Feasibility study of biogas energy generation from refuse dump in a community-based distribution in Nigeria

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Abstract

Energy generation remains one of the biggest challenges of developing nations like Nigeria. The World Bank estimated that ~80 million (44.4%) out of 180 million Nigerians living in 8000 villages across the country lack access to electricity. Lack of access to electricity to stimulate small- and medium-scale enterprises in rural communities is believed to be a major factor responsible for rural—urban migration and the lingering emigration crises across the globe. In this study, three different wastes generated were combined in a locally fabricated digester and each singly loaded in respective digesters to generate energy in the form of biogas with an anticipation of redistribution for a community-based use. The biodegradability test of the substrates were studied ab initio by evaluating for ash and moisture contents, C/N ratio, biochemical oxygen demand (BOD) and chemical oxygen demand (COD) for maize chaff, watermelon and cassava peels. The results showed 2.85, 0.66 and 2.40% for ash content, 11.18, 93.22 and 70.26% for moisture content, 12.10, 15.10 and 19.10% for C/N ratio, 155.07, 131.96 and 113.79 ppm for BOD, and 240.00, 212.00 and 264.00 ppm for the substrates, respectively. From the results, maize chaff with the highest ash content has the least biodegradable (organic) matter, while watermelon, with the least ash content, has the highest biodegradable matter. The moisture content results for maize chaff and watermelon were below and above the optimum value of '60–80%' and this confirmed the low biogas volume produced when used alone. The ideal C/N ratio for anaerobic digestion is between '20:1 and 30:1'. A comparison of these sets of values from the study showed that the C/N ratios obtained from the research work are below the optimum values of the C/N ratios and could be responsible for the poor biogas yield for the disjoined substrates. The biogas volume of 2100 ml was produced at the end of the retention time for the combined substrates and, was higher compared with the 18, 25 and 29 ml produced for maize chaff, watermelon and cassava peels, (the disjoined) substrates, respectively. In this study, the COD value for each substrate is higher than the corresponding BOD values. Hence, co-digestion of unavoidable food wastes is economic and, a potentially viable option to generate alternative renewable energy for rural community-based use.

Keywords: energy generation; wastes; biogas; biodegradability and rural community

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1 INTRODUCTION

Energy generation remains one of the biggest challenges of developing or third world counties like Nigeria. About 80 million (44.4%) out of 180 million Nigerians living in 8000 villages across the country lack access to electricity according to World Bank report for sustainable energy to all [1]. Lack of access to electricity to stimulate small- and medium-scale enterprises in rural communities is believed to be a major factor responsible for rural—urban migration (internal migration) and the lingering emigration crises across the globe. In this study, wastes generated from three different feed stocks namely: watermelon,

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maize chaff and cassava peels dumped at Rail way market, Wadata market/gari processing plant and Naka road, respectively, in Makurdi metropolis, Benue State of Nigeria were used to generate biogas for utilization. These unavoidable wastes are produced daily due to lack of adequate disposal system, poor transportation network and improper waste management system in the country.

A lot of studies have been implemented harnessing different substrates of food and agricultural wastes for biogas production and the results have been promissory. Adelekan and Bamgboye [2] did a study on the comparative analysis of biogas productivity of cassava peels when comingled with selected ratios of major livestock waste types vis a vis, poultry, piggery and cattle wastes. The results obtained were interesting for anaerobic production of methane in that for all livestock waste types studied at varying rations of by mass generated the highest yield of biogas by volumes and more from piggery wastes. The yield was also statistically significant, influenced by the different mixing ratios of cassava peels with livestock wastes. Another study by Kanger [3] presented a case of biogas production under food wastes co-digestion comingled with sludge from sewage with analysis of biogas potential, characterization of biogas residues and biological methane potential of substrates production. It was concluded that food wastes are highly valuable substrates for anaerobic digestion. Co-digestion of substrates is a significant process that also resulted in high productivity of biogas in comparison with mono- or single fermentation process. El-Mashad and Zhang [4] reported a study on the production of biogas from co-digestion of food wastes with diary manure in which the production potential was determined from unscreened dairy manure mixtures and comparable food wastes and also the yield of manure and/or food wastes alone. The outcome is ~90% of the final biogas produced from dairy manure was obtained after 20 days of digestion with significant differences in methane yields from mixtures.

