

Anaerobic co-digestion of brewery spent grain and cassava wastewater for the production of biogas using fixed dome biodigester

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Abstract: If not adequately managed, cassava wastewater and spent grain are an environmental problem. These wastes can be co-digested to create biogas in fixed dome biodigester. The study's major objective is to assess the co-digestion of used grain and cassava wastewater for the creation of biogas. The cassava wastewater was gathered from nearby processors in Nsukka, Enugu State, Nigeria, behind Ogige major market. The brewery's used grain was gathered. Three identical 48L capacity fixed dome biodigesters with a 30-day retention period were used in this study. In one digester, spent grain (SG) and cassava wastewater (CWW) were combined in a 50/50 ratio, with 100% CWW and 100% SG acting as controls. On the undigested slurry, physicochemical studies were performed using accepted standard techniques. Utilizing SPSS Version 16.0, a statistical analysis of the data received for the volume of gas produced from each digester was performed. With an 81.9% methane content, the digester using 100% CWW produced the most biogas overall. Cumulative biogas outputs and methane levels for the 100% SG and 50% CWW + 50% SG digesters were, respectively, 69.9 L and 83.9%; and 70.6 L and 82.91%.

Keywords: biogas, fixed dome biogester, anaerobic co-digestion, brewery spent grain, cassava wastewater

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1 Introduction

As a result of increased population development, urbanization, and industrialization, the need to explore alternative energy sources has become more urgent due to the rising expense of petroleum products. Due to their biodegradable nature and the lack of viable

conversion techniques to produce improved manure quality or usable energy, an increase in the production of organic wastes from agriculture is detrimental to human existence (Oparaku et al., 2013). If these wastes are not properly managed, the substantial amounts of biomass, livestock manure, agro-industrial waste, slurries, and moist organic waste that are produced pose a persistent pollution risk with possible environmental harm. Larger amounts of organic waste will be generated as agricultural operations expand.

The environment is negatively impacted by greenhouse gas emissions (GHGs), which are produced

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by fossil fuels like coal, oil, and natural gas. Because biomass absorbs CO₂ during growth and releases it after combustion, biofuels help reduce global warming. This aids in the recycling of atmospheric CO₂, and the use of these resources will be one of the most crucial elements in the preservation of the ecosystem. However, the issue of the energy crisis in some nations can be significantly decreased because energy can be obtained from renewable energy sources such as waste materials. Renewable energy sources can produce a significant amount of energy, such as biogas, which is created by the anaerobic digestion of organic waste materials found in municipal solid waste, agricultural waste, industrial waste, and domestic trash.

As opposed to allowing mixed energy crops to decay and produce more greenhouse gasses, methane biogas is largely obtained from the co-fermentation of these crops in an anaerobic digester. An alternative source of energy is required to replace petroleum fossil fuels, to reduce the high rate of pollution from agricultural waste, and to make use of organic waste in order to resolve all these environmental issues and the energy crisis.

If improperly disposed of, used grain and wastewater from cassava constitute a threat to soil and groundwater, while brewery waste is a risk if the waste is leached (Dillon, 2011). Waste water from cassava and discarded grains can be transformed into beneficial products, such as biogas, to minimize its organic load and prevent pollution. The energy needs of the world's rural population can be substantially met by biogas, a low-cost renewable energy source. The use of renewable energy from biogas over the non-renewable energy source of fossil fuels will not only reduce energy demands from fossil fuels but will also address the issues of GHGs, global warming, environmental pollution/degradation, and health challenge issues (COP 21, 2015; Igbum et al., 2019). Anaerobic digestion may break down the organic component of any biomass, including animal waste, sewage sludge, and industrial

effluents, into a mixture of carbon dioxide and methane known as biogas, which is regarded as an alternative green energy source. Biogas is a renewable energy source that is created by the biological deterioration of organic materials in the absence of oxygen, according to research by Mel et al. (2015). According to Mel et al. (2015), the gas generated by anaerobic digestion contains methane (50 vol.%–72 vol.%), carbon (IV) oxide (25 vol.%–45 vol.%), nitrogen (>2 vol.%), hydrogen sulfide (>1 vol.%), water (2 vol.%–7 vol.%), and oxygen (>2 vol.%). Lighting, heating, cooking, power generation, and car fuel have all been effectively accomplished with biogas energy. Furthermore, according to Verma et al. (2007), the properties of the feedstock, the conditions of the digester, the length of the hydraulic retention time, the carbon-nitrogen (C/N) ratio, and the size of the inoculum all play a significant role in the quality and quantity of the biogas yield. As a result, optimizing the digester's operational parameters and feedstock qualities are also necessary to increase biogas production efficiency. Furthermore, it is well known that co-digestion of two or more feedstocks results in a larger methane production than single-feedstock digestion. (Bożym et al., 2015).

