Biogas Production from Rumen, Municipal and Co-Digested Substrates: An Opportunity for Small and Medium Scale Entrepreneurs (SME)

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Abstract

Comparative study of anaerobic digestion of rumen, municipal waste and co-digested feedstock was investigated. 10kg each of rumen, municipal waste and co-digested feedstock each was used in a 30 litres anaerobic digester. The digester was loaded batch wise for 30 retention day runs up to 80% volume of the digester nominal volume. The cumulative biogas production was recorded as 181900, 217350 and 180250 ml/g VS-1 respectively. Methane composition of the various biogas was 56.42, 55.81 and 58.820 % untreated biogas samples. The treated scrubbed water produced a burning gas with methane composition 84.08, 51.54 and 95.518 % respectively for the feedstock. Co-digested substrate does not actually have any significant effect on production and composition of the gas produce. Since waste raise a major environmental concern, these simple steps could be exploited by small and medium scale entrepreneurs (SME), an alternative to convert waste into fuel that can be tremendously useful as renewable fuel source especially for domestic and industrial use.

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1. INTRODUCTION

Despite the availability of many technologically feasible sources of energy generation the Nigerian supply mix is positively skewed in favour of the dominance of thermal and other non-green sources such as fuel wood. For instance, over the period 1989-2000 fuel wood and charcoal accounted for between 32 percent and 40 percent of total energy consumption in the country. Also, current estimates put the proportion of Nigeria's rural population that relies almost entirely on fuel wood to power their cooking and other domestic operations at around 60 percent. It is well documented in literature that this pattern of consumption is not only unsustainable but also environmentally unfriendly. A need therefore exists for the country to seek for better ways of diversifying and improving the composition of its energy source so that it can engender a more efficient supply mix (Hartman et al., 2002). Biogas generally, describes gases released from decomposition of organic matter. Biogas production is through anaerobic decomposition of organic matter (Ward et al., 2008). Its production is generally viewed as a two-stage process; such as acid forming and methane forming stages (Batstone et al., 2002). Waste raises 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. 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 (Cheng et al., 2014 and TDBP, 2013)

Rumen is one of slaughter house wastes that is frequently disposed into drainage system. This waste disposal system causes environmental nuisance, particularly it poses health hazard to humans due to its content of millions of microorganisms and odour. However, rumen may be useful as an activator in producing biogas through anaerobic fermentation, since some of rumen microorganisms are cellulolitic and methanogenic bacteria. Rumen is part of digestion system in ruminants where the microbial fermentation occurs. This fermentation process is similar to that in biogas digester (Abdeshahian et al., 2016). Municipal solid waste (MSW) can be used as substrate for the biogas production; however, not so many plants are utilizing it, due to the problems with the sorting of impurities or due to the problems with the smell. Impurities should be picked away before the waste is entered into the continuous reactor, in order to protect the reactor from physical harm. Great efforts are spent on minimizing the impurities from the municipal solid waste, such as plastic, metal and glass. For municipal solid waste, substrate properties can widely vary depending on its origin of production (Biogas Handbook, 2008). Climate, extent of recycling, collection frequency and cultural practices are also the factors that influence the production and composition of MSW. The municipal solid waste investigated was from the region of Berger junction, Minna while the rumen waste was collected from central abattoir. The MSW sample contained both biodegradable and non-biodegradable materials. The non- biodegradable was sorted out from the mixture collected from waste bin.

2. MATERIALS AND METHODS

2.1 Feedstock Sourcing and Generation: food waste and rumen

10 kg food waste was collected directly from the University cafeteria (Bosso campus). This consisted of assorted food variety such as vegetable, rice, beans, fruits, noodles, wheat/ flower and other food items. 10 kg fresh cow rumen was sourced and collected directly from Minna central abattoir with appropriate pretreatment prior storage and transportation to laboratory for analysis and fermentation/anaerobic digestion experiment. Necessary sampling and analysis was done before and after complete digestion.

2.2 Feedstock Physiochemical Analysis

Before the digestion properly commenced, the following feedstock analysis was carried out.

Carbon nitrogen (C/N) ratio, dry matter content (DM), volatile fatty acid (VFA), total khjedahl nitrogen (TKN), volatile solid (VS), ammonia and ammonium ion, chemical oxygen demand (COD), total solid (TS) and pH. During the commencement of digestion, the AD parameters that was checked included: organic load, operating temperature, capacities, reactor volume, gas quantity, hydraulic retention time, gas composition analysis. Digestate analysis was done to determine its potential for nitrogen potassium and phosphorus content (NPK) fertilizer.

