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Full Length Research Paper

Anaerobic production of biogas from maize wastes

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A study on the anaerobic digestion of maize wastes that are being indiscriminately dumped on Nigerian urban streets was undertaken. Maize chaffs, stalks and cobs were shredded and mixed in water to waste ratios ranging from 3:1 to 4:1 (water to wastes) and anaerobically digested in three separate 0.1 m^3 digesters for 30 days. Some physco-chemical and microbiological analyses of the digesting substrates were carried out during the 30 days retention period to evaluate the progress of digestion. Results obtained show that even though maize chaffs, stalks and cobs have the potential to generate biogas, the chaffs produced more biogas than the other two wastes. It was also observed that the chaffs generated more methane gas than the other two and was the earliest to flame when tested.

Key words: Biogas, waste, anaerobes, digesters, maize.

INTRODUCTION

Biowaste refers to livestock manures, the biodegradable part of municipal wastes including food and garden wastes, treated sewage sludge, organic industrial wastes such as paper and textiles and compost. They are a major contributor to greenhouse gas emissions and pollution of waters courses if not managed properly. Biowaste can be degraded anaerobically in a biogas digester to produce biogas and other gases. It is a mixture of methane (CH_4), 50 to 70% carbon dioxide (CO_2), 30 to 40% hydrogen (H_2); 5 to 10% nitrogren (N_2) (Jewell et al., 1993) and 1 to 2% hydrogen sulphide (H_2S) (trace). Water vapour (0.3%) biogas is about 20% lighter than air and has an ignition temperature in the range of 650 to 750°C. It is a colourless and odourless gas that burns with 60% efficiency in a conventional biogas stove (FAO, 2007). Its caloric value is 20 MJ/m^3.

Maize is a cereal crop that is grown widely throughout the world and generally consumed by Nigerians than any other grains (IITA, 2009). It can be eaten after cooking or smoking and can also be converted into animal feeds. The wastes of maize which are left behind after harvest include the husks, chaff, stalks and the leaves (Oseni and Ekperigin, 2007). Chaffs, cobs and stalks are among the prominent wastes associated with maize. These disposed maize wastes have some positive and negative effects on the environment. In Nigeria, maize is abundantly produced and valued even though there is no effort on the ground on means and environmentally friendly waste collection and management strategies in its urban areas. The maize wastes just like other agro-based wastes are indiscriminately left on the farm to be mineralized and used by other crops. However, accumulation of these wastes in non-farming areas like homes, markets, schools and colleges and offices etc, poses a serious environmental threat to human beings because of the offensive odour and army of flies that usually emanate from heaps of these wastes. Anaerobic digestion of these wastes will not only produce biogas and a residue organic waste that has superior nutrient qualities over the usual organic fertilizer, it also minimizes environmental pollution as it reduces greenhouse emission (Voss, 2007). It is evident that by anaerobic digestion, biogas can be generated from different materials such as animal dung, sewage, industrial effluents, kitchen waste, municipal waste and any matter that once lived (Eze and Agbo, 2010). It can be burnt to produce heat, electricity or both (Cuéllar and Webber, 2008). Utilization of biogas would reduce the use of fossil-fuel-derived energy and reduce environmental impact as well as demand for wood and charcoal for cooking (Mshandete and Parawira, 2009).

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Figure 1. 0.1 m^3 proto-type digesters**.**

The major objective of this study is to investigate the potentials of using anaerobic digestion technique to challenge the threat to environment posed by accumulated maize wastes in Nigerian urban centers.

MATERIALS AND METHODS

The study was conducted using three 0.1 m^3 metallic digesters (Figure 1)**.** These digesters were designed and constructed with guage 16 metal sheets in the mechanical workshop of National Center for Energy Research and Development, University of Nigeria, Nsukka.