Co-digestion involves combining and digesting two or more substrates at the same time, which increases the generation of biogas and the concentration of methane (Mel et al., 2015). The careful selection of feedstocks, their features, and availability are also necessary to increase the anaerobic digestion efficiency for the production of biogas. Mass reduction, odor removal, pathogen reduction, less energy use, and most importantly, energy recovery in the form of methane (CH₄) are all benefits of anaerobic digestion technology, which aims to produce a methane-rich biogas by biological decomposition of organic matter in an oxygen-free environment. Anaerobic co-digestion is an option to address the shortcomings of single substrate digestion systems. The properties of the substrates and chemical composition, operating

parameters (pH, charge rate, temperature, etc.), and the bioavailability, biodegradability, and bioaccessibility are important parameters to be optimized.

Bioenergy from organic waste materials through anaerobic digestion can be used to produce renewable energy from this organic-rich wastewater, while reducing the concentrations of organic pollutants (Hassanein et al., 2019). The increase in population growth coupled with the low cost of living in Nigeria has led to a drastic increase in cassava utilization in garri, starch, fufu, lafu, and flour production. This has contributed to a tremendous increase in cassava wastewater (CWW) generation. The wastes from cassava processing in Nigeria include CWW, sievates and offal (wastes from “foo-foo” production). CWW has a high organic loading, with high concentrations of chemical oxygen demand (COD), biochemical oxygen demand (BOD), and total solids, as well as a low pH (Paulo et al., 2013; Sun et al., 2012).

Digestion of CWW is associated with low nitrogen concentration and rapid acidification (low pH) of Cassava waste (Palma et al., 2018; Amorim et al., 2018). Co-digestion with a nitrogen-rich substrate, such as manure, could decrease the C/N ratio and provide buffering capacity for stabilizing the pH in order to increase methane (CH₄) production. Previous studies have investigated cassava peels and pulps co-digested with livestock wastes (Glanpracha et al., 2018; Panichnumsin et al., 2010), digestion of cassava starch effluent with separation of the acidogenic and methanogenic phases, re-circulation of methanogenic sludge, dolomitic limestone addition to increase alkalinity, and use of up flow anaerobic sludge blanket (UASB) digestion processing (Jiang et al., 2018).

Spent grain (SG) is the major by-product of beer industry, representing ~ 85% of the total by-products generated (Mussatto, 2014). Beer is the fifth most consumed beverage in the world, resulting in an average annual global production of 39 million tons of SG. It is a readily available, high-volume low-cost

byproduct of brewing and is a potentially valuable resource for industrial exploitation (Robertson et al., 2010). Brewing removes the soluble part of the grain, thus concentrating insoluble material in SG. This includes 15%–26% protein and 35%–60% fibre on dry basis (Ikram, 2017).

Therefore, the study's objective was to assess the co-digestion of SG with CWW for the purpose of producing biogas. The following specific objectives were set: (1) assess the co-digestion of SG and CWW at various ratios; SG:CWW= 100:0, SG:CWW= 50:50, and SG:CWW= 0:100; (2) assess the impact of the feedstock mixing ratios on biogas generation; (3) compare data on biogas yield obtained from mono-digestion and co-digestion of feedstock; and (4) determine the maximum biogas output from the SG:CWW ratio. These steps can help you achieve the feedstock mixture and operating circumstances that would provide the highest biogas yield.

2 Materials and methods

2.1 Materials

Three identical 48-liter fixed dome biodigesters (Figure 1) were built at the National Centre for Energy Research and Development, UNN, specifically for this research investigation. During the experiment, the weights of the samples were measured using a weighing scale balance. Both the slurry's temperature and the surrounding air's temperature were measured using a mercury-in-glass thermometer. Throughout the 30-day experiment, this was done each day to determine the slurry's daily temperature. During the experiment, the hydrogen ion concentration of the digesters' content (slurries) was measured using a pH meter to determine if it was alkaline or acidic.

2.2 Methods

The amount of biogas produced by the co-digestion of used grain and wastewater from cassava was the major objective of the study. Its objective is to identify the mix that produces the most biogas. While others

were blended in various ratios to increase their capacity for producing biogas, some wastewaters were preserved as controls.

2.2.1 Collection and preparation of CWW and SG substrate

CWW was obtained from the local processors behind Ogige main market Nsukka, Enugu State,

Nigeria while the SG was collected from Brewery company. SG was co- digested with CWW in the ratio of SG:CWW =50%:50%, SG:CWW= 0:100%, and SG:CWW= 100%:0, which served as control. The three identical 48 L capacity biodigesters, CWW and SG are presented in Figure 2.



