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Co-digestion of Food Waste and Human Excreta for Biogas Production

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Authors' contributions

This work was carried out in collaboration between both authors. Author SOD performed the physico-chemical and statistical analysis, wrote the first draft of the manuscript and managed the literature searches. Author USO designed the study, wrote the protocol and performed part of the microbial analysis. Both authors read and approved the final manuscript.

Research Article

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ABSTRACT

The ever increasing cost of fossil fuels and its attendant pollution menace has provided the pedigree to consider alternative sources of energy. An investigation was launched into the design and construction of an Anaerobic Digester system from locally available raw materials using local technology and the production of biogas from food wastes and Human excreta generated within a University campus. The experiment lasted for 60 days using a 40-liters laboratory scale anaerobic digester. The volume of gas generated from the mixture was 84,750cm^3 and comprised of 58% CH_4, 24% CO_2, and 19% H_2S and other impurities. The physico-chemistry of the feedstock in the digester revealed an initial drop in pH to more acidic range and a steady increase 4.52 – 6.10. The temperature remained relatively constant at mesophilic range: 22.0ºC– 30.5ºC throughout the study. The Carbon/Nitrogen (C/N) ratio of the feedstock before digestion was within 139:1. Population distributions of the microflora show aerobic and anaerobic bacteria to include *Klebsiella spp, Bacillus spp, Escherichia coli, Clostridium spp* and a methanogen of the genera *Methanococcus*. In most developing nations of Sub-Saharan Africa where biomass is abundant, and where biogas technology is in its infant stage, the anaerobic digestion system could be the much awaited solution.

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1. INTRODUCTION

The world is currently moving from petroleum-based to a bio-based global economy, in this instance, biological wastes, which is usually seen as low-valued materials, are now being transformed from high volume waste disposal environmental problems to constituting natural resources for the production of eco-friendly and sustainable fuels [1]. Biological wastes contains high level of cellulose, hemicelluloses, lignin, starch, proteins, and lipids, these are good options for the biotechnological production of liquid biofuels without having interference with the ever-growing need for world's food supply [2].

Biogas digester technology is spreading fast in Asia and other continents but utilization in Sub-Saharan Africa has so far been slow, despite significant individual, institutional, national and international efforts to support technology adoption [3,4,5]. The slow pace of development of biogas technology in Africa has been attributed partly to shortage of raw materials to feed the digester, due to poor infrastructural development in animal rearing and plant cultivation [6].

In Africa, water pollution and access to energy resources present challenges to human health, environmental health, and economic development. According to [7], less than 10% of the population of 21 sub-Saharan African countries have access to electricity. The need for alternative renewable energy sources from locally available resources cannot be over emphasised. Besides, the alarming population explosion in Africa and its concomitant effect on natural resources due to increased woodfuel/charcoal fuel production and consumption [8,9] is not sustainable in the long term. Therefore, any reduction in woodfuel consumption as a result of biogas production might be expected to have favorable effect on reduction in deforestation.

Due to the limited nature of fossil resources, oil price is vulnerable to increase as from now on. Recent global increase in the price of fuels coupled with the upsurge in the Nigerian oil and gas industry proves that the above is true. Even though Nigeria is an oil and gas producing nation, the country faces a severe energy crisis because of continuous supply disruptions. Nigeria's centralized oil and gas distribution networks are easy targets for rebels, energy hackers and criminals [10]. Also, climate change issue is becoming more and more serious, and thus there has been a global movement toward reduced use of fossil resources.

Energy is a basic tool for development. Developing countries like Nigeria face added dilemmas regarding environmental protection due to their heavy dependency on biomass and fossil fuel. Adaramola and Oyewola, [11] opined that Nigeria is endowed with huge resources of conventional energy resources (crude oil, tar sands, natural gas and coal) as well as reasonable amount of renewable energy resources (e.g. hydro, solar, wind and biomass). Most of the developing nations are facing serious shortage of fuels, the most commonly used fuel being wood fuel. According to Nepalese 2001 population census, 65 percent of 4.17 million Nepalese households are using fuel wood for cooking purposes. As a result, 5.4 million tons of fuel wood is being burnt annually [12]. The case in Nigeria is not different.