Sources of the wastes and preparation

Maize chaff was procured from local pap processors in Nsukka town; the cobs from local maize milling industries while stalks from the National Center for Energy Research and Development Integrated Energy Farm, University of Nigeria, Nsukka. The maize cobs and stalks used for this study were chopped into smaller pieces using choppers from the Home Science and Nutrition department of the same university. This was to reduce their sizes and increase the surface area of the wastes for faster degradation. The shredded wastes were then transferred to the digesters and mixed with water. The cobs and stalks were charged at the ratio of 4:1 (that is, water to wastes) and 3:1 for the chaffs, respectively. The slurries formed were closed air-tight and stirred intermittently.

Methods of analyses

The moisture, crude protein, ash, fat, crude fiber and carbohydrate content of the three maize wastes were determined by appropriate AOAC (2010) methods. Total solids and volatile solids content were determined according to Meynell (1982) method. Microbial count was determined using the method of Frazier and Wolfe (1978) while volume of gas produced was measured using method of Varel et al. (1977). The pH of the slurries was measured using the Jean-way 320 model pH meter. The pH meter was standardized using buffer solution of pH 4.0 and 9.0; sufficient time was allowed for stabilization before taking the reading. Isolation and identification of the bacterial spectrum in the wastes were through gram staining and appropriate biochemical and physiological tests as described by Frazier and Wolfe (1978). The ambient and slurry temperatures were measured with thermometer and thermocouple, respectively. Flammability of the generated biogas was tested with a biogas stove fabricated at our Research Center, the pressure measured with a U-tube manometer while the biogas generated was characterized with gas detector (Geotechnical instrument, GA 45).

Statistical design and analysis

The moisture, crude protein, ash, fat, crude fiber and carbohydrate contents of the three wastes were tested statistically using the completely randomized design (CRD) statistical method. This is to determine if they are significantly different in the various maize wastes used. The analysis of variance table for CRD is as shown in Table 1 (Obi, 2002).

The decision rule for CRD is if F-calculated is greater than or equal to F-tabulated at a given probability level, then the F test is significant. A significant F test means that at least one of the maize wastes (treatments) is significantly different. Then, the multiple comparison test using Equation 1 was applied to find out which treatment differs from others (Obi, 2002).

$$F - LSD_{.05} = \left(t_{\frac{.05}{2}}, Error\ d.f. \right) \sqrt{\frac{2 * S^2}{r}} \qquad (1)$$

If the difference between two means is greater than the F-LSD$_{.05,}$ H_o is rejected with the conclusion that the two mean are statistically different.

RESULTS AND DISCUSSION

Table 2 shows the proximate composition of cobs, chaffs and stalks used in the experiment and also the result of the analysis of CRD. The analysis showed varying significant difference at 5% probability level for all the maize wastes. In all cases, chaffs gave the highest component contents with cobs giving the least values. Maize chaffs with carbohydrate content of 75.85% have better potential to generate biogas than the cobs and stalks. This is because chaffs are wastes obtained after processing maize kernels that are very rich in carbohydrates (Bar-zur and Schaffur, 1993; Douglas et al., 1993).

Results of the total volatile solids as shown in Figures 2 and 3 have further demonstrated that maize chaffs are better substrates for biogas generation among all the associated wastes. This result is supported by earlier

Table 1. The ANOVA format for a completely randomized design (CRD).

Source of variation	Degree of freedom (DF)	Sum of square (SS)	Mean square (MS)	F-Cal	F-Tab. (5%)
Among treatments	t_a -1	Among treatments SS (T_aSS)	Among treatments MS = TMS = (T_aSS)/ (t_a - 1)	TMS/EMS	From statistical table
Within treatments (experimental error)	t_a (r -1)	Within treatments SS (ESS) = TSS - T_aSS	Within treatments MS (EMS) = ESS /(t_a(r -1))	-	-
Total	t_a r -1	Total SS (TSS)	-	-	-

Source: Obi (2002).

Table 2. Proximate composition of maize wastes.

