A Comparative Study of Biogas Yield from Various Brewery Wastes and Their Blends with Yam Peels

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Abstract

A study was undertaken to determine biogas yield (% methane) from various local brewery wastes and their blends with yam peels (YP). The wastes investigated were *Kunu* chaff (KC), *Burukutu* (BKT) and spent grain (SG). The wastes were in two blends A and B. The blend A was SG:BKT:KC = 40:30:30 and blend B was SG:BKT:KC:YP = 40:20:20:20. All the waste types and their blends were bio-digested in an anaerobic digester in replicates for 20 days at ambient temperature experiment. The N, TS, VS, C, C:N, pH of the feedstocks were determined by standard methods. The gas yield was obtained by downward displacement of water. ANOVA at $p \leq 0.05$ was used to determine if there was any significant difference in the biogas yield from the waste types. The gas yield were of the order blend B > KC > blend A > SG > BKT > YP. Blend B which had the highest yield of 75.6% had the highest C:N of 27;1 while YP which had the least of yield 52.3% had the least C:N of 10:1.The results obtained indicate good prospects for generation of biogas while managing the wastes generated from various brewing activities in Nigeria both for small- and large-scale applications.

Keywords: Comparative, biogas, local brewery wastes, anaerobic digester, spent grain, yam peels, blends.

1. Introduction

Biogas generally, describes gases released from decomposition of organic matter. Biogas production is through anaerobic decomposition of organic matter [1 – 4]. Biogas production is generally viewed as a two stage process. Such as acid forming and Methane forming stages [5 – 7].

Wastes raise a major environmental concern both industrially and domestically, since proper disposal facilities are not available within the industrial layout of most towns of Nigeria, and even where available, they are costly to run. However, a simple conversion of waste into a fuel can be tremendously useful as renewable fuel source especially for domestic and industrial use. Unlike many other renewable energy sources, biogas is moderately simple and relatively cheap to produce. The expansion of biogas production in Europe and India for instance has resulted in expansion in all related industries leading to job increase [8 – 10]. Biogas production offers an alternate use for food by-products and solves the problem of managing or handling of by-products. It also offers a low cost solution to the problem of waste management and disposal [11, 12].

Biogas is a mixture of mainly methane gas and carbon dioxide gas. Natural gas contain about 90-95% methane while biogas contain mostly 50-75% methane [13, 14]. Organic matter is the major material for biogas production. The second ingredient necessary for biogas production is bacteria [15]. Biogas produced from animal waste at ambient temperature (27 – 40 °C) yields about 55% - 65% CH_4 and 30% - 35% CO_2 and traces of other gases like H_2S and N_2. Biogas is actually a mixture of gases, carbon dioxide and methane [16 – 18].When organic wastes are put in containers isolated from the outside air, conditions arise for anaerobic process. However, as long as there is oxygen inside the container, gas will not be produced. Since slurry also contains aerobic bacteria, the oxygen contained in the slurry is consumed in the aerobic reaction. Once the oxygen is used up, the anaerobic reaction commences, thus there is a time lag between feeding the waste into the digester and production of gas [19 – 23].

Brewery Spent grain is the residue of mash filtration. In Makurdi Nigeria, Benue Brewery PLC generates about 5,000 kg per week. Currently, it finds it difficult to properly manage these waste products thus constituting environmental pollution. *burukutu* (local beer) is an African fermented porridge beverage made from cereals. It is the most popular locally brewed drink and is found all over Nigeria especially in the northern parts. A survey of Makurdi, Nigeria showed that there are more than 37 producers and each is capable of generating a total of 35 – 90 kg of waste per week. Waste from these brew are carelessly thrown around and after decay, constitutes environmental pollution. *kunu*, a non-alcoholic African beverage drink is produced both domestically and commercially which may generate as much as 7 – 30 kg of waste per week on an individual basis. Both commercial and domestic producers of *kunu* get rid of their waste in an unhealthy manner constituting environmental pollution. Yam peels, a by-product of yam tubers processing, are generated in most households especially all over Nigeria where yam and its products are staple food. An average home and restaurant in Makurdi may generate as much as 1 – 8 kg of dried yam peels per week that are not properly disposed. All feed materials consist of a great extent of carbon (C) and also Nitrogen (N). The C/N ratio affects the gas production. C/N ratios of 20:1 to 30:1 are particularly favourable [24 – 26].

The two major products of anaerobic digestion of organic materials of concern here are biogas and spent slurry. Biogas is the more useful of the two, though the slurry is also useful for a few purposes. The rate and total level of biogas yield during anaerobic digestion has been suggested as being the most reliable and easiest means of categorizing digester performance [6, 24].