A biogas plant or latrine when successful is an appropriate and sustainable method to deal with human or animal waste. This system produces two extremely useful products from the waste: biogas and slurry. Using biogas for cooking and lighting reduces the strain on the environment by decreasing the use of biomass and the production of greenhouse gases (as methane that is produced normally from manure is now captured and used). The biogas system also provides a barrier protecting ground water from contamination from untreated waste [13]. To save the environment from further deterioration and also supplement the energy needs of the rural populace, a strategy incorporating local resources and new technology as biogas technology can be effectively utilized [14]. More so, with the declining quantity of fossil fuels it is critical today to focus on sustained economic use of existing limited resources and on identifying new technologies and renewable resources, e.g., biomass, for future energy supply [15].

Biofuels will be increasingly used to replace some of fossil fuel for our sustainable future [16,17]. Alkan-Ozkaynak and Karthikayan, [18] has demonstrated a high yield of biogas from the anaerobic digestion of corn stillage. Anaerobic digestion with the addition of co-substrates, i.e. co-digestion, has been considered an effective, low-cost, and commercially flexible approach to reduce process limitations and improve methane yields [19].

In Nigeria, research into biogas technology and its practical application is on-going, though, has not really received the deserved attention. Lack of adequate funding from government and sponsorship by individuals or corporate bodies has hindered the development of this technology in Nigeria [20]. The identification of feedstock substrate for an economically feasible biogas production in Nigeria, to include water lettuce, water hyacinth, dung, cassava leaves and processing waste, urban refuse, solid (including industrial) waste, agricultural residues and sewage have been made [21,22,23,24]. Many other raw materials available in Nigeria have been critically assessed for their possible use in biogas production by [25]. They include refuse and sewage generated in urban areas, agricultural residues and manure. It was concluded that poultry manure generated in Nigerian homes and in commercial poultry farms could be economically feasible substrates for biogas production. The potential to utilize poultry, cow and kitchen wastes for biogas production was demonstrated by other workers including [26,27,28,29,30,31]. Atuanya and Aigbirior, [32] reported the feasibility of biogas production using a UASB reactor of 3.50 L capacity.

Seeding of co-digested pig waste and cassava with wood ash was reported to result into significant increase in biogas production compared with unseeded mixture of pig waste and cassava peels [33]. Fariku and Kidah, [34] reported good biogas production from anaerobic digestion of waste shells of *Lophira lanceolata* fruit. The potential use of local algal biomass for biogas production in Nigeria was recognised by [35]. Odeyemi, [36] compared four other substrates, namely *Eupatorium odoratum*, water lettuce, water hyacinth and cow dung as potential substrates for biogas production. *Eupatorium odoratum* gave the highest yield of biogas and cow dung was the poorest substrate. He concluded that *E. odoratum* was a cheap source of biogas in Nigeria because of its luxuriant and ubiquitous growth. These laboratory studies demonstrated the potential of biogas production from agricultural waste, industrial and urban waste and animal waste in Nigeria.

Numerous health problems have been reported to be associated with spread of human and animal waste. Human waste can leach into ground water from a functioning pit toilet, contamination of groundwater and reservoirs by running storm water and flash floods can result in significant sporadic pollution events, and the type of contamination includes enterobacteria, enteroviruses and a range of fungal spores [37]. Cattle slurry is known to