Source of variation	Moisture content (%)	Ash (%)	Fibre (%)	Protein (%)	Fat (%)	Carbohydrate (%)
Cobs	17.36	0.35	2.87	0.41	0.39	70.9
Chaffs	25.55	1.03	3.72	0.61	1.43	75.85
Stalks	23.67	0.42	2.89	0.52	1.07	71.43
F-LSD.05	0.1425	0.1525	0.0926	0.0509	0.0609	0.1522

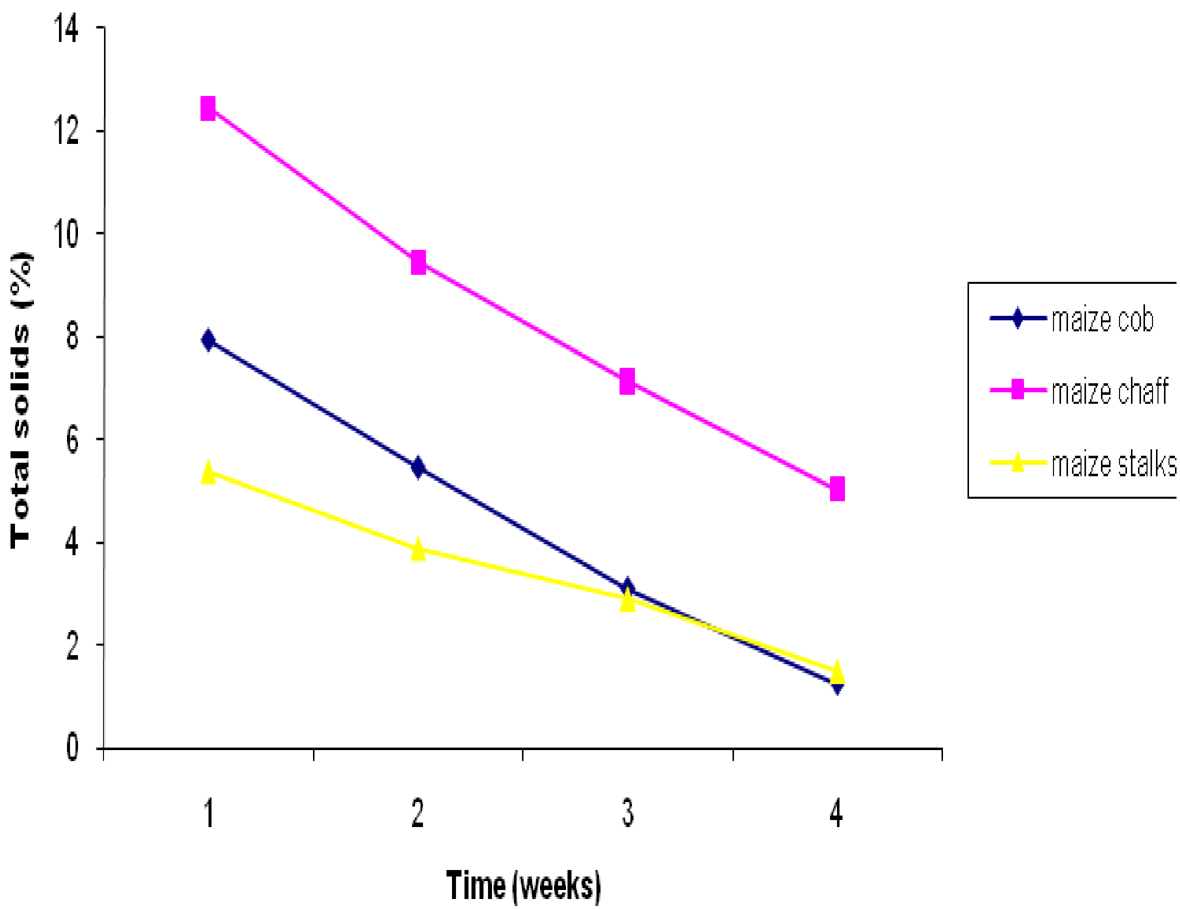

Figure 2. Variations in total solids during anaerobic digestion.