Biogas is used principally as a fuel. For years the Chinese and the Indians have used biogas as a fuel for cooking and lighting [27 -29]. The success of biogas production units depends on using the resulting methane gas to its maximum benefit. Gas utilization may involve direct use of the total mixture including impurities, or it may involve purification steps to remove carbon dioxide to increase the energy value of gas per unit volume and hydrogen sulphide to decrease corrosiveness of the mixture. The removal of carbon dioxide considerably improves the heating value of biogas from 22MJ/m^3 to 50 MJ/m^3 [14, 30].

There are many advantages of using biogas as fuel. The use of biogas as fuel saves other fuels such as kerosene and coal and eliminates the need to burn other valuable natural resources. Thus, by using biogas instead of fire wood, deforestation and soil erosion is reduced. It is estimated that about 22,425 MJ/m^3 of biogas can replace kerosene oils to an extent of 13,904 million litres. There has not been any reported case of injuries associated with the use and production of biogas [11, 12, 31].

Literature reveal that the use of food material of high carbon-hydrogen greatly improves the yield of biogas per given mass of material. Biogas production from cereals crop show the highest biogas yield in quality. That is a high percentage of methane content of the gas (65-75%) when compared with other food materials or other derivatives of food products [32 – 34].

Anaerobic breakdown of waste occur at temperature between 0 ^{0}C and 69 ^{0}C, but is most rapid between 29 ^{0}C and 41 ^{0}C or between 49 ^{0}C and 60 ^{0}C. Temperature between 32 ^{0}C and 35 ^{0}C has proven most efficient for stable and continuous production of methane. Biogas produced outside this range will have a higher percentage of carbon dioxide and other gases than within this range. Anaerobic digestion will occur within a pH range of 6.8 to 8. The biodegradation fraction of agricultural waste will vary being a factor of how the waste was generated and handled prior to digestion. It has also been found that the substrate should be of consistent quantity within the digester volume for improved biogas yield [35, 36]. The total solid can then be determined using equation1.

$$TS\% = 100 - MC \qquad 1$$

The moisture content of the sample denotes the amount of water that is contained in a material and this is determined by the percentage change of the difference between the initial weight and the weight of the dried product from a hot air oven at about 150 ^{0}C for 2 hours and re-weighing it, as in equation 2.

$$MC\% = \frac{Weight\ before\ drying - Weight\ after\ drying}{Initial\ weight} \times 100\% \qquad 2$$

Determination of volatile solid (VS) involves heating dry matter at 500 ^{0}C to remove organic material as carbon dioxide and determination of chemical oxygen demand, usually applied to low strength waste involving a quantitative chemical oxidation of organic materials [36]. A general method of determining Volatile solid involves using equation 3.

$$VS\% = \frac{Initial\ weight - final\ weight}{Initial\ weight} \times 100\% \qquad 3$$

The retention time of slurry in a digester has a direct relationship with gas yield, digester size, quantity of waste added and removed from the digester and the efficiency of the biodegradation process [33, 37 – 39]. The retention time of the slurry in the digester determines the efficiency of conversion of acid intermediates (which will be bio-converted into gas) produced during the anaerobic digestion process. Different retention times have been recommended for various waste types depending on the digester types and methods of operation.

The quality of biogas produced can be determined using different methods one of such methods is by using the Orsat apparatus [8, 11]. All measurements are usually done at constant temperature and pressure. The percentages of the component gas can be calculated using equation 4.

$$\frac{Final\ volume - Initial\ volume}{Total\ volume} \times 100\% \qquad 4$$

2. Materials and Method

Spent grain (SG) was collected from Benue Breweries Ltd, while chaff of *kunu* (KC), *burukutu* (BKT) and yam peels (YP) were collected from local producers of the drink and restaurants in Makurdi town.
The bio-digester and biogas collecting apparatus were made of a 4.6 l transparent jar with cover, measuring cylinder, valves (PVC), flexible hose of internal diameter of 12.7 mm, sealant glue, 1l plastic bottle, 20 ml syringe, water holding jar and 2.6 liter transparent jar. The bio-digester arrangement is as shown in Plate 1. The gas analysis apparatus is shown in figure 1.