introduce a range of pathogens including *Clostridium chavoie* (black leg disease), *Ascaris ova*, *E. coli* and *Salmonella spp*. as reported in cow dung slurries in Bauchi state, Nigeria and in poultry wastes in Cameroon [38,39]. Pathogen prevalence in the environment is affected by local climate, soil type, animal host prevalence, topography, land cover and management, organic waste applications and hydrology [40,41,42,43,44]. Installation of biogas digesters has potential to reduce the risks of encountering these pathogens if operated properly. The objective of this project therefore is to create a sustainable solid waste management system that supports greenhouse gas (GHG) emission reduction by the co-digestion of food waste and human excreta for biogas generation. The choice of these substrates was due to the fact that they are the most commonly generated wastes in every home in the country and also because the previous biogas researches in Nigeria have mostly focused animal wastes (cow dung, piggery wastes and chicken droppings) without any emphasis on human excreta or its co-digestion with other substrates. This is the first documented pilot scale attempt to use human excreta for biogas in Nigeria.

2. MATERIALS AND METHODS

2.1 Digester Design

A 40 liter Laboratory scale anaerobic digester was constructed at the Covenant University metal fabricating workshop. The digester was constructed using galvanized metal sheet (35cm in diameter and 53cm high) using a combination of the Karki's Biogas model and the separate floating gas holder system while the cylindrical shape was adopted to enhance better mixing. It was designed to have two handles for easy carriage, three openings; one for slurry inlet, the second serving as gas outlet whiles the third is the thermometer holder for temperature measurement. The gas produced in the digestion chamber was collected in the gas collection chamber by downward displacement of water (acidified water) as shown in Fig. 1.

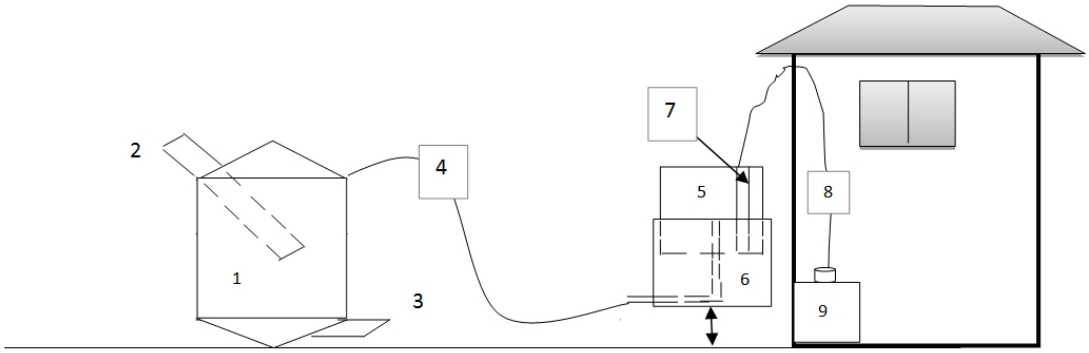

Fig. 1. Schematic View of the digester set up

1. Digester Body; 2. Feedstock Inlet pipe; 3. Effluent Outlet pipe; 4. Hose from digester to gas holder; 5. Gas holder; 6. Water Jacket ; 7. Rule; 8. Hose to gas cooker; 9. Gas cooker.

2.2 Sample Collection and Treatment

Carbohydrate food wastes (boiled yam, bread crumbs, boiled maize, boiled rice and boiled cassava products) were collected from the Covenant University Cafeteria and excreta was

obtained from the student's hall of residence (15 male students were placed on special diet containing the afore-mentioned carbohydrate products only and were strictly monitored for 7 days with little protein supplements from beans and beef). Prior to the commencement of the experiment, the food wastes was thoroughly homogenized using a blender (BLG-401-18N) to achieve minimal particulate size suitable for easy digestion and then mixed evenly with the excreta in constant agitation. The mixture used was a combination of 12kg of food wastes and 3kg of excreta as seed material. This was further mixed with water in a 1:1 w/v to make approximately final 30 liters slurry that was fed into the digester. The experiment was allowed to run for 60 days in continuous fermentation during and after which the following was carried out:

- Volume of gas produced was recorded daily.
- The temperature of the digester content was taken twice daily.
- The pH of the digester content was taken weekly.
- Weekly collection of samples for the isolation and assessment of the microbial population causing the bio-conversion at different stages.
- Measurement of the retention time i.e time between the commencement of gas production and termination of the experiment.
- Measurement of the amount of gas produced at the end of the experiment.
- Analysis of the gas to separate it to its different components.
- Physico-chemical analysis of the digester content after the termination of the experiment.
- Concentration of the digested substrate to form bio- fertilizer.