The need to convert uncontrolled amount of discharge of quantified amounts of food waste in municipalities, communities can no longer be avoided. Severe environmental effects and pollutions are attributed to these types of wastes in many countries [5]. Possible and potential treatment, valorization and exploitation such as anaerobic digestion of these raw materials hitherto seen as wastes can be a way to convert these wastes to wealth through biogas and fertilizer production. This approach is proven and effective [5]. Another valorization potential of food waste is biohydrogen production. Biohydrogen was produced through anaerobic digestion of food wastes in a study by Kim *et al.* [6]. There was inference that food wastes and sewage sludge are suitable main substrate and a useful auxiliary substrate, respectively, for hydrogen production. The metabolic results indicated that the digestion of organic matters was successful. Another assessment was conducted on the anaerobic co-digestion of food waste and cattle manure with the aim of identifying key parameters to determine total biogas and specific methane yields [7]. Total methane yield was enhanced by co-digestion with the ratio of the optimum food waste to cattle manure of 2:1. The high yield improvement was attributed to C/N ratio and possible higher degradation of lipids [7].

In this paper, feasibility study of biogas energy generation from refuse dump was evaluated in a community-based distribution in Nigeria with the aim of investigating the potential and subsequent redistribution for community use. Three different wastes generated from the dumpsite were combined in a locally fabricated digester and each singly loaded in respective digesters to generate energy in the form of biogas with an anticipation of redistributive use.

Four 25-l laboratory-scale galvanized anaerobic reactors, known as digesters in the work were fabricated locally for this research study. The digesters have four openings each, one serving as the inlet of the substrates, the second for the biogas outlet, while the third was for the removal of the slurry. The fourth opening was made on the cover through which a thermometer was permanently attached for temperature measurement. The gas outlet was connected to two Buchner flasks which served as purification chambers containing 20% NaOH and 20% lead acetate solutions each for the removal of CO_2 and H_2S, respectively, as adopted by Dahusi and Oranusi [8]. The Buchner flasks were then connected to a 500-ml measuring cylinder filled with water and inverted in a big beaker supported with a

Figure 1. *Fabricated digesters and experimental set-up.*

retort stand for measuring the volume of gas produced by water displacement method as seen in Figure 1.

2 MATERIALS AND METHODS

The substrates (cassava peels, maize chaffs and watermelons) were homogenized with mortar and pestle to increase the surface area in order to hasten up the digestion. A mixture consisting of ~12 kg of each food waste and water was prepared by mixing them in a ratio of 1:1 W/V to make ~30 l of slurry. Each of the reactors (digesters) was filled to three—quarters of its volume (19 000 ml), and three of the reactors were fed with maize chaffs, watermelon and cassava peels each, while the fourth reactor was fed with a mixture of the three substrates.

The digestion was allowed for 60 days in a batch fermentation mode. The physicochemical and biodegradability analyses of the substrates were evaluated before and after digestion using standard procedures (APHA and AWWA [9]).

3 RESULTS

Parameters analyzed include ambient and slurry temperature of the reactors for different substrate, slurry pH, moisture content, ash content, organic carbon, total nitrogen, biochemical oxygen demand (BOD), chemical oxygen demand (COD) and volume of biogas produced from each digester. These are presented in Table 1.

4 DISCUSSION

The biodegradability tests of the substrates are as shown in Tables 1 and 2 and in Figure 2. Table 1 shows the percentage ash, moisture, carbon and nitrogen contents of the substrates. From the table, maize chaff, watermelon and cassava peels have 2.85 ± 1.50%, 0.66±0.0.12% and 2.40 ± 0.61% ash content, respectively. It is evident from the results that maize chaff has the highest percentage ash content but with the least biodegradable (organic) matter, while watermelon has the least ash content with the highest organic matter.