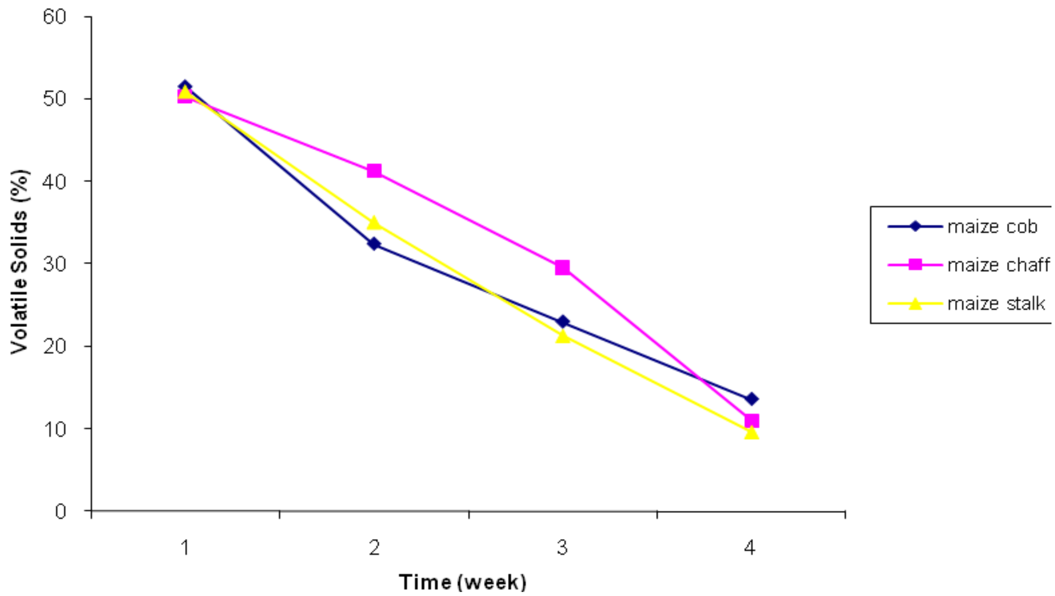

Figure 3. Changes in volatile solids during anaerobic digestion.

Table 3. Effect of temperature on generation of biogas from the waste.

Source of variation	Mean temperature (°C)
Ambient	30.688
Cobs slurry	33.969
Chaff slurry	34.423
Stalks slurry	33.667
F-$LSD_{0.05}$	1.0267

claim by Igoni et al. (2008) that when the total solids of municipal solid waste in an anaerobic digestion process increases, there is a corresponding geometric increase in biogas produced. There was a decrease in the total solids and volatile solids after the first week of fermentation. This result supports the earlier claim by Meynell (1982) and Uzodinma and Ofoefule (2009) who noted that total and volatile solids of organic wastes decrease as anaerobes degrade them in anaerobic environment.

From Table 3, the temperatures of the slurries of the wastes are not significantly different from each other. However, they are all significantly different from the ambient temperature.

The changes in pH of the fermenting maize waste slurries are shown in Figure 4. The maize cob had an alkaline pH of 5.9 while chaffs and stalks have pH values of 6.31 and 6.11, respectively at the beginning of the digestion. However, the pH of the three waste samples increased steadily as digestion progressed. It was observed that with an increase in pH, chaff and maize stalk produced more gas. Figure 4 shows the influence of pH values of chaffs, stalks and cobs on the volume of gas produced during the digestion process.

