of the three substrates were determined before and after the co-digestion process using standard methods. Analysis of the generated gas revealed 68.0% Methane, 20.0% Carbon dioxide, 6.0% Nitrogen, 2.5% Hydrogen, 1.5% Hydrogen sulfide and 2.0% Oxygen for co-digestion of watermelon peels with food wastes while co-digestion of pineapple peels with food wastes yielded 71.0% Methane, 18.0% Carbon dioxide, 7.0% Nitrogen,1.5% Hydrogen, 1.5% Hydrogen sulfide and 1.0% Oxygen. The anaerobic digestion was found to be efficient in terms of pathogen treatment, since the reduction of coliforms reached five logarithmic units. The availability and renewable nature of biomass, green energy production and ease of management and deployment of energy produced makes biogas a better option to fossil fuel and thus could be the much awaited solution to energy crisis in Nigeria and other developing nations.**

Index Terms—Biogas; Biofuel; Co-digestion; Deforestation; Desert encroachment; Fossil fuel; Pollution.

I. INTRODUCTION

Energy is a very important factor in any nation [1]. The inadequacy of energy supply is known to limit economic growth and adversely affects socio-economic activities as well as the quality of life. The need for increased energy especially in Sub-Saharan Africa where only 58% of the population is served with safe and clean water supply has made biogas technology a welcomed development. The development of biogas technology will facilitate the achievement of the Millennium Development Goals (MDGs) of the United Nations [2].

Furthermore, rising crude oil prices have forced nations of the world to think about alternative energy sources. This is beside high rate of environmental degradation which has given the impetus to consider the development of renewable alternative energy sources [3]. Simultaneously, the need for diversification of energy sources to secure our energy supply has also been on the increase [4]. These alternative energy sources include biofuels (biogas, bioethanol, biodiesel etc.) which has been widely recognized as feasible energy source because of their general compatibility with the current combustion engine technology and existing distribution networks [5, 6, 7].

Biogas is a renewable, high quality fuel, which can be utilized for various energy services such as heating, combined heat and power, or a vehicle fuel instead of the current practice of using fossil fuels [8]. Biogas technology can serve as a means of reducing energy poverty, which has been a serious clog in the wheel of economic development in Africa [9]. The methane and energy content of the gas generated usually varies and is dependent on the physical and chemical properties of the substrate used [10].

In the past, researches on biogas in Nigeria have focused majorly on animal dung, some kitchen wastes and human excreta as feedstocks while the use of succulent plants and plant wastes such as peels have been limited to water lettuce, water hyacinth, cassava leaves and peels and *Cymbopogon citratus* [11, 12, 13]. Watermelon (*Citrullus lanatus*) originated from Western Kalahari region of Namibia and Botswana [14], Africa and is now found in most tropical countries including Nigeria. Nigeria is one of the world's largest producers with over 347,000 tons at year 2002 alone [14]. Pineapples (*Ananas comosus*) on the other hand originated in Brazil (South America), its world total production is dominated by Southeast Asia and the World production is 15,287,413 metric tons by 82 countries [15]. Nigeria is currently world 7th producer with total production in 2011 as 1,400,000 metric tons [15]. The abundance of these two crops in Nigeria and thus their peels, which are put to no use, end up in the environment contributing immensely to solid waste accumulation and subsequent pollution.

The objective of this study therefore is to compare the production of biogas from Watermelon and Pineapple peels in co-digestion with food wastes as a way of contributing to Nigeria's alternative energy generation.

II. MATERIALS AND METHODS

A. Materials

Two (2) identical 24 Litre-biogas digesters each of height 0.5m and diameter 0.25m were fabricated from Galvanized steel which is strong enough to withstand the weight and pressures of the contained slurry. The cylindrical shape was adopted to enhance better mixing.

The tank is air tight and is clearly placed above the ground level and outside the shed where it is exposed to the sunlight for partial heating. The two identical 12.1L gas holder tanks each of height 0.25 m and diameter 0.25 m were fabricated from thin sheet metal and used to temporarily store the biogas until it was used to produce heat or used to replace or supplement the supply of cooking gas. Plastic hose was used to connect each digester to its gas collection system and the biogas stove burner while plastic valves were installed to control the gas flow.

