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GENERATION OF BIOGAS FROM SEGREGATES OF MUNICIPAL SOLID WASTES IN JOS, NIGERIA

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ABSTRACT

A study was carried out to explore the amount of biogas that could be produced using segregated portions of municipal solid wastes (food residue, leaves, paper and a mixture of the three segregates) in Jos city, Nigeria, as substrates. The segregates were mixed with water and cow dung as inoculums, in the ratio of 3:3:1 and subjected to anaerobic digestion using a laboratory-biogas generation system set at 37^{o}C for a period of 25 days. The initial and final pH values of the substrates were recorded. The amount of biogas generated was measured by the method of downward displacement of water from a measuring cylinder. Total plate and methanogenic bacterial counts were taken prior to, during and after fermentation respectively. The bacteria associated with the wastes were cultured on nutrient agar and modified methanogenic agar medium, enumerated, isolated and then characterized using standard bacteriological techniques. Microbial succession during the fermentation process of biogas production was determined. The results show that all the substrates demonstrated potentials for biogas production with leaves generating the highest volume of biogas. The volumes generated by each segregate were 996cm^3, 52cm^3, 36cm^3 and 24cm^3 for leaves, food residue, mixture of segregates and paper respectively. The microorganisms isolated include *Staphylococcus aureus, Streptococcus spp, Escherichia coli*, *Clostridium spp, Methanococcus spp* and *Methanobacterium spp*. The results on the microbial succession study indicate that *Streptococcus spp, Clostridium spp, Escherichia coli, Methanobacterium spp* and *Methanococcus spp* were the most active organisms involved in the biodigestion/biogas generation process. It can be concluded from the study that municipal solid wastes are a potential energy source for biogas generation that could be optimized at industrial scales.

KEY WORDS: Municipal solid wastes, segregates, biogas, fermentation, microbial succession.

INTRODUCTION

The amount of solid wastes in urban cities of developing countries such as Nigeria, has witnessed an increased level due particularly to population explosion, increased agricultural activities and the growth of industries (Odejimi and Udotong, 2005). Municipal solid wastes are made up of household garbages, market, industrial and agricultural garbages as well as wastes due to other activities carried out by man in urban centres. These wastes, which in a study conducted by Egbere*, et al.* (2002) on municipal solid wastes in a slum of Jos metropolis, involved both biodegradable and non-biodegradable bulks such as leaves, food processing wastes and newspapers as the major classifiable biodegradable segregates. The study showed the wastes as not only creating unpleasant odours to environment, but harbouring high levels of pathogenic bacteria of public significance, including Escherichia *coli* of *Klebsiella, Shigella, Proteus species* and *Staphylococcus aureus and as well serving as* breeding spots for disease vector-insects and rodents.

Biogas is a mixture of colourless, inflammable gas containing methane (CH_4), carbondioxide (CO_2) and some traces of nitrogen, hygrogen sulphide and oxygen. The economic prospect of biogas technology in Africa is great because of the availability of raw materials such as animal, human, agricultural and industrial wastes. In biogas production waste such as cow dung and human faeces can be used as inoculum in the production of biogas. Biogas production will not only serve as a waste disposal unit but also as a source of employment as huge amounts spent on waste disposal can be conserved for other purposes.

Biogas has offered an appreciable level of energy and high quality fertilizer to man and has received strong advocacy as an alternative energy source (Odejimi Udotong, 2005). Fuel consumption rate within a nation now represents its index of development and improved standard of living. The world's concern is the rate of depletion and exhaustion of fossil fuel reserves. This is because the rate of formation is not commensurate with that of consumption. With this, nations struggle for the scarce available fossil fuels thereby stimulating researchers to look for alternative energy sources such as biogas (Garba and Sambo, 1992)

The fuel value of biogas depends on the methane content of the gas. A gas containing 65% CH_4]

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and 35% CO_2 has a fuel value of 24mJ/m^3 since pure CH_4 has a fuel value of 37mJ/m^3 which is half the heating value per volume of gas. An amount of $1m^3$ of biogas is equivalent to 2kg fuel wood, 0.6 liters kerosene, 0.5 liters gasoline and 0.4 liters diesel. $1m^3$ can be used for cooking three meals for three persons and also for generating electricity. (1.25 kW of electricity could be generated from $1.0m^3$ of biogas) (Von-Buren, 1980).

Biogas technology has been well documented (Itodo and Kucha, 1997) but little to nothing has been done to apply the technology for effective utilization of solid wastes in Nigeria.

Biogas technology has been used extensively throughout rural china and India for more than 50 years. Other countries including Nepal, Vietnam and Costa Rica are currently engaged in biogas production and massive utilization.