Cumulative biogas generated

The volume of biogas generated during the digestion period is shown in Table 4. The chaffs produced more gas than the other two wastes. However, the gas became flammable on the 10th day of fermentation while the maize cobs and stalks flamed on the 14th and 12th day, respectively. This is attributable to the better anaerobic environmental conditions of the chaffs with oxygen content of 0.4% which is virtually anaerobic (Table 5). It was also noted that the chaffs gave the highest yield of CH_4 followed by stalks. The high yield of CH_4 in chaffs is due to its high protein content which was degraded to cellulotic materials during fermentation to yield biogas by micro-organisms secreting some extra cellular enzymes (proteins) (Oseni and Ekperigin, 2007). Among the three wastes, biogas generated from the cobs gave the highest percentage of oxygen by composition. This is apparently responsible for the lowest CH_4 yield.

Changes in total viable count

The results of the total viable micro organisms in the three wastes are shown in Table 4. There was a decrease in the total viable count (TVC) as fermentation progressed. Similar result was reported by Eze and Agbo (2010) who noted that a drop in pH value of organic waste undergoing anaerobic degradation results to displacement of some acidogenes. This may be attributed

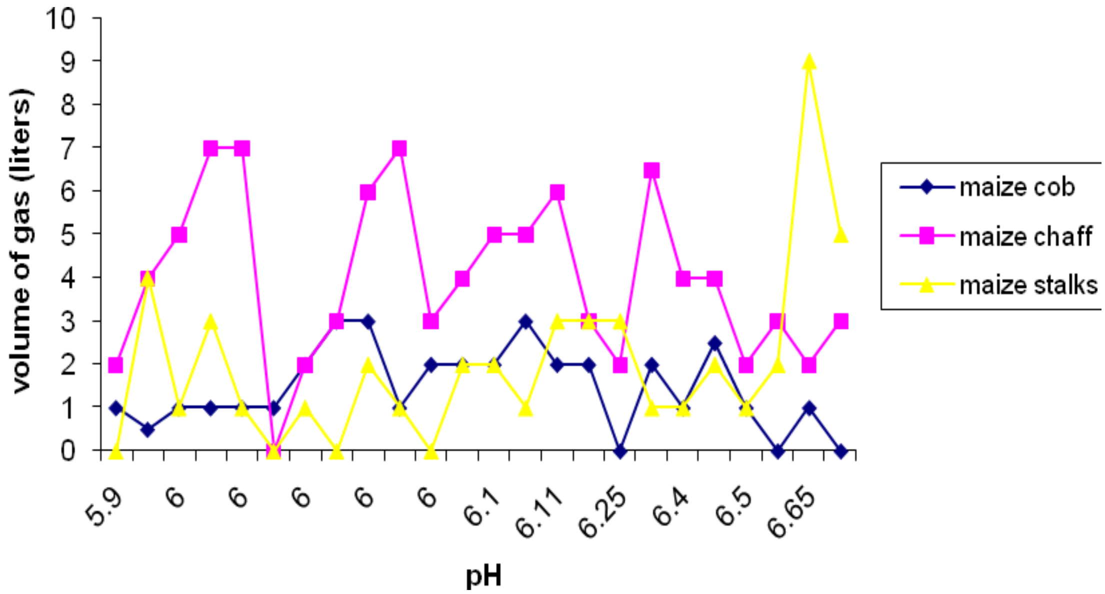

Figure 4. Effects of pH on volume of biogas produced during anaerobic digestion.

Table 4. Volume of biogas generated by the maize wastes.

Sample	Volume (litres)	Flammable (day)
Chaffs	89.5	10^{th}
Cobs	35	14^{th}
Stalks	44	12^{th}

to a decrease in the pH of the wastes. The highest concentration of microbial population was recorded in maize chaff digester. This portrays the chaffs as being more nutritious than the other two wastes. This view can be substantiated by comparing Tables 2 and 5 together.