B. Biomass collection, Preparation and Digester Loading

The design volume of the two identical batch flow anaerobic digesters was sized according to the amount of volatile solids that must be treated and the period of time the material will remain in each of the digester (Retention time). The design of the digesters was based on Ajoy Karki's Biogas model [16] incorporating the separate floating gas holder system for ease of daily measurement of gas volume. The cylindrical shape was adopted to enhance better mixing. The digester is a separate component, with the gas holder in a separate water jacket.

The theory behind the design is simply "downward delivery and upward displacement" following the example of [17]. The slurry on fermenting in the digester produces gas. This gas is delivered to the bottom of the water jacket via a pipe; the pipe extends above the surface of the water level (water seal) in the water jacket. The gas displaces the gas holder (upward) and gets trapped between the gas holder and the water seal. The displacement of the gas holder is dependent on the pressure and volume of the gas produced. The Watermelon and Pineapple were obtained from Omu Aran market and their peels were removed and crushed to smaller particles using the Hammer mill [2, 18] before they were transported to the laboratory for further pre-treatment. Food wastes on the other hand were collected from the Landmark University's cafeteria and they composed majorly of carbohydrate wastes such as boiled rice, yam cassava flour etc. Partly decomposed bovine rumen content was used as seed material for the substrates digested in this study. Since the watermelon and pineapple peels are both lignocellulotic materials, they were further pretreated using a combination of thermal and chemical pretreatment methods [19, 20, 21].

The digestion was a batch process and 6 kg each of pre-fermented substrate was respectively mixed with water to form slurry in the ratio 1:1 by volume and introduced into the two digesters respectively through an inlet pipe of 50mm at the top of each reactor. The slurry was allowed to occupy three quarter of the digester space leaving a clear height of about 0.0625 m as space for the gas production. Before feeding the digesters, the flexible hose connecting the gas outlet from the digester to the gas holder was disconnected, such that the gas outlets from the digesters were left open. This was done to prevent negative pressure build up in the digesters. The gas was collected from the digesters through a 10mm diameter flexible hose connected from the digesters to the bottom of the gas collection systems. The collected gas was allowed to pass through water and slaked lime respectively as scrubbers.

Slaked lime ($Ca(OH)_2$) is known to be used for carbon dioxide (CO_2) removal from gas according to earlier finding [22] and that there is evidence that the $CO_2/Ca(OH)_2$ reaction also requires the uptake of water to have reaction. The overall reaction is expressed by (1) as follows.

$$Ca(OH)_{2(s)} + CO_{2(g)} \rightarrow CaCO_{3(s)} + H_2O_{(ads)} \quad (1)$$

The volumes of gas collected before and after scrubbing were taken and recorded following the method described in the succeeding section. The gases collected before and after scrubbing were used to boil water using the Ahmadu Bello University biogas stove burner [23] to estimate and compare the cooking rates. A solid retention time (SRT) of 30 days was chosen for the substrates after a previous study [24]. During this period, daily ambient temperature of Omu Aran fluctuated between30°C and 39°C which is within the mesophilic temperature range [25]. Prior to and after the digestion, all parameters shown in tables 1and 2 were analyzed for the three substrates.

C. Analytical Procedures

The Total solids (TS), Volatile solids (VS), Chemical oxygen demand (COD), and pH were measured according to the Standard Methods for the Examination of Water and Wastewater [26]. Total Kjeldahl nitrogen (TKN) and Total ammonium nitrogen (TAN) were determined using a spectrophotometer (HACH-LANGE DR 2800) and a modified Nessler method (No. 8038). Total phosphorus (TP) and PO_4^{3-} were determined using same spectrophotometer coupled with the PhosVer 3 Phosphate Reagent Powder Pillow Test (method 8048). Volatile fatty acids (VFA) were determined using same spectrophotometer coupled with cuvette tests (HACH-LANGE LCK 365). Metals (K, Na, Mg, Ca, Fe, Cu, Znand Cd) were determined using the atomic absorption spectrophotometer, AAS (SOLAAR 969 UNICAM). Composition (CH_4 and CO_2 content) of generated biogas was determined using a gas chromatography (GC) (HP 5890, Avondale, USA) coupled with a Hayesep Q column (13m x 0.5m x 1/800) and a flame ionization detector (FID). This was carried out two times a week in duplicate from each digester using a gas-tight glass hypodermic syringe, with Luer-lok tips for taking biogas samples (1 ml) from the digesters head space after releasing the gas and followed by injecting the biogas sample into the GC. Enumeration of coliforms and *Escherichia coli* count was carried out according to the method of [26] using Nutrient agar, MacConkey agar and Eosin methylene blue (EMB) agar. Methanogens were however isolated using Brain Heart Infusion (BHI) agar in an anaerobic chamber. Analyses of individual samples were performed in triplicates and all analyses were performed weekly except for pH value and daily biogas yield which were measured daily.