2.3 Sample Analysis

The physical and chemical composition of the feedstock was evaluated before and after digestion using standard procedures [45]. Parameters analyzed includes organic carbon, moisture content, total solids, total nitrogen, ash content, biochemical oxygen demand (BOD) and chemical oxygen demand (COD).

Total organic carbon was determined by the direct method using the DRB200 reactor. The pH of the sample was maintained at 2 using 0.2 M hydrochloric acid HCl for the expulsion of carbon dioxide. For the moisture content, the samples were dried in moisture dish in an oven at 105ºC until constant weights was obtained. Pre-dried samples obtained from moisture content analysis were ashed in furnace at 550ºC overnight to determine the ash content of the samples. The convection oven method was used to determine the total soilds in 4 grams of the slurry sample. Total nitrogen was determined according to the kjeldahl method using the kjeltec system 1002. The BOD test was performed using a dissolved oxygen test kit. The BOD was determined by comparing the DO level of the sample taken immediately with the DO level of sample that was incubated in complete darkness at 20ºC for 5 days. For the COD measurement, Organic and oxidizable inorganic substances in the sample were oxidized by potassium dichromate in 50% sulfuric acid solution at reflux temperature. Silver sulfate was used as a catalyst and mercuric sulfate was added to remove chloride interference. The excess dichromate was titrated with standard ferrous ammonium sulfate, using orthophenanthroline ferrous complex as an indicator.

2.4 Isolation and Assessment of Microbial Populations

The microbial species in the digester were enumerated by standard plate count technique using 0.1 ml aliquots of appropriate dilution pour plated onto Nutrients agar, MacConkey, Eosin Methylene Blue agar and Fastidious Anaerobic agar for bacteria. Potato Dextrose agar (PDA) plus Chloramphenicol was used for fungi isolation and enumeration. Nutrient agar, MacConkey and EMB agar plates were incubated at 37ºC for 24 – 48 h, PDA plates were incubated at room temperature for 3 – 5 days while Fastidious Anaerobic agar plates were incubated in an anaerobic jar (Oxoid) containing a moistened pack of gas generating kit (Bio-oxoid) at 37ºC for 7 days. Individual colonies were purified and identified by morphological and biochemical techniques [46]. In the case of fungal isolates, the microscopic and macroscopic features of the hyphal mass, morphology of cells and spores, nature of the fruiting bodies, among other criteria were used for identification [47].

2.5 Analysis of Gas to Evaluate its Contents

In the absence of a gas analyzer, the constituent determination of the produced biogas was carried out using an approximate method, which was developed at the Sokoto Energy Research Centre, Usmanu Danfodio University, Sokoto [20]. Since the major constituents of biogas are methane (CH_4) carbon dioxide ($C0_2$) and hydrogen sulphide (H_2S), the method aims at absorbing $C0_2$ and H_2S, thereby leaving an almost entire methane gas.

In doing this, 25g each of potassium hydroxide and lead Acetate was dissolved in 250ml distilled water to obtain a 10% solution. Two conical flasks were washed clean, dried and securely corked at the top, with delivery tubes passing through the corks. A vacuum pump was used to evacuate the two conical flasks via the outlet tube to make them air free. The lead acetate solution was then charged into one of the flasks, while potassium hydroxide solution was charged into the second flask. The flasks were then securely sealed with araldite glue to ensure air tightness. Weights of both flasks were then measured, using an electronic scale.