2.3 Anaerobic Digestion

The experimental studies were all conducted in batch bio-digester reactor of 30-litres capacity of compact water plastic material from chemical industry at an ambient environmental condition. The reactor was coupled with appropriate channel for feeding feedstock, stirring and mixing, digestate discharge and biogas collection. The reactor was sealed such that it was air tight and also purged or evacuated of air.

2.4 Biogas Sampling

PVC gas bag was connected to the screw lock valve with gas line turned on. The valve was tightened before the bag becomes over pressurized with gas line turn off, the gas was emptied with repetition of this procedure three times to ensure purging band evacuation of air and impurities contaminant before filling of the sample bag with appropriate biogas product there after transported to laboratory for composition analysis.

2.5 Gas Chromatography Column Analysis and Composition.

The first step for preparation of sample analysis in the laboratory was to conduct appropriate GC calibration. It was done by analyzing samples of premixed H2S standards at 1000, 2000, 3000 and 5000 ppm trice each time, the output result will be displayed on programmed peak simple and this step must be ensured conducted properly prior to sampling to avoid delay in actual sample analysis. For greater sample precision and accuracy, it is recommended that the analysis be done within 8 hours of sample collection. The sample was injected and vapourized onto the GC head column to separate the gas components of sample complex. The sample was always injected with inert or mobile gas called carrier gas (helium). The gas analyzer was calibrated and programmed to measure raw biogas stream in every count run. It measures btu, C1 – C6, N2, CO2, NH3, H2S, water vapour and methane. The most significant reading includes methane (CH4), carbon dioxide (CO2), hydrogen sulphide (H2S), water vapour and nitrogen or ammonia (NH4-N). Table 1 shows the standards used for the GC calibration.

Table 1: Calibration Standard for GC Column Analyzer

Compound	Calibration Concentration
CH4	0 – 100%
C2H6	0 – 25%
C3H8	0 – 25%
i- C4H10	0 – 10%
n- C4H10 + n-C5H12	0 – 10%
CO2	0 – 100%
H2S	10000 ppm
H2O	0 – 100%

Obtained from Kaduna refinery and petrochemical product company, KRPC. Gas laboratory

2.6 Fabrication of Bio-digester Reactor

A mini cylindrical plastic digester (30 litres) was fabricated from pantaker, Minna as the bioreactor for the anaerobic digestion. The reactor was fitted with piping, PVC 32 mm and 25 mm, sealing material of M-seal or waterproof adhesive valves. The scrubber was made of a 2-litre colourless glass material and equipped with a stirrer. Mechanical shaking and vibrating frequency of was 2-10 seconds once daily.

3.0 Results and Discussions

3.1 Methane and CO2 Content

A flammable biogas system must contain at least 45% methane in composition as reported by Ofuefule et al. (2009). The methane content associated with the three samples are summarized in the Table 4.1 showing the content of unscrubbed sample with their impurities. The samples contained 56.42%, 55.81% and 58.82% methane in the manure, municipal waste and the mixture of both respectively. However, these values are lower compared to Alseadi et al. (2008). The difference could be due to the temperature and pressure used by the authors. Contrasting with result obtained by Uzodinma et al. (2011) and Usman et al. () but in range with result reported by Abdulkareem (2005), Nitin et al. (2012), Dieter et al. (2008) and Umar (2014). It was realized the Uzodinma et al. (2011) used fresh maize bract classified as DEC with higher methane content as reported by Teodorita et al. (2008). The scrubbed or purified biogas using simple constructed water scrubber should have a recovery ability up to 80-95% methane content in a scrubbed sample, absorbed CO2 and H2S to minimum acceptable level to improved efficiency while curbing the corrosive effect of the gas with metal utilities (gas stove, burners, storage facility and internal combustion engine and combined heat and power engine). As reported in general biogas handbook, a biogas sample should contain a standard methane content 50%, heating value of 21MJ/Nm3, density of 1.22 kg/m3 similar to that of air 1.29kg/m3.

