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Investigation of the biogas production potentials of Bambara nut chaff (*Vigna Subterranea*)

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ABSTRACT

An investigation of the biogas production potentials of Bambara nut chaff (Vigna Subterranea) (BNC) was carried out. The waste was charged into a metal prototype digester of 50L capacity in a ratio of 2:1 of water to waste, under mesophilic temperature range of 24° - 37°C and within a retention period of 22 days. Results obtained showed that the BNC had a cumulative biogas production of 4.04 L/kg. slurry and mean biogas yield of 0.18± 0.09 L/kg. slurry. The onset of gas flammability took place on the 10th day though it discontinued after five days. The gas production also stopped after 19 days (giving effective retention time of 19 days). The result of the microbial total viable count (TVC) showed zero count at the end of the digestion showing that the microbes died. Overall results indicate that Bambara nut chaff has the potentials to generate biogas but would require some form of treatment to optimize its biogas production.

Keywords: Bambara nut chaff, biogas production, flammable biogas production, biogas yield, biowaste.

INTRODUCTION

The rising cost of fossil fuels, its erratic supply to the end user and the prediction that current reserves may not last more than three decades has necessitated the need for alternative sources of energy. In the developing countries, majority of the populace are rural and sub-urban dwellers without access to gas for cooking and electricity [1]. This has contributed immensely to the rapid rate of deforestation and desert encroachment. The establishment of biogas plants in these communities is expected to greatly ameliorate these problems and help preserve the environment [2]. Biogas is a mixture of gases consisting mainly of methane (50 – 70%), CO_2 (20 – 40%) and traces of other gases like CO, H_2S, NH_3, O_2, H_2, N_2 and water vapour etc. [3]. Generally, the production of this gas involves a complex biochemical reaction that takes place under anaerobic conditions in the presence of highly pH sensitive biocatalysts that is mainly bacteria. Three important nutrient polymers such as carbohydrates, proteins and lipids are required for the reaction to take place and these are broken down by the anaerobes in a three stage digestion process given by the reaction equation below;

$$(C_6H_{10}O_5)\,n + 2H_2O \rightarrow n\,(C_6H_{12}O_6) \quad - \text{Hydrolysis}$$
$$n\,(C_6H_{12}O_6) \rightarrow n\,CH_3COOH \quad - \text{Acidogenesis/ Acetogenesis}$$
$$3n\,CH_3COOH \rightarrow n\,CH_4 + CO_2 \quad - \text{Methanogenesis}$$

Methane has a heating value of 22MJ/m^3 (15.6MJ/kg) [4]. Consequently, biogas can be utilized in all energy consuming applications designed for natural gas. The content of biogas varies with the material being decomposed and the environmental conditions involved [5]. Potentially, all organic waste materials contain adequate quantities of the nutrients essential for the growth and metabolism of the anaerobic bacteria in biogas production. However, the chemical composition and biological availability of the nutrients contained in these materials vary with species, factors affecting growth and the age of the animal or plant [6]. Biogas technology amongst other processes (including thermal, pyrolysis, combustion and gasification) has in recent times also been viewed as a very good source of sustainable waste treatment /management as disposal of wastes has become a major problem especially to the third world countries [7]. The effluent of this process is a residue rich in essential inorganic elements like nitrogen and phosphorus needed for healthy plant growth known as biofertilizer which when applied to the soil enriches it with no detrimental effects to the environment [8]. Various wastes have been utilized for biogas production and they include amongst others; animal wastes [9], [10], plant wastes [2], [11], Industrial wastes [12] food processing wastes [13] etc. Further researches on many locally available wastes as potential feedstock for biogas production are still on going. Bambara nut chaff is one of such locally available wastes viewed as a potential feedstock. Bambara nut chaff is obtained from Bambara nut (*Vigna subterranea*) which is grown in the Northern part of Nigeria and other parts of West Africa like Cameroon [14]. It is largely consumed in the north eastern part of Nigeria. The processing leaves the chaff which is either used as blend for poultry feed by some people or thrown away, thereby constituting a nuisance to the environment. This study was undertaken to investigate the biogas production potentials of Bambara nut chaff (BNC) in terms of biogas yield, onset of gas flammability and effective retention time.