Table 1. *Percentage proximate composition of substrates.*

Parameters (%)	Food wastes		
	MC	WM	CP
Ash	2.85 ± 1.50^{b}	0.66 ± 0.12^{a}	2.40 ± 0.61^{b}
Moisture	11.18 ± 0.18^{a}	93.22 ± 0.27^{c}	70.26 ± 1.86^{b}
Carbon	70.64 ± 0.76^{b}	59.91 ± 1.08^{a}	60.21 ± 0.98^{a}
Nitrogen	5.93 ± 0.06^{b}	3.87 ± 0.03^{a}	3.08 ± 0.05^{a}
C/N ratio	12.10	15.10	19.10

Values are mean ± standard deviation. Superscripts with same alphabet denote values within the same range at $P \le 0.05$ for maize chaff (MC), watermelon (WM) and cassava peels (CP), respectively.

Table 2. *Substrates biochemical and chemical oxygen demand.*

Parameters (%)	Food wastes		
	MC	WM	CP
BOD	155.07 ± 1.96^{c}	131.96 ± 3.01^{b}	113.79 ± 3.85^{a}
COD	240.00 ± 4.00^{b}	212.00 ± 4.00^{a}	264.00 ± 4.00^{c}

Values are mean ± standard deviation. Superscripts with same alphabet denote values within the same range at $P \le 0.05$ for maize chaff (MC), watermelon (WM) and cassava peels (CP), respectively.

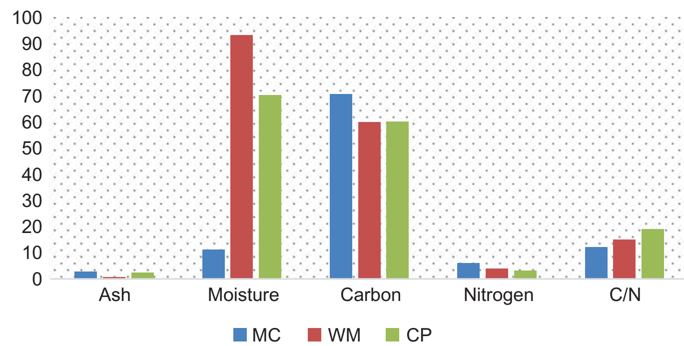

Figure 2. *Substrates proximate composition variation chart.*

The percentage moisture content study of the substrate showed that watermelon has the highest moisture content of 93.22 ± 0.27%, followed by cassava peels with 70.26 ± 1.86%. Maize chaff is the least with 11.18 ± 0.18%. Comparing these results with the optimum value of moisture content of 60–80%, Khalid *et al.* [10] indicated in his study that it is evident that maize chaff and watermelon may not produce much biogas since their values are below and above the optimum range, respectively, cassava peels whose value falls within the range may produce more biogas under the same conditions. The carbon contents of the substrates are presented in Table 1. This also shows some variations in the percentage content. Maize chaff has a carbon content of 70.64 ± 0.76%, watermelon has 59.91 ± 1.08%, while that of cassava peels is 60.21 ± 0.98%. From these, maize chaff has the highest percentage carbon while watermelon has the least. The implication of which is that high amount of biogas yield is anticipated from maize with high composition of carbon.

The table further shows values for percentage nitrogen content of the substrates: maize chaff has a nitrogen content of 5.93 ± 0.06%, watermelon has 3.87 ± 0.03% and cassava peels have 3.08 ± 0.05% as also the carbon to nitrogen ratios: 12:1, 15:1 and 19:1 for maize chaff, watermelon and cassava peels respectively. The carbon to nitrogen ratio expresses the relationship between the quantity of carbon and nitrogen present in the substrates. Materials with different carbon to nitrogen ratios differ widely in their yields of biogas.