Figure 1 Constructed 48 liters fixed dome biodigester



(a)fixed dome biodigesters, (b) cassava wastewater(CWW) and, (c) spent grain (SG)

Figure 2 Fixed dome biodigester, cassava waste water and spent grain feedstocks used in the anaerobic digestion

2.2.2 Experimental study

Three bio-digester were used for the co-digestion of SG and CWW and the retention period was 30 days. A quarter of the way up, the digester was charged, leaving a head space for gas collection. Throughout the retention period, they were vigorously blended and swirled every day to ensure that the bacteria were

evenly distributed throughout the entire mixture. The amount of gas produced was calculated as $m^3 kg^{-1}$ slurry or $L/Total\ mass\ of\ slurry$ by forcing water downward by the gas. The following feedstock mixture ratios were used in this research investigation, as shown in Table 1.

Table 1 Feedstock mixture ratios used in this research

Feedstock mixture ratio	Amount of fresh substrate	Amount of water (kg)	Total volume of surry (L)	Volume space for gas (L)	Total volume of digester (L)
100% SG	12kg of SG	24	36	12	48
100% CWW	12kg of CWW	24	36	12	48
50%SG + 50% CWW	6kg of SG + 6kg of CWW	24	36	12	48

Note: SG = Spent grain, CWW = Cassava wastewater

2.3 Physicochemical analysis of the wastes

The physical-chemical characteristics of wastes,

including their ash content, moisture content, crude fiber and fat contents, crude nitrogen and protein

contents, phosphorus, potassium, carbon content, carbohydrate content, total solids, and volatile solids, were typically assessed for all fresh wastes and slurries using established laboratory techniques (AOAC, 2015). The fresh slurry was also subjected to testing for BOD, COD, and pH over the course of the 30-day retention period.

2.3.1 Total solids

Three g of the raw waste from each sample was dried for 20 hours at 105°C in an oven to determine the total solid content. The dried sample was weighed after cooling in a desiccator. The whole solid's weight was what was left after all moisture had been lost. The proportion of the total solid content was calculated using the formula below.

$$\%TS = \frac{X_w}{B_w} \times 100 \quad (1)$$

Where: TS = total solid (%); X_w = weight of dry sample, $X_w = S_w - C_w$, (g); SW = weight of both container and dry sample (g); CW = weight of container only (g); BW = original weight of sample (g).

2.3.2 Moisture content

The Association of Official Agricultural Chemist (AOAC) (2015) technique was used to calculate the samples' moisture content. Each piece of raw waste weighted 1g was put into a crucible, which was then heated to 105 °C for three hours. After the samples had cooled in the desiccator and been taken out of the oven, they were weighed. Once a steady weight was attained, the drying process was resumed

$$\%Moisture\ Content(MC) = \frac{B_w - M_w}{B_w} \times 100 \quad (2)$$

Where: MC = moisture content (%); M_w = weight of the dry sample (g).

2.3.3 Ash content

The AOAC (2015) method was used to calculate the ash content of the samples. Each of the finely ground samples weighed 1 g, which was placed into porcelain crucibles that were then cleaned, dried at 100°C, cooled in a desiccator, and weighed. The next step involved

heating them for four hours at 600°C inside a muffle furnace. Following this, they were taken out, cooled in a desiccator, and weighed.

$$\%Ash\ Content(AC) = \frac{G_w}{B_w} \times 100 \quad (3)$$

Where: A_w = weight of both crucible and ash (g), C_w = weight of crucible (g), G_w = weight of ash ($A_w - C_w$); B_w = original weight of sample (g).

2.3.4 Crude fiber content

The AOAC (2015) technique was used to determine the crude fiber content. Defatted material weighing 1g was treated with boiling solutions of KOH weighing 0.23 N and H₂SO₄ of 0.26 N. The residue was then filtered out, cleaned, and deposited into a crucible before being heated to 105°C for 18 to 24 hours. The sample-containing crucible was weighed, ashed at 500°C in a muffle furnace, and then weighed again. The formula below was used to compute the crude fiber.

$$\%Crude\ fiber(CF) = \frac{W_2 - W_1}{W_3} \times 100 \quad (4)$$

Where: CF = crude fibre (%); W_1 = weight of residue (g); W_2 = weight of dry matter (g), W_3 = weight of sample (g).