A PVC rubber tube was used to connect the outlet of the flask containing lead acetate to the inlet of the flask containing potassium hydroxide, thus linking the two flasks. The same tube material was used to connect the inlet tube to the lead acetate flask to the valve on the gas bottle (cylinder where the biogas was stored). The outlet of the flask containing potassium hydroxide was then connected to the inlet of a vacuum pump, with a clip used to resist gas flow. A collecting bag was attached to the outlet of the vacuum pump. All joints were sealed with araldite glue to ensure air tightness. The valve on the gas bottle was then opened and the biogas flowed through the PVC tubes into the delivery tubes. Piping system was done such that the delivery tubes dipped into the solution, thus biogas was passed through the solutions.

As the biogas flowed, lead acetate solution absorbed H_2S, while potassium hydroxide solution absorbed CO_2. The remaining unabsorbed gas was collected as methane. The gas valve was then closed and the set up was allowed to settle for 15mins. The vacuum pump was then used to evacuate the unabsorbed gas into a collecting bag which was then weighed. The set up was disconnected and weights of flask with their solutions were again taken. The difference in weights of (flask + solution) from the initial readings gave the mass of H_2S and $C0_2$ absorbed; while the increase in mass of the collecting bag indicated the mass of methane in the gas. The procedure was repeated twice, in each case; fresh

solutions of lead acetate and potassium hydroxide were prepared. The sketch for the setup is as shown in Fig. 2.

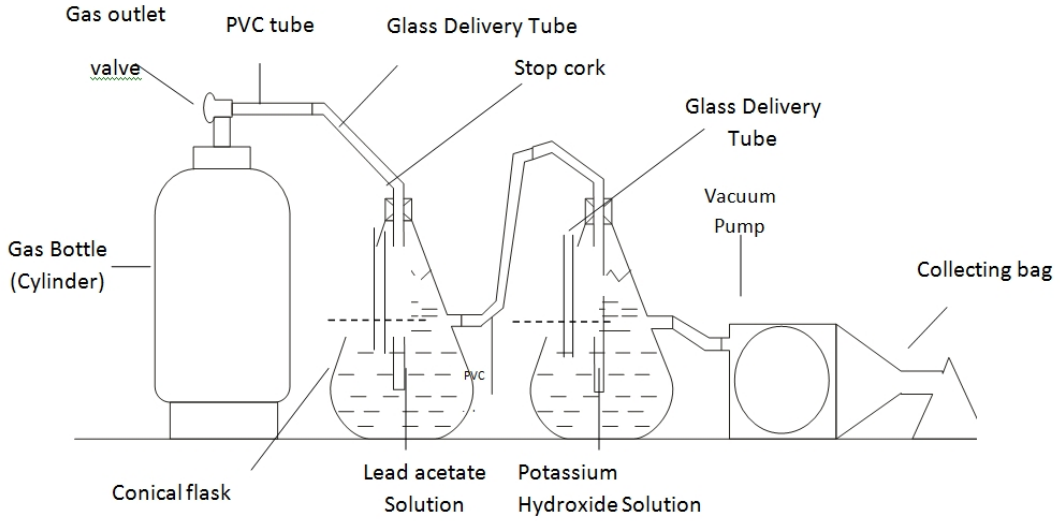

Fig. 2. Sketch of gas analysis

3. RESULTS

The physico-chemical dynamics of the digester feedstock before and after the anaerobic digestion is shown in Table 1. The value obtained for BOD, COD and Ash content show a decrease after the anaerobic digestion while other parameters like total solids, total suspended solids, organic carbon and nitrogen content increased in values after the digestion process. The Carbon/Nitrogen ratio of the feedstock was 139:1.