To upgrade crude biogas obtained the sample was scrubbed with water a simple technique but economically effective and simple in terms of operation. The method used here is most preferred to reduce the cost of cleaning and upgrading the sample. However, an abnormality was observed within methane composition obtained from purified rumen and municipal waste. This could be as a result of poor storage handling time and proximity of the analysis laboratory where they were conducted. As seen from the peak diagram (chromatograph) in Figure 3 (a, b and c). The CO2 content in the scrubbed sample were still high for R and M but lower for R+M substrate. Water scrubber had absorbed the CO2 to lower its amount; 12.698, 12.614 and 0.019% respectively to corresponding substrate R, M and R+M. The high values of CO2 for R and M are likely due to air contamination. Hydrogen sulphide was determined using a separate device. The suction aid helps in sucking the sample through a column of pack bed containing hydrogen sulphide indicator. This indicator was expected to change colour (yellow) as the sample contained H2S. Analyzing the scrubbed sample indicated a negligible H2S in the sample showing no colour change. In turn deducing that water has the ability to scrub all the sulphide content associated with the gas produced.

3.2 Biogas Composition.

Biogas composition obtained for this thesis was analysed using GC equipment at KRPC Kaduna gas laboratory station. GC analysis revealed that the substrate rumen (R), municipal waste (M) and mixture of both (R+M) contains methane, CO2, CO, H2S, H2O, O2 and trace of impurities; but among these impurities few were taken care of by investigating their composition/concentration in the biogas samples. The chromatograms indicating the presence of methane in the three different substrates are given in Figures 1 to 3.

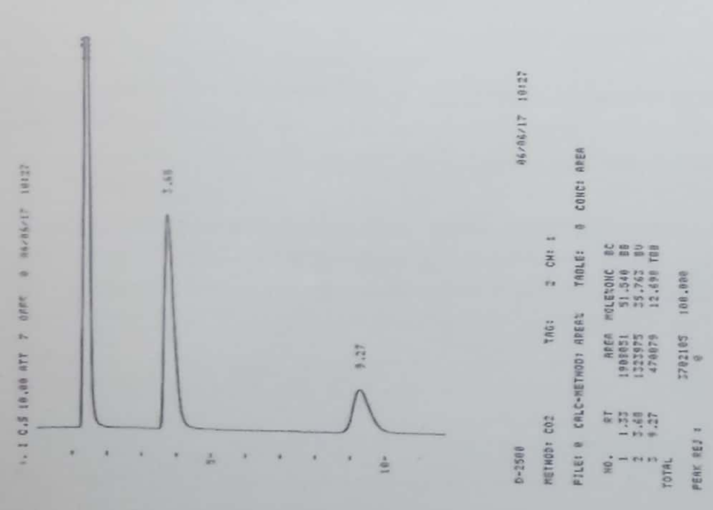

Figure 1: Chromatogram of Purified Biogas from Rumen Waste

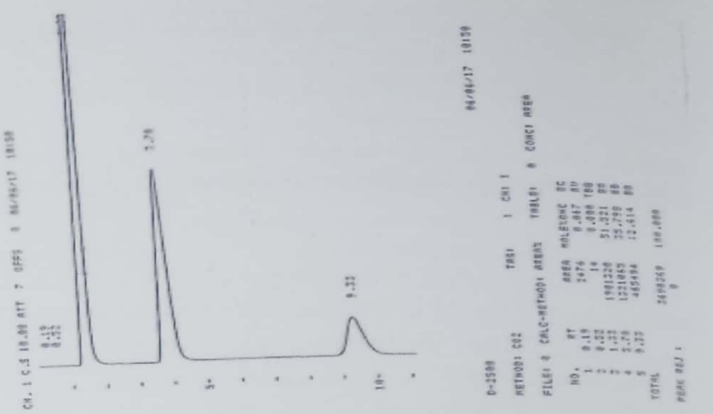

Figure 2: Chromatogram of Purified Biogas from Municipal Waste

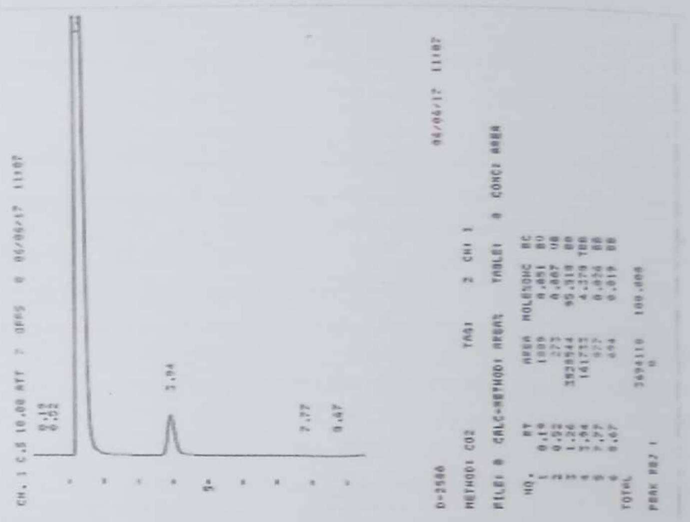

Figure 3: Chromatogram of Purified Biogas from Co-digested

The GC equipment was programmed to read CH4, CO_2, CO and O2. H2S was analyzed using another device. Table 2 summaries the analysis and composition of the most analyzed constituent and composition.