2.3.5 Crude fat content

The AOAC (2015) method was used to calculate the sample's fat content. These techniques entailed using a Soxhlet extraction device and petroleum ether for an 8-hour period. Two grams of each sample were weighed, placed in an empty, clean, dry extraction round-bottomed flask, a clean extraction thimble, and cotton wool were placed on top. The extractor contained the thimble. The extraction flask received some petroleum ether that was poured into it. The extractor was wired to the condenser and flask.

$$\%Fat\ Content(FC) = \frac{W_1}{W_2} \times 100 \quad (5)$$

Where: FC = crude fat content (%), W_1 = weight of sample (g), W_2 = weight of fat (g).

2.3.6 Crude nitrogen/ protein

According to AAOC (2015), the micro-kjeldahl

method was used to assess the sample's crude nitrogen level. The following equation was used to compute crude nitrogen:

$$\%Crude\ Nitrogen(CN) = \frac{T \times 0.014 \times DF \times M \times 100}{W_s} \times 100 \quad (6)$$

Where: CN = crude nitrogen (%), T = titration reading (mL), M = molarity of HCL (mol L⁻¹), W_s = weight of sample (g), DF = Dilution factor (-)

The percentage of the crude protein was then calculated by inputting the crude nitrogen value in the following equation below.

$$\%Crude\ Protein(CP) = \%CN \times 6.25 \quad (7)$$

Where: 6.25 is the protein factor.

3.3.7 Carbohydrate content

The total carbohydrate content was calculated by deducting from 100 the difference between the levels of the four macronutrients—fat, protein, moisture, and ash.

$$Carbohydrates = 100 - (Ash\% + moisture\% + Protein\% + fat\% + fiber\%) \quad (8)$$

2.3.8 Volatile solids

APHA (1995) method was used to calculate the volatile solids in the garbage. The sample's volatile solids are represented by the weight loss caused by solids' ignition.

$$\%VS = \frac{C_s - C}{B} \times 100 \quad (9)$$

Where, C_s = weight of dry matter, C = weight of sample after future heating at 550 °C; B = original weight of sample.

2.3.9 Biochemical oxygen demand

The BOD test was conducted in accordance with APHA (1995).

The mg L⁻¹ BOD was calculated thus;

$$BOD\left(\frac{mg}{L}\right) = \frac{(DO_1 - DO_2) \times DF}{V} \quad (10)$$

Where: DO_1 = dissolved oxygen of dilute sample 15 minutes after preparation (mg/L); DO_2 = dissolved oxygen of dilute sample after 5 days incubation; DF = dilution factor (-). V = volume of sample (mL).

2.3.10 Chemical oxygen demand

The Chemical Oxygen Demand was calculated using the formula below.

$$mg / lCOD = \frac{(M - y)N \times 16000}{ml\ sample} \quad (11)$$

Where: m = mL of Fe (NH₄)₂ (SO₄)₂ in blank titration; y = mL of Fe (NH₄)₂(SO₄)₂ in sample titration; N = normality of Fe (NH₄)₂ (SO₄)₂.

2.3.11 Total viable count (TVC)

The surface viable count method was used to get the TVC. Following the equation below, developed colonies were counted:

$$Mean\ Count = \frac{Number\ of\ colonies\ in\ each\ segment}{8} \quad (12)$$

$$Total\ Viable\ Count = \frac{Mean\ count \times 10^4}{vol\ per\ drop} \quad (13)$$

Where: Vol. per drop = 0.015 mL; Dilution factor = 10⁴.

2.3.12 Carbon content

The wet method by Walkey-Black (1934) was used to calculate the sample's carbon content. The carbon content was calculated using the equation shown below.

$$\%carbon = \frac{B - T \times M \times 1.33 \times 0.003 \times 100}{g} \quad (14)$$

Where: B = titration volume (Blank) (mL) ; T = titration volume (Sample) (mL); M = molarity of Fe solution (mol L⁻¹)

g = weight of sample.

2.3.13 Temperature

Daily temperature readings were recorded with a liquid-in-glass thermometer to determine the samples' ambient and slurry temperatures. In order to prevent the handler's body temperature from affecting the ambient or slurry temperature, a short piece of rope was connected to the thermometer. By holding the thermometer freely and making sure it made no contact with anything, the ambient temperature (AT) was measured. Before recording the reading for that day, the thermometer was constantly checked to make sure it was stable. The slurry temperature (ST) was measured similarly, but to stabilize the reading and record it, the

thermometer was partially dipped into the slurry in the bio digester's outflow.

2.3.14 pH

A pH meter was used to determine the samples' pH levels. Throughout the 30-day digestion period, the pH (hydrogen ion concentration) of the digesters was checked and recorded every day. Using buffer solutions with a pH of 7.0, the pH meter was standardized. The pH meter was given enough time to stabilize before the measurements were taken. The pH meter bulb was inserted into the slurry through the outlet cup to obtain the reading. It was important to make sure the bulb at the end was completely submerged in the slurry. The pH meter was maintained for a short while to allow the reading of the sample for that day to stabilize and be displayed and recorded.