The ideal carbon to nitrogen ratio for anaerobic digestion is between 20:1 and 30:1 according to studies of Yadvika *et al.*

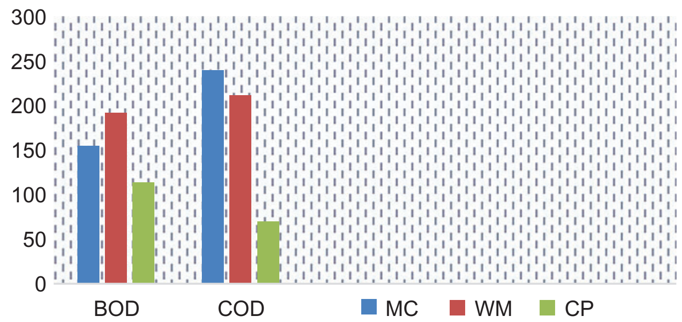

Figure 3. *Substrates biochemical and chemical oxygen demand variation chart.*

Table 3. *Weekly pH of the slurry.*

Weeks	MC	WM	CP	CS
1	5.20	4.76	4.83	
2	3.88	4.39	3.84	3.85
3	3.89	4.65	3.99	3.86
4	3.76	4.74	3.73	3.97
5	3.85	4.94	4.10	4.09
6	3.81	4.94	4.60	4.16
7	3.88	5.12	4.30	4.27
8	3.77	5.06	3.81	4.30

Key: CS, combined substrates.

[11], Khalid *et al.* [10] and Poliafico [12]. A comparison of these sets of values shows that the C/N ratios obtained from this study are below the optimum values of the C/N ratios and could be responsible for the poor biogas yields for individual substrate. When the C/N ratio is lower than the ideal values, nitrogen will be liberated and it will accumulate in the form of ammonia and will raise the pH value of the slurry in the digester. This is not an ideal situation. pH value higher than 8.5 (alkaline) are toxic to the methanogenic bacteria in the slurry [12] and the cumulative effect of this is the low generation of biogas. However, if the C/N ratio is higher than the ideal range, biogas production will be low. This is because the nitrogen will be consumed rapidly by the methanogenic bacteria for meeting their protein requirements and will no longer react with the leftover of carbon remaining in the material. In such a case of high C/N ratio, the gas production can be improved by adding nitrogen in form of cattle urine or by fitting latrine to the plant according to Fulford [13]. Materials with high C/N ratio typically are residues of agricultural plants. Materials having low C/N ratio could be mixed with those having high C/N ratios so as to bring the average C/N ratio of the mixture to a desirable level. Human excreta, duck dungs, chicken dungs, and goat dungs are some of the materials which typically have low C/N ratios.

The BOD and COD values of the substrates as presented in Table 2 indicate that maize chaff has a BOD of 155.07 ± 1.96 ppm and COD of 240.00 ± 4.00 ppm, watermelon has BOD of 131.96 ± 3.01 ppm and COD of 212.00 ± 4.00 ppm, while those of cassava peels are 113.79 ± 3.85 ppm and 264.00 ± 4.00 ppm respectively. BOD and COD are indicative of the degree of both biological and chemical decompositions that are taking place in the digesters. The COD gives a precise estimation of the organic (degradable) material content of the sample. The results showed that the COD value for each of the substrates is higher than that of the corresponding BOD. as observed in Table 2 and Figure 3. This is in agreement with the earlier work of Curry and Pillay [14] where he reported that higher values of COD than BOD are favorable for anaerobic digestion, hence more biogas production. Therefore in this context, maize chaff, watermelon and cassava peels are good substrates for anaerobic digestion for the production of biogas. The characterization results suggest that mixing the food wastes is necessary to provide a nutrient balanced feedstock for anaerobic digestion.