It is estimated that facilities for biogas production exists in over two million households in India and one of it's pioneers is Ram Bux Singn (Brown and Tata, 1994). In Columbia experiments with diesel have been carried out on engine generator sets partially fueled with gas. It demonstrated that biogas could be used to power the generation of electricity reducing cost by 40%. In Rwanda, the Kigali institute of science and technology developed and installed large scale biogas plants at prisons to treat sewage and provide gas for cooking. A number of African countries are also involved and Latin American countries too are currently engaging in biogas production (Breag Chittenden, 1979)

The economic prospect of biogas technology in tropical Africa is great because of the large availability of raw materials (Breag and Chittenden, 1979). The process of biogas production is non-polluting. The poor urban waste management problem, high cost of living, unpredictable energy supply, high cost of waste management and daily increasing cost of fertilizer has made biogas technology an appropriate choice for a country like Nigeria. It will not only serve to dispose wastes, but also as a source of employment. (Odejimi and Udotong, 2005)

Exploitation of animal dung for production of biogas in Nigeria is still in it's infancy. The pioneer biogas plants were a 10m3 biogas plant constructed in 1995 by the Sokoto Research Centre (SERC). In Zaria, a $18m^3$ biogas plant was constructed in 1996 and at Ojokoro Ifelobun piggery in Lagos, a biogas plant was built by the Federal Institute of Industrial Research, Oshodi (FIIRO), Lagos (Abubakar, 1990 and Zuru *et al*., 1998)

Approximately 70% of Nigeria's 140 million people live in areas where no formal waste management systems are in place. A recent study assessed Nigeria's biogas potential (minimum value) from solid wastes and livestock excrements and it revealed that in 1999, Nigeria's biogas potential represented a total of $1.38x10^9m^3$of biogas per year, equivalent of 4.81 million barrels of crude oil. The amount of solid waste generated in Nigeria is steadily increasing as a result of population explosion and the continual growth of industries and agricultural practices (Oke *at al*., 2007). Governments and industries are on the lookout for technologies that will allow for more efficient and cost effective waste treatment.

Biogas technology has been well documented but little has been done especially in Nigeria regarding the conversion of the vast amount of municipal solid waste available into the gas. This study was therefore, designed to explore the possibilities of producing biogas at the laboratory phase using various segregates of municipal solid waste and to isolate and identify microorganisms associated with the laboratory generated biogas

MATERIALS AND METHODS

Experimental Design

The experimental design used for the laboratory production of biogas involved the use of various segregates of municipal solid wastes and cow dung which served as an inoculum. The design is shown in the Table below;

Table 1: Experimental design for the laboratory production of biogas from municipal solid wastes

	Food Residue	Leaves	Paper	Mixture
Water (L)	300	300	300	300
MSW (g)	300	300	300	300
Cow dung (g)	100	100	100	100
Total	700	700	700	700

Key: MSW - Municipal Solid Waste

Sample Collection

Municipal solid wastes were collected from the central waste dump at the custody of Jos Metropolitan Development Board (JMDB) in Jos. In the laboratory, the wastes were air-dried and sorted into the different segregates (food residue, leaves and paper). The segregates were then crushed into fine particles using a mortar and pestle. Slurry of each segregate was prepared in the ratio of 3:3:1 containing the segregate, water and fresh cow dung respectively. The fresh cow dung was collected from the central abattoir market, Jos, in a tightly sealed sterile bottle.

Formulation and preparation of Modified Methanogenic agar Medium.

The medium used for isolating bacteria with potentials for production of biogas was modified after the methanogenic medium as described by Uzaezuoke *et al*., 1998). Components used in the formulation of the Modified Methanogenic Agar Medium in 250 mls of distilled water were yeast extract (3.0g),agar agar (8.0g), calcium chloride (0.2),ammonium sulphate (1.3g), magnesium sulphate (0.5), sodium chloride (1.3g), folic acid (0.5g), vitamin B12 (0.6g), pyrodoxine hydrochloride (0.7g) and cow dung (1.5g)

Cultivation, enumeration and Characterization of Bacterial isolates associated with the municipal solid waste biodigestion

The various samples of the waste samples were cultivated in nutrient agar and the modified methanogenic agar media at 37 C for 24 to 48 hours in anaerobic jars. The colonial growths were enumerated using digital colony counter. The colonial morphology, gram staining, and biochemical characteristics of the various purified isolates were studied according to methods described by Fawole and Oso (1988) and Cheesbrough, 2005)