2.3.15 Gas volume measurement

The volume of the gas produced in the digestion by the various samples was measured on a daily basis using volume displacement method. This was done by using a calibrated transparent bucket that had a lid and a trough. The bucket was calibrated in litres and a hole on the lid of the bucket to allow for the attachment of a hose. The calibrated bucket was filled with water, the hose on the lid then attached at the gas outlet of the digester. The bucket was then inverted in the trough in a way that the lid of the bucket was very tight to prevent the water from pouring out.

The initial volume of water in the bucket was recorded. The tap of the gas outlet was opened and gas entered the bucket through the hose, thereby displacing the water. The water displacement continued till the gas in the digester was exhausted. The final volume was also recorded. The volume of biogas produced was obtained by using the following equation.

$$\text{Volume of biogas} = \text{final volume} - \text{initial volume} \quad (15)$$

2.3.16 Gas composition

The gas composition was determined using the field gas analyzer.

2.4 Flame test

Flame test was carried out on each of the digesters to ascertain the flammability of the biogas produced during the anaerobic digestion process.

2.5 Data analysis

The data obtained for the volume of gas production from each of the systems were subjected to statistical analysis using computer Microsoft Excel, 2016. The ST, pH and volume of gas produced were subjected to one way ANOVA to determine the effect of substrate (feedstock) on the performance of the fixed dome biodigester during the 30 days anaerobic digestion for biogas production. Multiple comparison of mean of studied parameters were carried out using Duncan Multiple Range Test (DMRT) in SPSS Version 16.0.

3 Results and discussion

3.1 Physicochemical parameters

The results from the research are shown in the following tables, graphs and equations. The physicochemical analysis of 100% CWW, 100% SG and 50% cassava wastewater {(CWW) + 50% SG} are presented in Table 2.

3.2 Discussions

3.2.1 Effect of C/N Ratio on 100% CWW, 100% SG and 50% CWW + 50% SG

From the results in Table 2, the C/N ratio of 100% CWW, 100% SG, 50% CWW+ 50% SG, were seen to be within the range of the optimum C/N ratio. Only 100% SG digesters flamed. Digesters 100% CWW and 50% CWW+ 50% SG each had low C/N ratio that possibly led to ammonia accumulation and consequently could not flame. C/N ratio is an important indicator for controlling biological systems. When C/N ratio is too high, biogas yield does not show the optimum due to acidogenic bacterium rapidly consuming nitrogen compared with methanogenic bacteria. When C/N ratio is too low, most microbes rapidly consume nitrogen for growth (Choi et al., 2020). To meet these requirements, microbes need 20 to 30:1 ratio of C to N.

Table 2 Physicochemical analysis of 100% CWW, 100% SG and 50% CCW + 50%SG

Parameters	100% CWW	100% SG	50% CWW + 50% SG
Total solids (%)	3.82	4.2	4
Volatile solids (%)	3.45	3.83	3.7
Moisture content (%)	83.98	82.24	83.15
Ash content (%)	2.59	3.19	2.87
Crude fibre (%)	3.48%	3.76%	3.59%
Fat content (%)	1.7	1.9	1.8
Carbohydrate content (%)	6.66	6.69	6.66
Nitrogen (%)	0.254	0.355	0.308
Protein (%)	1.59	2.22	1.93
Carbon (%)	4.69	6.38	5.59
BOD (mg L ⁻¹)	64	76.8	68.8
COD (mg L ⁻¹)	213.6	256	229.6
Phosphorus (%)	0.26	0.37	0.31
Potassium (%)	0.21	0.32	0.27
TVC (cfu mL ⁻¹)	4.5×10 ⁴	5.7×10 ⁴	5.0×10 ⁴
C/N Ratio	18.46	17.97	18.15

3.2.2 Proximate analysis OF 100% CWW, 100% SG and 50% CWW + 50% SG

The proximate analysis includes the ash, moisture, crude fibre and crude fat content of the wastes. 100 % SG waste had the highest crude fibre and ash content of 3.76% and 3.19 respectively. 100 % CWW had the highest Moisture content of 8.98 %. The crude fat for each of the wastes was appreciable.

3.2.3 Phosphorus and potassium content of 100% CWW, 100% SG and 50% CWW + 50% SG

From Table 2 there is the presence of phosphorus and potassium which are the nutrients contained in the digester. 100% CWW, 100% SG and 50% CWW + 50% SG each had a phosphorus content of 0.26%, 0.37% and 0.31% respectively. The potassium content of 100% CWW, 100% SG and 50% CWW + 50% SG each had a potassium content of 0.21%, 0.32% and 0.27% respectively.