Table 4. *Volume of biogas produced and the percentage yield.*

Food wastes/reactors	Volume of biogas (ml)	% Yield
Maize chaff (R1)	18.00	0.09
Watermelon (R2)	25.00	0.13
Cassava peels (R3)	29.00	0.15
Combined food waste (R4)	2100.00	11.05

The pH data presented in Table 3 shows the values of the weekly pH of the slurry for the period of 8 weeks. The pH values showed initial fall to a more acidic level before assuming gradual increase. The pH of the maize chaff dropped from 5.20 to 3.88 and that of watermelon were from 4.76 to 4.39. Cassava peels fell from 4.83 to 4.84. The initial drop in pH is important since activities of aerobes and facultative aerobes are essential in producing relevant acidic metabolites, which are acted on by methanogenic bacteria to yield methane. According to similar studies, microorganism involved in anaerobic bio digestion requires neutral or mildly alkaline environment, as a too-acidic or too-alkaline environment will be detrimental to them [15]. The acidic environment of the digester accounts for the low biogas production. The pH value of a digester depends on the ratio of acidity and alkalinity and the carbon dioxide content in the digester, the determining factor being the density of the acids [15].

The pH requirements of the groups of microorganisms participating in anaerobic digesters differ. While acidogenic bacteria can perform well when the pH is above 5, methanogenic bacteria require a minimum pH value of 6.2. Anaerobic bacteria especially the methanogens are sensitive to the acid concentration within the digester and their growth can be inhibited by acidic conditions. During digestion, the two processes of acidification and methanogenesis require different pH levels for optimal process control. The retention time of the digestate affects the pH value and in a batch reactor, acetogenesis occurs at a rapid pace [3]. Acetogenesis can lead to accumulation of large amount of organic acids resulting in pH below 5. Initially, pH