D. Measurement of gas production

The gas holder was calibrated with the aid of a rule to enable the reading of the daily gas production from the digesters. The volume of biogas produced was measured each day shortly before sunset, by computing the volume of the gas holder floating over water level in the water jacket.

The base area of the gas holder is expressed by (2):

$$A = \pi d^2 / 4 = \pi \times 0.25^2 / 4 = 0.0491 m^2 \quad (2)$$

The height of cylinder above water level was read off on the calibration on the gas holder.

Let this height (h) = x, which varies.

Volume of biogas is obtained as the volume of cylinder above water level, given by (3)

Volume,

$$V = (\pi d^2 / 4)h \quad (3)$$

Where h = x

Substituting for A in equation (2), the volume of biogas, V = 0.0491x m^3

The values given by the calibration were written down in order to obtain the daily production by subtracting this value from the one of the day before. It was assumed that other impurities apart from carbon dioxide were negligible, thus, the difference in volume of gas produced before and after scrubbing were used to estimate the methane content.

E. Statistical Analysis

Analysis was carried out using IBM SPSS software for Windows version 20.0. The values obtained were confirmed using one-way ANOVA at 0.05 level of significance.

III. RESULTS AND DISCUSION

A. The characteristics of the substrates used

The characteristics of the substrates (Watermelon and Pineapple peels and Food wastes), used for this study are as shown in Table 1. Among these substrates, combination of Pineapple peels and Food wastes was denser than Watermelon peels and Food wastes in terms of total solids, volatile solids, moisture content, Total Phosphorus, Sodium, Potassium and Iron contents while the combination of Watermelon peels and Food wastes was denser in Total organic Carbon, Total Kjehdahl Nitrogen, Calcium, Magnesium, Zinc, Copper, *E. coli* and total coliform contents. This could easily be linked to the nature and proximate composition of the fruits from which each of these materials is derived from.

B. Gas production

The quantity of biogas produced from the two co-digestion regimes over a period of 30 days retention time (RT) is shown in Figure 1. Biogas production was observed on the third day for digester B (Pineapple peels plus food wastes), and on the second day for digester A (Watermelon peels plus food wastes) and they increased gradually until the maximum values were recorded on the 18th and 24th day respectively and production dropped progressively after that. It was observed that the digesters temperature fluctuated between 32°C and 37.5°C while the pH of the medium changed progressively from acidic to slightly alkaline fluctuating optimally between 6.40 and 7.93throughout the study. This could be attributed to the nature of feed materials used and agrees with earlier submission of [1, 27] that the organic matter content of the substrates is a factor that affects both the digestion and microbial environments. Also, the observed pH falls within the acceptable range for anaerobic digestion [28].

Fig. 1 and Fig. 2 both show the cumulative biogas production for the 30 days RT. The result shows that the co-digestion of Pineapple peels and food wastes produced higher volume of biogas. The figures further shows the total biogas produced, the biogas yield per day, the biogas yield per kg of slurry as well as the daily biogas yield per kg slurry. The figures also shows the estimate of the methane content of the biogas produced on the basis of the decrease in volume after removal of carbon dioxide which ranged between 68% and 71%. These results correspond with the values by [29] for succulent grass and [30] for animal manure.

The higher and faster biogas generation in digester B could be attributed to the availability of more fermentable sugar in the pineapple peels more than in the watermelon peels. Therefore, the action of hydrolytic bacteria on this waste is faster relative to the watermelon peels which contain more fibrous tissues (lignin) and which may not have been completely degraded during the pre-fermentation stage prior to anaerobic digestion.

On scrubbing the gas, the volume of biogas recorded for both digestions reduced and the fluctuations observed in the volume of biogas produced may be attributed to the change in metabolism of the bacteria in response to the fluctuations in the temperature and pH of the digestion media. However, both the digester and ambient temperature remained within the mesophilic range (20°C-40°C) throughout the digestion period. Usually, biogas production rate in batch condition is directly equal to specific growth of methanogens [31].