3.2.4 Solid content of the wastes for 100% CWW, 100% SG and 50% CWW + 50% SG

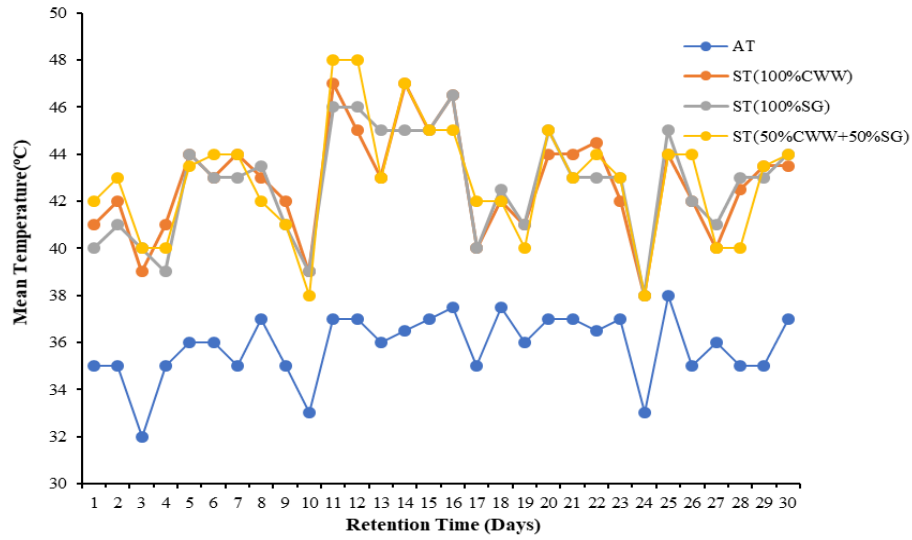
Total solid shows the total solid matter constituent of the entire organic waste both degradable and non-degradable. The total solid content of 100% CWW, 100% SG and 50% CWW+ 50% SG are 3.82%, 4.20% and 4.00% respectively.

The results of the research for the temperature (AT and ST), Slurry pH, volume of gas (VoG) and cumulative volume of gas (CVoG) produced from the sample wastes CWW, SG and CWW+ SG (50% CWW + 50% SG) during the 30 days anaerobic digestion retention period are shown in Figure 3.

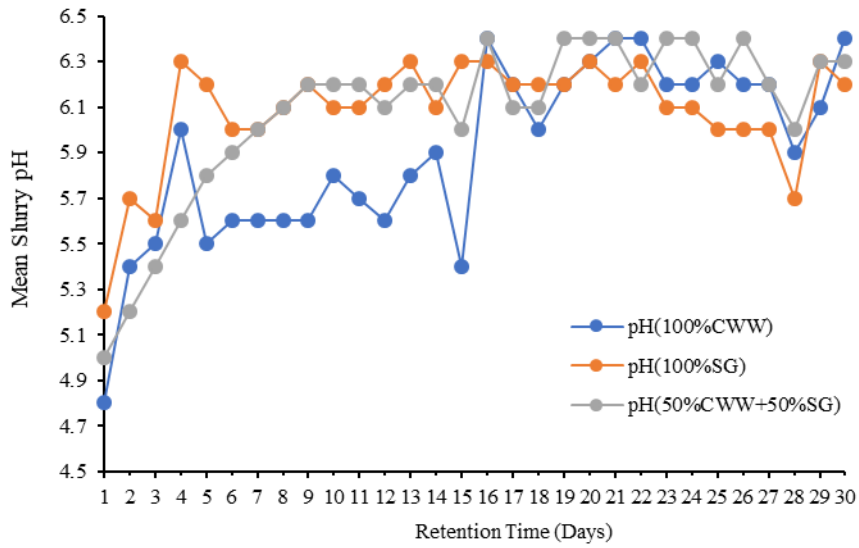
The cumulative volume of biogas (L) and methane contents for the various wastes combinations are presented in Table 3. The Comparison of methane contents of all the three fixed dome biodigesters is shown in Figure 4.