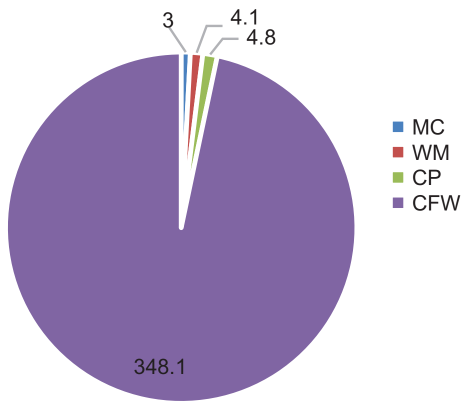

Figure 4. *Substrates biogas volume chart.*

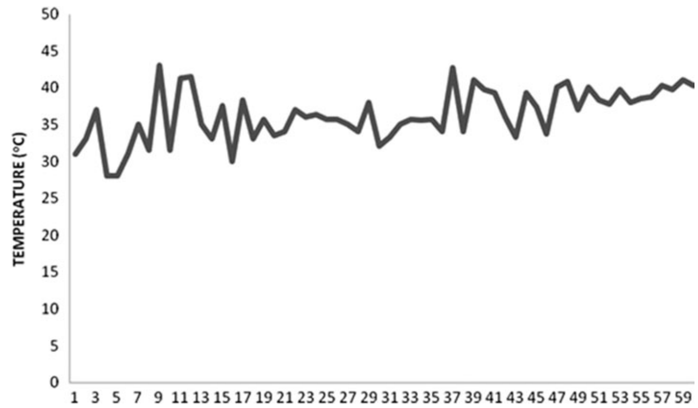

Figure 9. *Average temperatures of combined food wastes (Reactor 4).*

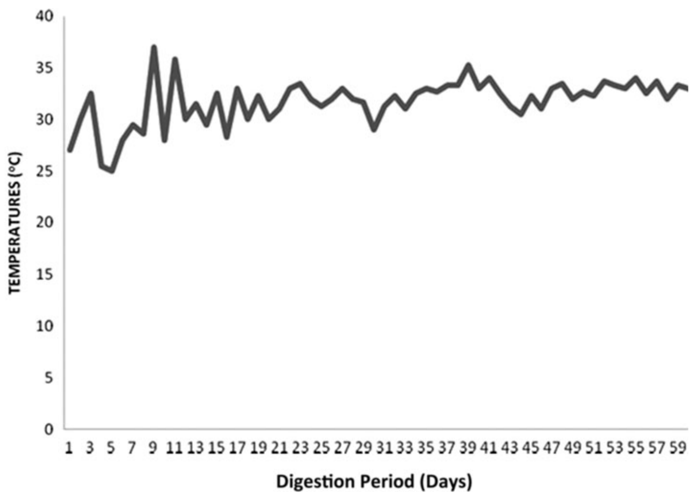

Figure 5. *Average daily ambient temperatures.*

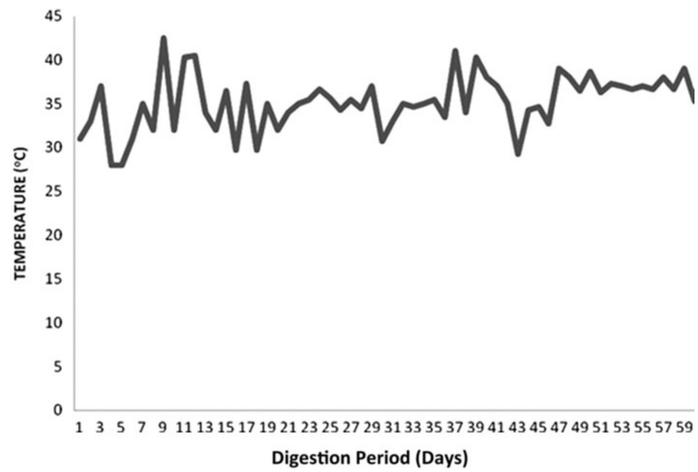

Figure 6. *Average temperatures of maize chaff (Reactor 1).*

decreased as organic matter undergoes acetogenesis, but methanogens rapidly consume those acids increasing pH and stabilizing digester performance. Due to their sensitivity to acid conditions, excessive generation of acid can inhibit methanogens. Reduction in pH can be controlled by the addition of lime, recycled filtrate obtained during residue treatment [12]. The biogas production process from co-digestion of food wastes was investigated for the samples under study. The individual biogas yields were recorded in Table 4 and in Figure 4. The biogas volume produced at the end of the retention time for combined substrates was the highest at 2100.00 ml, while for disjoined substrates were 18.00 ml, 25.00 ml and 29.00 ml for maize chaff, watermelon and cassava peels, respectively. The higher biogas yield for the combined food wastes is in concord with a similar work by Kanger [3] which reported that co-digestion of substrates resulted in higher biogas yields when with organic materials are converted biogas with organic fertilizer (effluents) as bio-products. These are end products of biogas technology unlike simple composting which produces only fertilizers from organic solid wastes [16]. Thus, comparatively BT could be considered as better option for its compactness, cleaner operation and better product range (i.e. both gas as energy source and processed solid waste as manure). Methane is the main constituent of biogas. About 90% of energy of substrate is retained in methane.

Figures 5–9 showed the ambient and slurry temperatures of the four reactors. The results show that the temperatures of the slurry were gradually higher than the corresponding ambient temperatures. Bacterial activities in the digesters may have caused the increase in temperature. It was observed from the study that bio-digestions in the reactors predominantly occurred within the mesophilic temperature range (30°C–38°C), although there were some cases of temperatures fluctuations below and above the range, as seen in the figures. Temperature is a critical environmental factor affecting digester's performance. It affects the physical and physicochemical properties of compounds present in the digester and the kinetics and thermodynamics of