The collected samples were sun-dried for 4 days to constant weight before each of the samples was grounded to fine particles using grinding machine. The moisture content of samples were determined by first weighing the prepared samples and then drying it in a hot air oven at about 150^0C for 2 hours until a constant weight reached. The Meynell method was used to determine volatile and total solids, while the pH of each sample was determined using a glass-electrode pH meter.
All samples were digested in the 4.6 l digester. The sample water ratio used was determined from the preliminary experimental analysis performed. Brewery spent grain (SG), 1:3; *burukutu*, 1:4; *kunu* chaff (KC), 1:4; and yam peel, 1:2. 750 g of each sample were weighed then mixed with water at each ratio. Also SG, BKT, KC and YP were blended in the ratios 40:20:20:20 and mixed with water in the ratio 1:2 and the SG,BKT and KC blends were mixed with water in the ratios 1:3. All these slurries were charged into different digesters of the same capacity. The volume of gas produced was daily taken by measuring the downward displacement of water [3]. A total retention period of 22 days was used. All measurements were done at constant temperature and pressure.

The biogas was collected in a 20 ml syringe and analyzed using equation 4 for the percentage constituent gas. The process was repeated five times for each gas extraction. The percentages compositions of the biogas produce are shown in Table 2. For carbon dioxide, a 400 g/dm^3 solution of Potassium hydroxide solution was used, while 30% by volume of lead acetate solution in 3ml acetic solution was used as reagent to determine the percentage of H_2S. A solution of Alkaline Cuprous Chloride was used in the analysis for carbon monoxide.

3. Results and Discussion

The results of the physicochemical analysis are presented in Table 1. The results of volume of water displaced (measured in ml) on daily basis is as shown in Figure 2 while the average daily biogas yield is as displayed in Figure 3. The results obtained for the gas quality analysis are shown in Table 2. The averages for every two days of the values obtained for the biogas yield was calculated to give the moving averages of biogas produced. This is displayed in the Figure 4.

None of the samples showed evolution of gas for the first day. The KC; SG: BKT: KC and SG: BKT: KC: YP blends showed noticeable activity at the second day. *Burukutu* and *kunu* are already fermented materials and may have already contained necessary bacterium that causes fermentation and hydrolysis of carbohydrates.

From the 5th day, the yield began to steadily increase as the retention period increased which is in agreement with [8]. Most of the samples have the highest yield between the 9th and 11th day as shown in Figure 2. *Kunu* chaff is very viable as its highest biogas yield (723ml) makes it outstanding and seems to be good kick starter of the bio-digestion process. This is due to the high value of C: N ratio, (22.8) and high pH value (6.63) [24, 30, 34].

Table 1 indicate that SG, KC and S G: BKT: KC: Y blend have a high C: N ratio and reflectively have high yield in the biogas produced (817ml) as in Figure 4. This is inconsistent with the report of [33, 39]. It is noted also that the quantity of H_2S produced in samples involving KC are relatively low. On the other hand the additive yam peel have the lowest quantity and quality of biogas produced with about 52.3% CH_4 and a relatively high amount of CO_2 which may be due to high acidity of the sample at the initiation of the experiment. The ANOVA shows that there is a significant variation in the yield of the gas across the samples at 5% significant level as presented in Table 3.

Conclusion and Recommendation

Brew waste have a very high potential for biogas, *kunu* chaff which is a very common domestic waste is the most viable waste for the process of biogas production and yields relatively low H_2S proving less need for further processing. *Kunu* chaff (KC) is good waste for this process and it is very advisable that a blend involving KC always is used because it help speed up the process of bio-digestion and influences the quantity of H_2S produced.

It is also recommended that homes adopt a capacity expanded version of this method of biogas digestion to provide for their energy needs and the same time solve their waste disposal problem especially in rural areas.

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Table 1: Physicochemical Properties of Undigested Samples.

Para-meters	**SG**		**BKT**		**KC**		**YP**		**SG:BKT:KC**		**SG:BKT:KC:YP**	
	U	**D**	**U**	**D**	**U**	**D**	**U**	**D**	**U**	**D**	**U**	**D**
N (%)	1.82	4.78	0.93	1.33	1.10	1.96	2.25	3.25	2.35	2.35	1.13	4.06
TS (%)	67.30	53.03	71.3	59.3	88.00	18.3	73.0	73.0	88.76	24.76	83.81	33.81
VS (%)	14.84	92.33	63.34	69.34	83.81	73.91	79.25	83.25	92.10	94.10	90.01	86.01
CC (%)	47.20	17.20	24.34	13.84	25.13	30.13	21.63	31.63	38.79	37.01	26.84	33.84
C:N ratio	25.90	3.60	15.42	10.41	22.85	15.37	9.61	9.73	16.51	15.74	23.75	8.33
pH	5.30	5.71	5.68	5.18	6.63	6.63	5.21	6.3	5.97	5.07	6.13	5.33
MCt	85.10	86.59	16.10	6.10	41.20	4.20	8.00	8.00	13.43	10.43	19.83	9.83

Table 2: The Percentages of Composition of The Biogas Produced.