Production of biogas from solid wastes

The prepared slurry was placed in each of the four biodigester systems in the ratio of 3:3:1 of the respective segregates, water and cow dung in a water bath set at 37^{o}C. The inlet of each biodigester was tightly fitted to prevent the entry of oxygen using glass delivery tubes attached to polyvinyl chloride tubes (PVC tubes) of length 50cm. The unattached end of the PVC tube was channeled to an empty Buchner flask via a straight glass delivery tube through the cork. The Buchner flask was used to prevent the suck back of water into the biodigester during the production of biogas which could lead to a halt in the process. A second PVC tube was attached to the empty Buchner flask. The unattached end of the PVC tube was then fitted with an L shaped delivery tube and positioned under an inverted measuring cylinder filled with water trough. The measuring cylinders were firmly held using retort stands. The rate of downward displacement of water in the measuring cylinder served as a measure for determining the amount of biogas generated. Air tightness was made secured by the use of masking tapes and occasional stirring of the biodigester was done to avoid scum formation in the improvised biodigester. The experimental set up was left for 25 days and a daily record of the amount of gas produced was taken.

Identification of Isolate

The bacteria isolates were identified based on their Gram reaction and biochemical test.

3colony of the test organism was smeared on it using sterile wire loop. The smear was then heat fixed. The smear was covered with crystal violet for a minute and washed off, Lugol's iodine was added for another minute and (Cheesebrough, 2005)

Cultivation, Isolation and Identification of Bacterial isolates

Using the composition below a Modified Methanogenic Agar Medium was developed in the laboratory to simulate the standard methanogenic agar as described by Uwaezuoke (1998). The various components used in the production of the medium were as shown below;

The components used in the formulation of Modified Methanogenic Agar Medium (for 250mls) were yeats extract (3g), agar agar (8g), calcium chloride (0.2g), ammonium sulphate (NH_4SO_4) (1.3g) yeast extract (3g), agar agar (8g), calcium chloride ($Cacl_2$) (0.2g), ammonium sulphate (NH_4SO_4) (1.3g), Magnesium sulphate ($MgSO_4$) (0.5g), sodium chloride (Nacl) (1.3g) folic acid (0.5g), vitamin B_{12} (0.6g), pyridoxine hydrochloride (0.7g) and cow dung (1.5g)

Other organisms were cultivated on conventional Nutrient agar and Blood agar media. The various bacterial isolates were repeatedly subcultured and subjected to morphological, microscopic and biochemical characterization following the methods described by Cheesbrough (2005) and Egbere (2008).

RESULTS

The result on Table 2 shows the pH values of various segregates of municipal solid wastes before and after fermentation. The results show that there was a general decrease in the pH values with the paper waste yielding the highest percentage decrease in the pH value, and the mixture yielding the lowest.

The results on table 3 shows the cumulative volumes of biogas produced from different categories of municipal solid wastes. The results show that leaves produced the highest amount (996 cm^3), food residue (52 cm^3), the mixture of segregates (36 cm^3) and paper (24 cm^3) respectively. Table 4 depicts the total plate and methanogenic counts of solid wastes during and after fermentation. Leaves had the highest number of microorganisms during fermentation and there was a general increase in the number of microorganisms during fermentation. The result in Table 5 shows a pattern of bacterial succession during the production of biogas. The most active bacteria involved in pre-digestion process were *Staphylococcus aureus* and *Clostridium* sp having a prevalent occurrence of 100% each while organisms prevalent during the process of digestion process were *Staphylococcus aureus Methanococcus* and *Streptococcus* sp respectively. *Methanobacterium* and *Methanococcus* species were predominant at the final stage of the biogas production process.

Table 2: **Changes in pH values of the various segregates of municipal solid wastes.**

Sample	Food Residue	Leaves	Paper	Mixture
Duration of fermentation (days)	8	23	9	17
Initial pH	7.5	7.7	8.4	7.9
Final pH	6.7	6.9	7.2	7.4
Percentage Decrease in pH	10.66	10.38	14.28	6.32

Table 3: **Cumulative volumes (cm^3) of biogas produced in the laboratory using different categories of municipal solid wastes as substrates**

Waste Category Days	Food Residue	Leaves	Paper	Mixture
1	-	29	-	-
2	-	129	-	-
3	-	247	-	-
4	5	370	-	6
5	14	495	-	10
6	34	596	-	16
7	40	644	-	25
8	44	706	-	25
9	46	770	-	25
10	52	832	-	27
11	52 *	900	2	27
12	52	918	7	30
13	52	930	14	32
14	52	938	21	33
15	52	945	21	33
16	52	953	22	34
17	52	962	22	34.5
18	52	966	23	35
19	52	972	24 *	35
20	52	978	24	36 *
21	52	985	24	36
22	52	991	24	36
23	52	996 *	24	36
24	52	996	24	36
25	52	996	24	36

Key: - = no gas production, * = Optimum biogas yield

Table 4: **Total plate and methanogenic counts in segregates of municipal solid wastes during and after fermentation.**