C. Characteristics of digestates

Anaerobic process is a veritable method of releasing locked up nutrients from substrates being digested. From the two digestates in the study, Pineapple and food wastes co-digestion was found to be denser in terms of Total solids, Volatile solids, Calcium, Magnesium, Iron, Zinc, Copper and *E. coli* contents while co-digestion of Watermelon and food wastes recorded higher values of Organic Carbon, Nitrogen, moisture content, Phosphorus, Sodium, Potassium and total coliform contents. The VS reduction observed is consistent with the findings of [32, 33]. Considering the effectiveness of the anaerobic digestion on pathogen, the process proved to reduce pathogens (coliforms and *E. coli* counts) in both digestates. Previous investigations [34, 35] have reported decrease in *Enterobacteriaceae* and *E. coli* counts by 1 to 2 logarithmic units. The retention time used (30 days) was in favor of pathogen reduction and supports the earlier submission of [34].

IV. CONCLUSION

The research has shown that Biogas could be produced from Pineapple and Watermelon peels as well as food wastes. The total biogas yield and methane content for the respective substrates are comparable with those from other utilized substrates. Therefore, establishment of biogas plants utilizing these substrates will go a long way to reduce solid wastes menace been faced by the country as well as ensuring safe and low-carbon environment.

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TABLE I. CHARACTERISTICS OF THE SUBSTRATES USED IN THE STUDY

Parameters	Units	Watermelon peels only	Watermelon peels + Food waste	Pineapple peels only	Pineapple peels + Food waste
pH	-	7.60±1.36	7.93±2.05	6.9±1.20	6.4±0.5
Total solids	g/kg	3.10±0.23	4.81±0.53	9.23±2.30	11.10±2.10
Volatile solids	g/kg	7.40±3.13	6.00±4.08	10.05±0.13	8.40±1.01
Total Kjedahl Nitrogen	%	0.04±0.03	0.08±0.01	0.08±0.02	0.06±0.01
Organic Carbon	%	0.95±0.01	0.65±0.16	0.84±0.12	0.55±0.10
Moisture content	%	6.86±1.22	6.05±1.04	8.71±1.15	6.19±1.14
Total Phosphorus (TP)	Ppm	53.89±2.11	108.89±5.13	62.17±9.10	127.22±10.45
Calcium	Ppm	0.02±0.02	0.07±0.01	0.08±0.01	0.03±0.01
Sodium	Ppm	1.70±0.02	1.00±0.83	1.10±0.12	1.90±0.02
Potassium	Ppm	38.11±1.03	30.61±2.13	52.1±1.13	50.20±5.03
Magnesium	Ppm	327.5±27.23	225.01±10.04	371.8±11.0	97.50±12.34
Iron	Ppm	156.5±9.03	128.12±11.08	182.3±9.40	87.20±10.10
Zinc	Ppm	10.05±1.30	0.90±0.09	11.01±1.15	0.60±0.09
Copper	Ppm	0.65±0.20	0.90±0.03	0.91±0.02	0.62±0.01
Cadmium	Ppm	ND	ND	ND	ND
E. coli	Cfu/g TS	$11.2x10^5±3.23$	$9.11x10^5±2.23$	$5.11x10^5±2.10$	$6.10x10^4±1.00$
Total coliforms	Cfu/g TS	$1.10x10^6±1.64$	$1.21x10^4±0.11$	$1.10x10^3±0.10$	$1.00x10^4±1.00$

N = 3 for each parameter measured

TABLE II. CHARACTERISTICS OF THE DIGESTATES

Parameters	Units	Watermelon peels + Food waste	Pineapple peels + Food waste
pH	-	7.1±0.20	7.4±1.93
Total solids	g/kg	2.02±0.02	5.22±1.02
Volatile solids	g/kg	2.01±0.01	3.12±1.01
Total Kjedahl Nitrogen	%	0.40±0.01	0.05±0.01
Organic Carbon	%	0.80±0.01	0.38±0.09
Moisture content	%	8.56±2.13	7.86±1.30
Total Phosphorus (TP)	Ppm	135.47±27.32	114.39±12.01
Calcium	Ppm	0.01±0.01	0.05±0.01
Sodium	Ppm	0.90±0.01	0.60±0.04
Potassium	Ppm	43.03±3.03	40.04±3.01
Magnesium	Ppm	59.47±4.14	110.40±0.01
Iron	Ppm	54.82±2.29	85.01±2.10
Zinc	Ppm	0.28±0.21	0.55±0.10
Copper	Ppm	0.41±0.10	0.50±0.05
Cadmium	Ppm	ND	ND
E. coli	Cfu/g TS	$4.4x10^5±1.23$	$5.00x10^5±0.11$
Total coliforms	Cfu/g TS	$0.10x10^4±0.40$	$0.01x10^2±0.01$