Sample / Gas component	SG	BKT	KC (%)	YP	SG:BKT:KC	SG:BKT:KC:YP
CO	9.0	5.8	7.3	11.9	7.1	2.6
CO_2	17.5	30.5	20.7	33.7	23.3	21.6
H_2S	0.8	2.0	0.6	2.1	1.3	0.2
CH_4	67.7	61.7	71.4	52.3	68.3	75.6

Table 3 : ANOVA of the Daily Biogas Yield

ANOVA

Source of Variation	*SS*	*df*	*MS*	*F*	*P-value*	*F crit*
Between Groups	890780	5	178156	4.711087	0.00056	2.286184
Within Groups	4764857	126	37816.33			
Total	5655637	131				

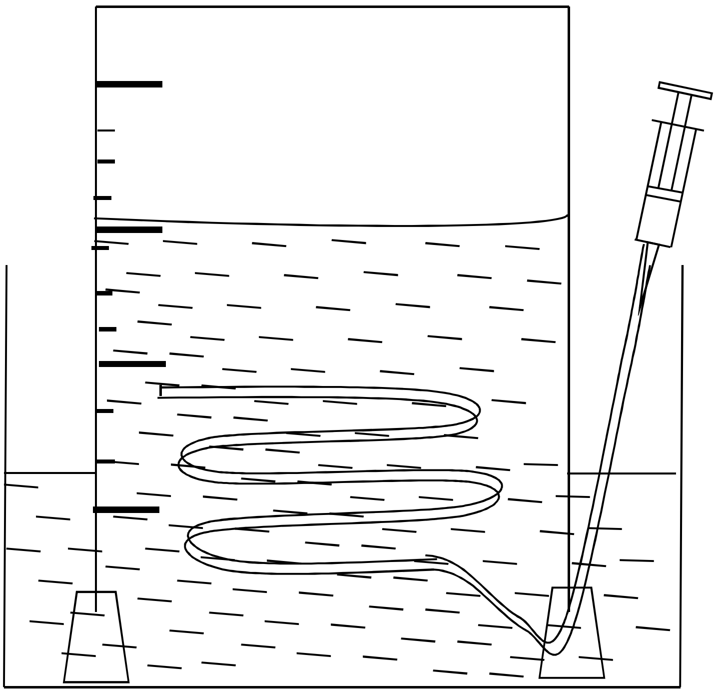

Fig. 1: Schematic diagram of the apparatus used for the biogas quality analysis

Plate 1: Picture of the Laboratory Setup of the Biodigester

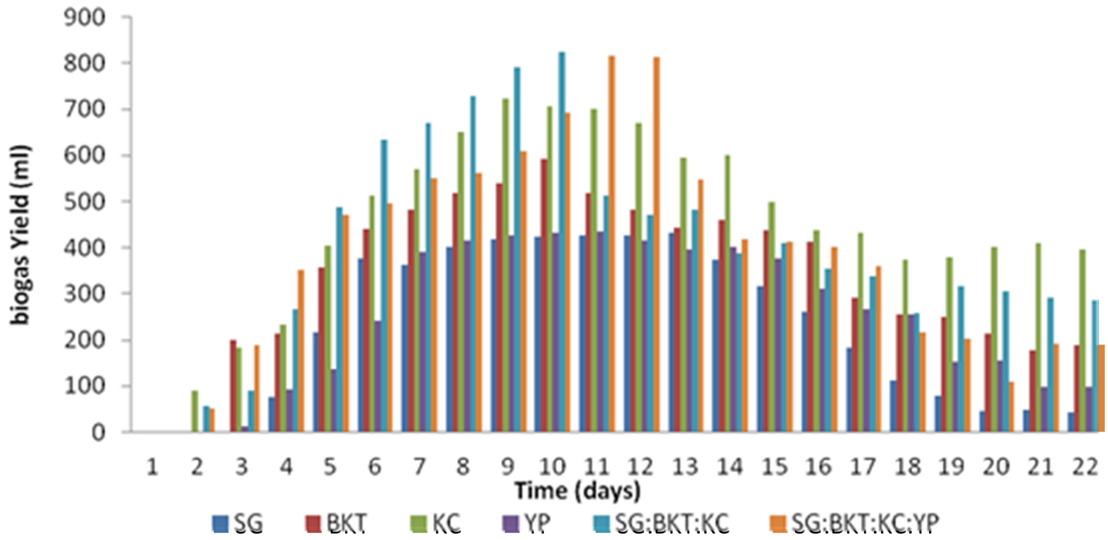

Fig. 2: Histogram of dialy biogas yield.