Table 3 Cumulative volume of gas and Methane contents

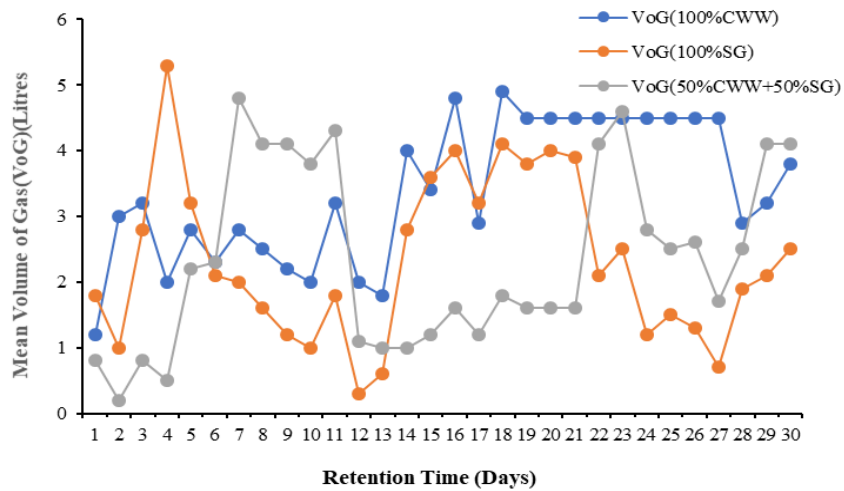
Digester/Wastes	Flamed Day (day)	Retention time (Day)	Cumulative vol. of biogas (L)	Vol. of gas per unit wt. of waste(L)	Component of biogas		
					CO ₂ (%)	CH ₄ (%)	CO(ppm)
100% CWW	-	30	100	8.33	11	81.9	5
100% SG	21	30	69.9	5.83	17	83.9	18
50% CWW + 50% SG	-	30	70.6	5.88	17	82.9	6



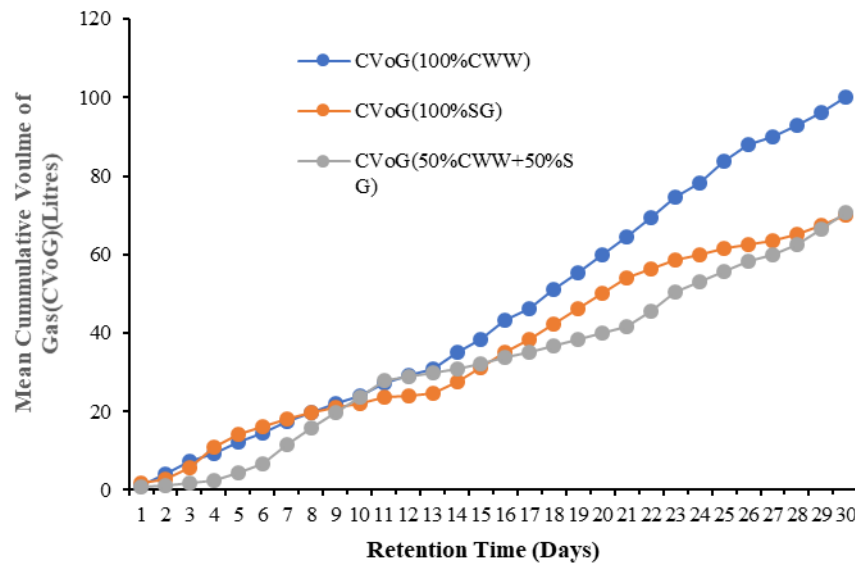
(a) Slurry Temperature(ST) and Ambient Temperature(AT)



(b) Slurry pH



(c) Volume of Gas(VoG)



(d) Cumulative volume of gas (CVoG)

Figure 3 Daily variation of slurry temperature, ambient temperature, slurry pH, volume of biogas and cumulative volume of biogas during the anaerobic digestion