Composition of the gas generated

Laboratory characterization of the biogas generated shows that biogas from maize chaffs produced 67.25% CH_4. This was followed by stalks that generated 66.30% CH_4 and maize cobs that yielded 66.20% CH_4. Maximum N_2 yield was recorded in maize cobs waste and this apparently explains why it was the last among the three to be combustible. Table 6 shows the composition of the biogas obtained by the different samples. A 0.4% N_2 content in maize chaffs slurry, made the most anaerobic environment among the samples.

Identification of bacteria

Among the bacteria that were isolated during fermentation was *Bacillus subtilus*. During isolation, the colonies when viewed under the microscope appeared to be rod shaped, arranged in chains and had a central spore. It was gram-positive and appeared purple. It was suspected to be *B. subtilis*. This bacterium is mainly found in the hydrolysis and acidiogenesis stages of anaerobic digestion of organic waste (Eze and Agbo, 2010). Another colony identified appeared to be singularly dispersed, rod shaped, gram-negative and appeared red when viewed under the microscope. This organism displayed the characteristics of *Escherichia coli*. It is the common organism that is known to be present during acidiogenesis.

Another isolate displayed the same characteristics like *E. coli* but it has a cocci shape and was thus suspected to be *Aerobacter aerogens*. One of the organisms appeared blue-green when viewed without a microscope. It was a gram-negative bacteria, rod shaped, singularly dispersed in arrangement and had a pink colour when viewed under the microscope which identified it as *Pseudomonas aeruginosa*. This organism is found to be one of the predominant organisms found in the acidiogenesis stage of anaerobic digestion. Another organism found to be oval in shape and purple in colour when viewed under a microscope was identified. This organism displayed the characteristics of *Clostridium* spp. which is a predominant bacterium in the acetogenesis stage of anaerobic digestion. This organism, which is gram-positive and grows at 37°C, can catabolize higher fatty acids to yield hydrogen and acetic acid. The following, are bacteria species isolated from the three different samples during the period of digestion,

For the maize chaff, the organisms isolated include *B. subtilis*, *E. coli*, *P. aeruginosa* and *A. aerogens*.

For the maize cobs, the following were isolated: *B.*

Table 6. Composition of biogas generated from three maize waste samples.

Component	Cob	Chaff	Stalk
Methane (%)	66.2	67.25	66.30
Nitrogen (%)	10.7	9.40	8.10
Carbon dioxide (%)	21.4	22.20	23.00
Oxygen (%)	0.7	0.4	0.6
Other gases (%)	1.1	0.75	2.0

Table 5. Total viable count at intervals of digestion.

Day	Chaff (cfu)	Stalks (cfu)	Cobs (cfu)
0	3.4×10^{-2}	7.4×10^{-2}	7.8×10^{-2}
9	1.2×10^{-2}	3.7×10^{-2}	2.0×10^{-2}
16	1.0×10^{-2}	2.3×10^{-2}	1.8×10^{-2}

subtilis, *E. coli*, *A. aerogens* and *Clostridium* spp*.*

For the maize stalks, the following were isolated: *B. subtilis*, *E. coli* and *A. aerogens*.

Other organisms found to be common in all the samples were the fungi species*.* One of fungi was suspected to be *Candida tropicalis* because it showed a gram-positive characteristic and appeared to be spherical in shape, clustered in arrangement and purple in colour when viewed under a microscope. *Aspergillus niger* which is one of the common species of the genus *Aspergillus* was also identified. Under the microscope, this organism was found to form yellowish colonies with black spots. Results obtained from the microbial analyses support the earlier work of Garba (1999) who reported that the presence of *A. niger* in maize wastes blended with maize leaves.

Conclusion

This study has shown that anaerobic digestion technique is a viable option for combating environmental pollution in urban areas in Nigeria where accumulated maize wastes have continued to pose a serious challenge to Sanitary and Waste Disposal Authority. It was observed that both maize chaffs and stalks have greater potential for biogas production than the cobs. Finally, it was also observed that temperature of the waste slurries in the digesters have no significant effect on biogas generation from the maize wastes in Nigeria where mesophilic temperature prevails all the year round.

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