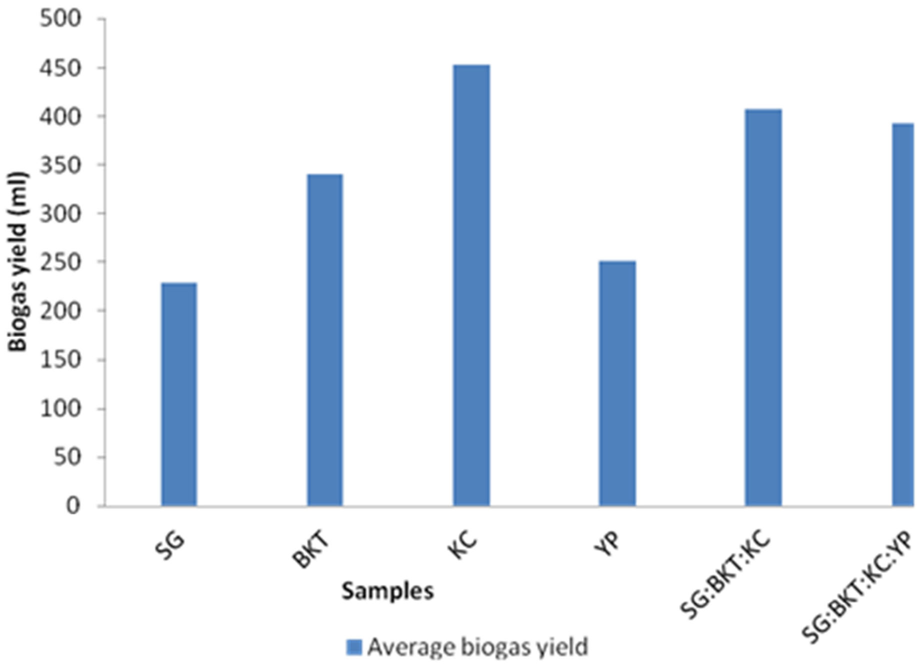

Fig. 3: Histogram of Average Yield

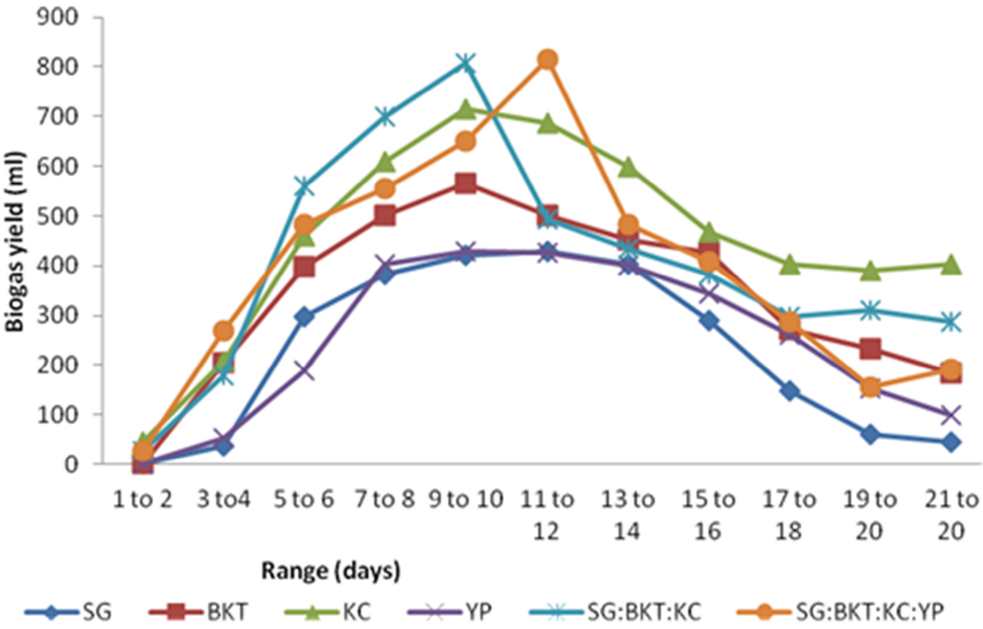

Fig. 4: Rate of Biogas Production with Time