N = 3 for each parameter measured

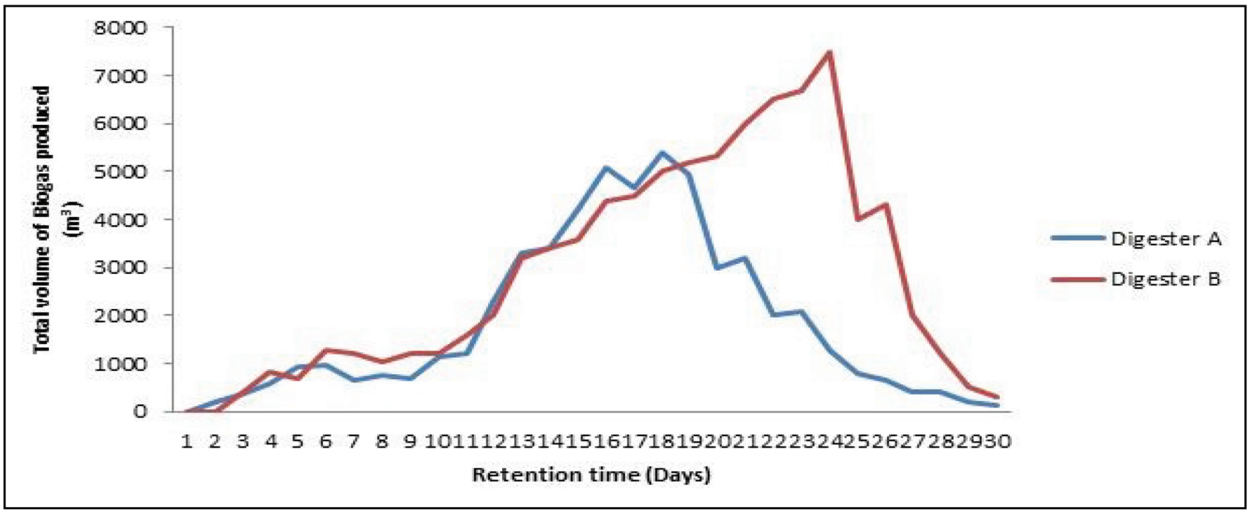

Fig. 1. Daily biogas production for the two co-digestions

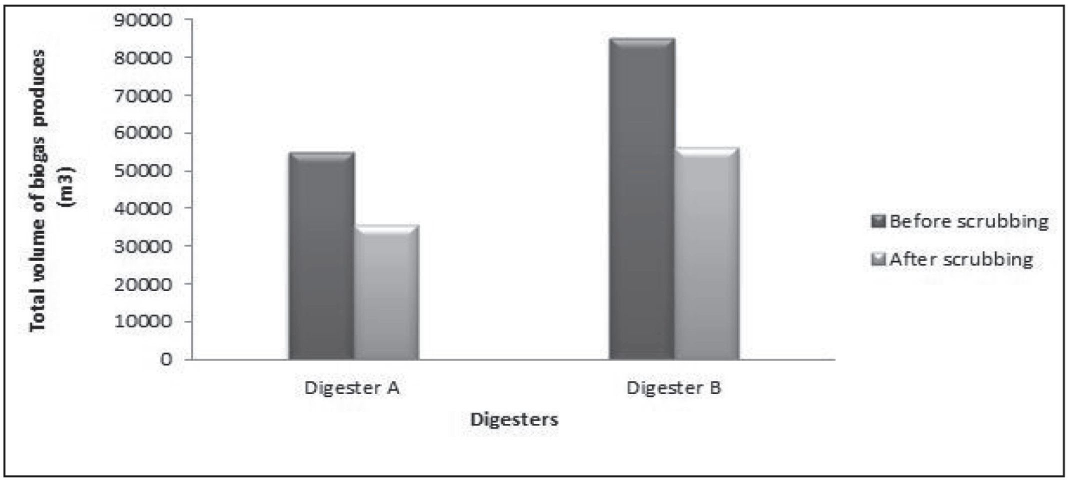

Fig. 2. Cumulative biogas production from the two co-digestions before and after scrubbing