MATERIALS AND METHODS

The Bambara nut chaff used for this study was obtained from a local processor of Bambara nut flour (a staple food in the north eastern part of Nigeria). The digester used is a metal prototype digester of 50L capacity constructed at the National Center for Energy Research and Development, University of Nigeria, Nsukka (Fig. 1) and the study was carried out between August and September, 2008 at the same Research Institute. Nsukka is located 6.9°N and 7.4°E and 445m above sea level. Other materials used include; top loading balance (50kg capacity, "Five Goats" model no Z051599), water trough, graduated transparent plastic bucket for measuring volume of gas production, thermometer (-10-110°C), digital pH meter (Jenway, 3510), hosepipe, biogas burner fabricated locally for checking gas flammability.

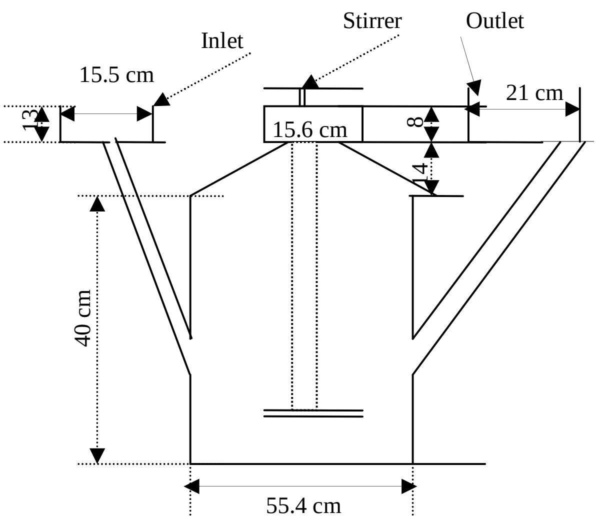

Fig. 1: Schematic diagram of the biodigester

Digestion Studies

Experimental Set- up

BNC (12kg) was weighed and mixed with water (25kg) giving a water to waste ratio of approx. 2:1. The moisture content of the waste determined the water to waste ratio. The slurry was then charged into the 50L metal prototype digester. The waste slurry was charged up to ¾ of the digester leaving ¼ head space for gas storage and collection.

The digester content was stirred adequately and on a daily basis throughout the retention period to ensure homogenous dispersion of the microbes in the mixture. Gas production measured in dm^3/Total mass of slurry (TMS) was obtained by the downward displacement of water by the gas.

Analyses of Wastes

Physicochemical Analyses

Ash, moisture and fiber contents were determined using AOAC (1990) method [15]. Fat, crude nitrogen and protein contents were determined using Soxhlet extraction and micro-Kjedhal methods described in Pearson (1976) [16]. Carbon content was carried out using Walkey and Black (1934) method [17], Energy content was carried out using the AOAC method described in Onwuka (2005) [18], while Total and Volatile solids were determined using Renewable Technologies (2005) method [19]. Total Carbohydrate was determined by difference (Onwuka, 2005) [18].

Biochemical Analysis

The pH of waste was monitored using digital pH meter (Jenway, 3510). Ambient and slurry temperatures were also monitored and recorded daily using liquid in glass thermometer (-10 to 110^oC).

Microbial Analysis

Microbial Total viable counts (TVC) for the waste slurry was carried out to determine the microbial load of the sample using the modified Miles and Misra method as described in Okore (2004) [20]. This was carried out at four different periods during the digestion; At the point of charging the digester, at the point of flammability, at the peak of gas production and at the end of the retention period.

Statistical Analysis

The standard deviation was carried out using SPSS 15.0 version.