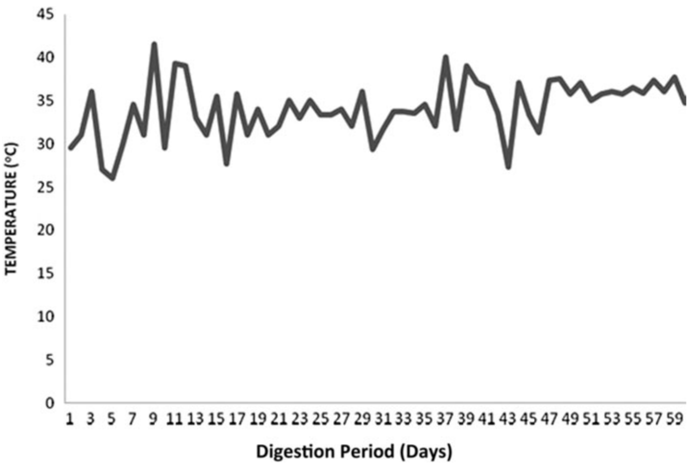

Figure 7. *Average temperatures of watermelon (Reactor 2).*

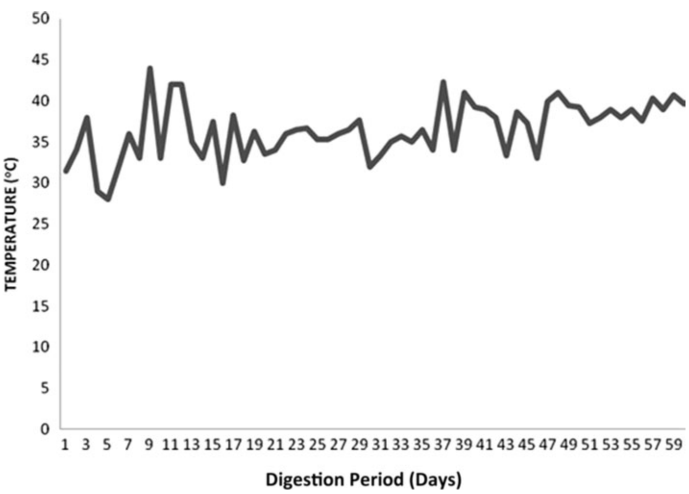

Figure 8. *Average temperatures of Cassava peels (Reactor 3).*

biological processes [17]. Anaerobic bacteria communities can endure temperatures ranging from below freezing to above 57.2°C but they thrive best at temperatures of about 36.7°C (mesophilic) and 54.4°C (thermophilic). Bacterial activity and thus biogas production falls off significantly between about 39.4°C and 51.7°C and gradually from 35°C to 0°C. To optimize the digestion process, the digester must be kept at a consistent temperature as rapid changes will upset bacterial activity as observe by Carcelon and Clark [18]. In order to reach optimum operating temperatures (30°C–37°C), some measures must be taken to insulate the digester. Straw or shredded tree bark can be used around the outside of the digester to provide insulation ([19] as cited in Adeleke and Bamgboye, 2009).

5 CONCLUSION

Biogas production from maize chaff, watermelon, cassava peels and a combination of the three substrates was carried out using batch fermentation mode for a retention time of 60 days. The ideal carbon to nitrogen ratio for anaerobic digestion is between 20:1 and 30:1 according to studies of Yadvika *et al.* [11], Khalid *et al.* [10] and Poliafico [12]. A comparison of these sets of values shows that the C/N ratios obtained from this study are below the optimum values of the C/N ratios and could be responsible for the poor biogas yields for individual substrate It is evident from the result that biogas yield was enhanced by co-digestion of the substrates. Co-digestion of the selected food wastes significantly increased biogas volume produced and eco-friendly sludge was as well formed. Materials with high C/N ratio typically are residues of agricultural plants. Materials having low C/N ratio could be mixed with those having high C/N ratios so as to bring the average C/N ratio of the mixture to a desirable level. Human excreta, duck dungs, chicken dungs, and goat dungs are some of the materials which typically have low C/N ratios. The biogas production from co-digestion of food wastes gave individual biogas yields. The biogas volume produced at the end of the retention time for combined substrates was the highest at 2100.00 ml, while for disjoined substrates were 18.00 ml, 25.00 ml and 29.00 ml representing maize chaff, watermelon and cassava peels, respectively. The study is part of waste to wealth strategy adopted in developing country like Nigeria to generate energy and to mitigate waste accumulation and its disturbing environmental effects and challenges. Biogas technology under anaerobic conditions possesses huge potentials for waste management and energy generation especially at off-grid level in communities where sustainable wastes can be turned to sustainable investment in methane generation and organic fertilizer production.

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