`Sample	Food Residue		Leaves		Paper		Mixture	
	NA	MMAM	NA	MMAM	NA	MMAM	NA	MMAM
Before fermentation	$1.5x10^3$	-	$1.06x10^4$	-	$1.3x10^4$	-	$1.05x10^4$	-
During fermentation	$1.9x10^2$	$6.3x10^{42}$	$1.9x10^5$	$5x10^3$	$8x10^3$	$9x10^2$	$1.8x10^3$	$8x10^2$
After fermentation	$1.4x10^3$	4.7x10	$1.3x10^3$	$2.1x10^4$	$3x10^3$	$4x10^2$	$2x10^2$	$7x10^2$

Key: NA = Nutrient agar, MMAM = Modified Methanogenic Agar Medium

Table 5: Succession of bacterial isolates in the Municipal solid waste segregates during biogas production

Isolates	*Staphylococcus aureus*			*Streptococcus spp*			*E.coli*			*Clostridium spp*			Methanobacterium Methanococcus *spp*			*spp*
Samples Is. No	B	D	A	B	D	A	B	D	A	B	D	A	B	D	A	
Food residue	+	+		+	+	-	+	-	-	+	+	+	-	-	+	9
Leaves	-			+		+	-	+	+	+	+	+	-	+	+	12
Paper	+	+	+				-	-	-	+	+	-	-	-	-	5
Mixture	-			-		-	+	+	-	+	-	-	-	-	+	6
Occurrence(%)	+	+	+				50	50	25	100	75	50	0	25	75	
	-			-	+	-										
	+	-	-	50		75										
	100	75	0	50												

KEY: + = Present, – = Absent, B - Before fermentation, D - During fermentation, A – After fermentation respectively, Is. No – Number of bacterial isolate

DISCUSSION

There was a general decrease in the pH values of each segregate (Table 1) of municipal solid wastes. Paper had the highest percentage decrease in pH (14.28%) while the mixture of the wastes had the lowest (6.32%). The decrease in pH values is obviously due to the acid production, a second stage of biodigestion (acidogenesis) in the production of biogas. The pH values fell within the optimum pH range as reported by Okeke (1986) for the production of methane.

Results on the cummulative volumes of gases produced by each segregate of municipal solid wastes

(Table 2) shows the leaves having the highest amount of gas (996cm^3) generated within 23 days. Food residue generated 52cm^3 within 8 days, the mixture (36cm^3) within 17 days and paper generated the lowest (24cm^3) within 9 days.

The production of more gas in leaves was observed to be due to the three favourable factors consisting of carbon/Nitrogen ratio, the longer retention time and the amount of available cellulose nutrient which has over the other segregates. Leaves are known to have a high carbon content due to cellulose, so that microorganisms present within the digester tend to use up carbon 30-35 times faster than they convert nitrogen (Steadman, 1975), thereby yielding more gas. It can also be attributed to the presence of indigenous microorganisms associated with plant surfaces such as the roots (Rhizoplane Flora) and the leaf (Phylloplane Flora) (Egbere, 2008). It was observed that a methane yield was generally higher in leaves than in stems of *Ipomoea fistulosa* as substrates (Ramasamy *et al*., 1997). High availability of nutrients makes microorganisms more active thereby depleting the nutrients and producing gas at a higher rate.

Less biogas production in food residue and the mixture of the segregates could be attributed to the presence of oils and fats in the residues which act as inhibitors to biogas -producing organisms and could lead to scum formation (Oke *et al*., 2007).

The results on the total plate and methanogenic counts (Table 3) show that there was a general increase in the number of microorganisms during fermentation and a decrease after fermentation. Leaves had the highest population of microorganisms. It indicates that the organisms grew at an exponential or logarithmic rate by utilizing nutrients at their disposal to enmass themselves before producing the gas. This continued until the nutrients were used up resulting in a decline in the number of microorganism at the final phase of the process.

Microbial succession of microorganisms (Table 4) indicates the active microorganisms involved in biogas production. They include: *Streptococcus spp*, *Staphylococcus aureus*, *Escherichia coli*, *Clostridium spp*, *Methanobacterium spp* and *Methanococcus spp*.

CONCLUSIONS

The main contributions to scientific knowledge from the results of this study can be summarized as follows: different segregates of municipal solid wastes can be used independently for the generation of biogas. Secondly, the active bacterial species present during biodigestion include *Clostridium spp*, *Streptococcus spp*, *Escherichia coli*, *Methanobacterium spp* and *Methanococcus spp* and finally, leaf liter seeded with cow dung has superior potential for biogas production over other segregates used.

RECOMMENDATIONS

The following recommendations could be made based on the results obtained. Pilot studies should be carried out using leaf liter seeded with cow dung as a substrate to produce biogas in large quantities. Secondly Methanogenic bacterial involved in biogas production should be isolated and characterized to species and strain levels and then used selectively for biogas production.

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