RESULTS AND DISCUSSION

The experiment was carried out under mean ambient temperature range of 24°C-31.5°C and influent temperature range of 27°C-37°C within a 22 day retention period. Daily biogas production of the waste is graphically represented in Fig.2. Biogas production commenced within 24hr of charging the digester. The onset of gas flammability took place on the 10th day, however, after five days from then, the flammability ceased even though gas production was still on. A biogas that will satisfy the basic need of cooking and lighting must be combustible. If it flames, it means that the methane content is at least 45%. If it does not flame, it means that the methane content is less than 45% and has higher content of CO_2 and other gases [21]. The result of the physicochemical properties of the waste is shown in Table 1 while the cumulative and mean biogas yield is shown in Table 2. The result in Table 2 shows that the effective retention period was 19 days since the overall biogas production stopped after the 19th day. This indicates that the waste had a problem and would require treatment to extend both the retention time and flammable biogas production. The result of the physicochemical properties (which is the intrinsic quality the waste possesses for effective biogas production) shows that the waste possessed adequate nutrients (fat and carbohydrate). The Energy and volatile solids content (which is the biodegradable portion of the waste) were equally adequate. The crude protein and nitrogen levels were high indicating that the waste would be a very good biofertilizer providing adequate nitrogen to the soil. However, the high protein and nitrogen content may have aided the formation of ammonia gas which if in excess becomes toxic to the system. Toxicity from ammonia is known to affect biogas production to the point of stopping gas flammability [22], [23]. This may have contributed to the cessation of the gas flammability. The properties that were also not found in adequate measures to effect reasonable biogas production were the carbon to nitrogen (C/N) ratio and the pH. The C/N ratio of any waste affects the growth of biocatalyst and has been given to be optimal in the range of 20-30: 1 [24]. This is because the bacteria that convert wastes to biogas take up carbon 30 times faster than nitrogen. Since the C/N ratio of this waste was much lower than the optimum range, it again indicates that the waste would require some form of treatment or blending with other wastes having higher C/N ratio to shore it up to the required level. The table further shows that the pH of the waste was low at the point of charging the digester and even decreased after two weeks. The microbes that convert wastes to biogas are highly pH sensitive and survive optimally in the range 6.5-8.0 [25]. This again underscores the importance of pH in anaerobic digestion. The result of the microbial total viable count (TVC) (Table 3) indicates that the microbes actually died and could not survive in the acidic medium. This further confirms that the waste needs treatment/pretreatment for effective and efficient biogas production.

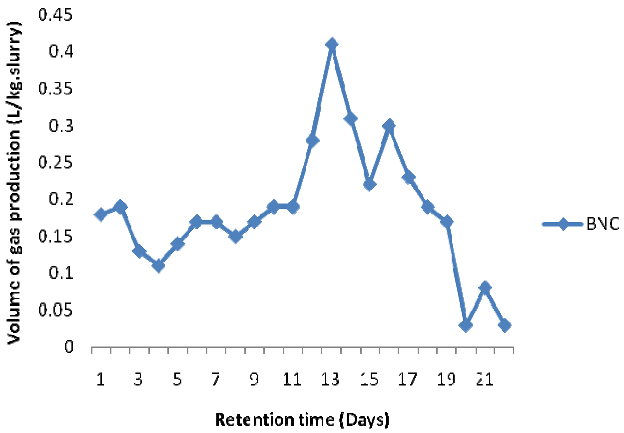

Fig. 2: Daily Biogas Production for BNC.

Table 1: Physicochemical properties of the BNC.

Parameters	**BNC**
Moisture (%)	9.91
Ash (%)	5.6
Crude Fat (%)	3.6
Crude Fibre (%)	17.25
Crude Protein (%)	19.71
Crude nitrogen (%)	3.04
Carbon (%)	45.88
Total solids (%)	90.09
Volatile solids (%)	34.49
Total Carbohydrate (%)	47.53
Energy (Kcal/mol)	3.46
C/N ratio	15.09
pH at Charging	6.45
pH after two weeks	5.34

Table 2: Lag period, cumulative and mean volume of gas production.

Parameters	**BNC**
Lag period (Days)	9
Cumulative volume (dm^3/kg. slurry)	4.04
Mean volume (dm^3/kg. slurry)	0.18± 0.09

Table 3: Microbial Total Viable count (TVC) of the waste slurry (cfu/ml)

Period	**BNC**
At charging	4.20×10^9
At the point of flammability	3.01×10^7
At the peak of production	2.62×10^4
At the end of digestion	0

CONCLUSION

The result of the investigation has shown that Bambara nut chaff has potentials to produce biogas but would require treatment by either blending it with animal wastes or chemically treating it to increase the pH and C/N ratio for effective biogas production, in terms of sustained gas flammability, extended retention time and cumulative biogas yield. The cumulative biogas yield under an effective 19 day retention period shows that when treated, the retention period would be extended and the cumulative biogas yield much higher than the observed quantity.

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