Table 2: Biogas Composition as Obtained from Gas Chromatography

Biogas samples	CH_4 %		CO_2 %		CO %		H_2S ppm
	U	S	U	S	U	S	U
R	56.42	84.08	37.7837	12.742	0.2102	_	0.000075
M	55.810	51.521	33.784	13.743	0.216	_	0.000062
R+M	58.820	95.518	35.6556	4.378	_	_	0.00006

U is unscrubbed; S is scrubbed

3.3 Cumulative Biogas Production

Cumulative of 181900 ml/g.VS-1, 217350 ml/g.VS-1 and 180250 ml/g.VS-1 was obtained as shown in Figure 4. The two-slurry containing food waste produced higher biogas yield while the rumen and co-digested substrate possessed the same production rate as shown in the cumulative chart. According to Dhaghat (2001), Elijah et al. (2009) and Umar (2014), they recorded no biogas production at the initial retention time probably due to inactiveness of methanogen during their metamorphic stage undergoing growth. In this experiment work, the reverse was observed from day 1 associated with the pre-digestion of substrate before feeding proper into digester.

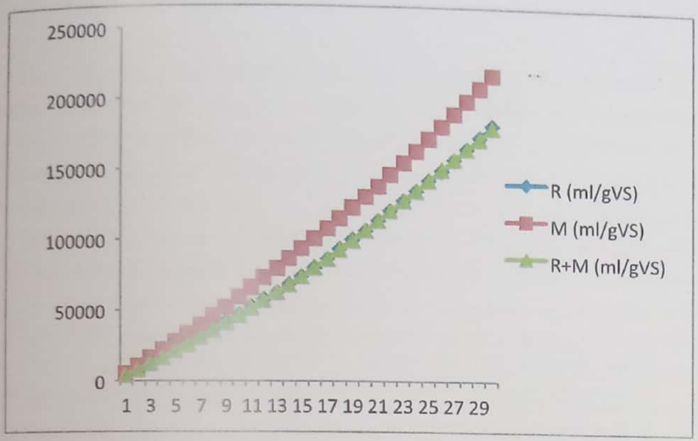

Figure 4: Cumulative Biogas Yield with Retention Time

From the initial digestion and retention time, it is generally agreed that first batch biogas production was relatively small due to acid forming and liberating volatile fatty acid resulting in declining pH, and diminishing methanogen growth. Subsequently low pH deactivate methanogen responding for digestion (Cuzin et al., 1992). Table 3 compares the present experimental work and previous used feedstocks' physiochemical characterization.

Table 3: Comparison of Physiochemical Characteristics of Previous Study and Research Result.

Parameter	ER	MBBW	CDQD	CPAW
Retention days	30	35	12	30
pH	5.9-8.2	5.68-8.11	7.25-7.62	7.25-7.6
moisture content (%)	70.85-79.55	5.6-38.85	44.85-54.83	6.7-58.05
C/N ratio	18.33-22.333	16.37	20.39-24.34	7-27
VS (%)	38.36-54.18	33.35-93.99	27.34-36.97	7.02-41.52
TS (%)	20.45-29.42	61.55-94.4	44-69.42	13.95-77.38
Alkalinity(mg/l)	510-725.34			
Acidity(mg/l)	628-840.0			
CH4 (%)	51-95	77.16-83.48	60-71	54-57

Key: Experimental result (ER), Maize bract and biogenic waste (MBBW) (Uzodinma et al., 2011), Cow dung and Quail dung (CDQD) (Umar, 2014), Cassava peel and animal waste (CPAW) Ofuefule et al. (2009).

4.0 Conclusion

The results shown that municipal waste produced less biogas from co-digestion with rumen waste due to preheating effect on the food wastes collected which resulted in loss of volatile solid content. But the reverse is the case for rumen having the high methane content and burning potential of 2 days retention time. Water as the purifying solvent has a potential of treating biogas up to 95% by methane composition with adequate, reliable and durable storage facility.

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