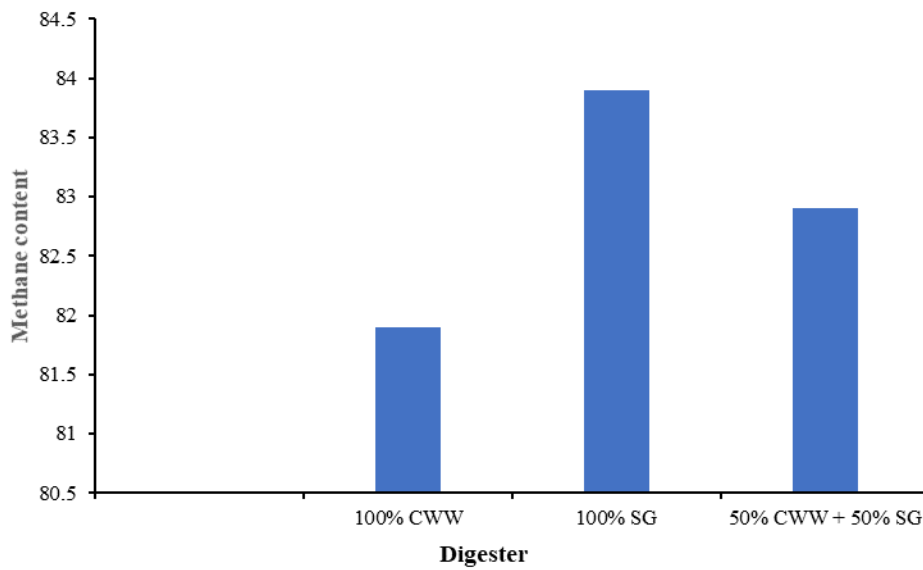


Figure 4 Comparison of methane contents of all three fixed dome biodigesters

3.2.5 Digester performances of 100% CWW, 100% SG and 50% CWW + 50% SG

The results of digester performances of Digester A, B and C (Figures 3a,3b,3c and 3d) respectively) indicated that Digester B (100% SG) flamed on the 21st day. Digester A (100% CWW) and Digester C (50% CW+ 50 SG) didn't flame at all.

From Table 3, the cumulative gas yield from three digester treatments was different: the 100% CWW had cumulative gas yield of 100 liters/ 36kg mass of slurry

and a mean VoG of 3.33 L; 100% SG had cumulative gas yield of 69.9 liters/ 36kg mass of slurry and a mean VoG of 2.33 L while 50% CWW+50% SG had cumulative gas yield of 70.60 liters/36kg mass of slurry and a mean Vog of 2.35 L during the 30 days retention period.

100% CWW had 81.9% methane; 100% SG produced 83.9% methane while 50% CWW+50% SG produced 82.9% methane.

3.2.6 Ambient temperature (AT), slurry temperature

(ST), pH and biogas production

Figure 2 showed fluctuations in AT, ST, pH and daily volume of biogas production. Fluctuation in AT causes fluctuation in all other parameters and biogas production as a result of AT condition. In the night or windy situations, AT goes low which will cause ST to equally go low. AT is the temperature of the local surrounding of the digester while ST is the temperature of the contents of a digester undergoing anaerobic digestion. Ambient conditions for the wastes (CWW and SG) all coincided for each of the three digesters. This is expected since the digesters were exposed to the same ambient environment, same geometry of digester and same proportion of mix for the 30 days retention time. It was also observed that the pH for the digester fluctuated and finally came to 7.0 (neutral condition), indicating that digestion was now complete.

3.2.7 Comparison of methane contents of the three digesters

From Figure 4, 100% SG had the highest methane content of 83.9%; 50% CWW+50% SG had a methane content of 82.9% while 100% CWW had a methane content of 81.90%. This implies that SG should be recommended for biogas production and also 50% CWW+50% SG mix ratio should be recommended for co-digestion of biogas production.

3.2.8 Statistical analysis results

The ANOVA of effect of feedstock on measured parameters during the 30 days biogas production from the fixed dome biogas digester is presented in Table 4. The multiple comparison of the mean of the measured parameters of the anaerobic digestion during the 30 days biogas production using Duncan multiple range test (DMRT) is presented in Table 5.

Table 4 ANOVA of effect of feedstock on measured parameters during the 30 days biogas production from the fixed dome biogas digester ($\alpha=0.05$)

		Sum of Squares	df	Mean Square	F	Sig.
ST	Between Groups	0.517	2	0.258	0.046	0.955
	Within Groups	488.083	87	5.61		
	Total	488.6	89			
pH	Between Groups	0.602	2	0.301	2.634	0.078
	Within Groups	9.934	87	0.114		
	Total	10.536	89			
VoG	Between Groups	21.571	2	10.785	6.946	0.002
	Within Groups	135.086	87	1.553		
	Total	156.657	89			
CVoG	Between Groups	2855.703	2	1427.851	2.279	0.108
	Within Groups	54500.31	87	626.44		
	Total	57356.01	89			

Table 5 Multiple comparison of the mean of the measured parameters of the anaerobic digestion during the 30 days biogas production using Duncan multiple range test (DMRT)($\alpha=0.05$)*

Digester	Feedstock	ST(°C)	pH	VoG(L)
A	100%CCW	42.75a	5.907a	3.380b
B	100%SG	42.68a	6.083a	2.330a
C	50%CCW+50%SG	42.87a	6.077a	2.353a

Note: *Values followed by the same lower case letter in the same column are significantly the same ($\alpha=0.05$)

4 Conclusion

The conclusions of the research are as follows: Digester containing 100% CWW had the highest

cumulative biogas yield of 100 L with a methane content of 81.9%. Digesters containing 100% SG and 50% CWW + 50% SG had cumulative biogas yields and methane contents as follows: 69.9 L, 83.9 %; 70.6

L, 82.9% respectively. This implies that SG blended with CWW produces more biogas than CWW only. SG is recommended for single biogas production while SG blended with CWW is recommended for co-digestion for biogas production.

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