Table 1. Physico-chemistry of the digester feedstock before and after digestion

Parameter	Before	After
BOD (mg/L)	2590.00	2295.00
COD (mg/L)	12986.70	11486.70
Total solid (%)	6.57	7.38
Total suspended solid (%)	6.50	7.35
Organic carbon (%)	76.75	76.81
Nitrogen content (%)	0.55	0.63
Ash content (%)	1.56	1.52
pH	4.52	6.41

Table 2 reveals the mean microbial count for each week of the digestion process. The count of aerobic organisms showed a decrease trend from 1.4 x 10^8 Cfu/ml in the first week of digestion to 1.0 x 10^4 Cfu/ml in the sixth week. A further steady decrease was observed till the ninth week of digestion with counts of < 10 Cfu/ml. Anaerobic count was found to have an increasing trend from 6.0 x 10^4 Cfu/ml in the first week of digestion to 1.2 x 10^6 Cfu/ml in the last week. For fungal counts, an initial increasing trend from 6.0 x 10^5 Cfu/ml to 9.0 x 10^6 Cfu/ml was observed, after which fungal counts decreased throughout the digestion process.

There was no observable count of methanogens from the first through the fifth weeks; there was however, increased count from 5.0 x 10^3 Cfu/ml in the sixth week to 9.0 x 10^6 Cfu/ml in the ninth week of the digestion.

Table 2. Mean microbial count per week (Cfu/ml)

Week	Aerobes	Anaerobes	Fungi	Methanogen
1.	1.4 x 10^8	6.0 x 10^4	6.0 x 10^5	-
2.	1.2 x 10^7	6.8 x 10^4	7.8 x 10^5	-
3.	1.3 x 10^6	8.0 x 10^4	9.0 x 10^6	-
4.	1.0 x 10^6	9.1 x 10^4	6.2 x 10^5	-
5.	9.0 x 10^5	6.5 x 10^5	8.0 x 10^3	-
6.	1.0 x 10^4	8.9 x 10^5	4.0 x 10^2	5.0 x 10^3
7.	1.2 x 10^2	9.8 x 10^5	7.0 x 10^1	5.5 x 10^5
8.	1.4 x 10^1	1.0 x 10^6	<10	7.6 x 10^6
9.	<10	1.2 x 10^6	-	9.0 x 10^6

Table 3 shows the different species of bacteria and fungi present in the digester during the digestion process. Nine species of bacteria including *Escherichia, Citrobacter, Bacillus, Pseudomonas, Proteus, Klebsiella, Clostridium, Bacteroides,* and *Methanococcus* were isolated and identified while four species of fungi including *Aspergillus, Mucor, Rhizopus and Penicillium* were identified.

Table 3. Species of bacteria and fungi in the digester

Aerobes	Anaerobes	Fungi	Methanogen
Escherichia coli	*Clostridium*	*Aspergillus*	*Methanococcus*
Citrobacter	*Bacteroides*	*Mucor*	
Bacillus		*Rhizopus*	
Pseudomonas		*Penicillium*	
Proteus			
Klebsiella			

The different composition of the generated biogas by analysis reveals CH_4 to be 58%, CO_2 was 24%, while H_2S and other impurities was found to be 19%. Fig. 2 depicts the experimental set up for gas analysis.

Fig. 3 is the graph showing pH changes of the digester feedstock on a weekly basis. The initial pH was 4.52, a sequential increase in pH was observed after a sharp drop in the first week of fermentation. A final pH of 6.41 was recorded at the end of the experiment.

Fig. 4 gives the mean daily records of temperature during the digestion process. The temperature remained at mesophilic range throughout the study. The lowest temperature reading of 22ºC was obtained on the forty ninth, fifty seventh and fifty eighth day while the highest of 30.5ºC was recorded on the first day of the digestion process.

Fig. 5 is the graph of the daily gas production; the production started on the ninth day of fermentation with 600m^3 and followed an increasing trend. It reached its peak on the twenty third day before a gradual fall in production rate was recorded for the rest of the study period and 200 m^3 was obtained on the final day of the experiment.

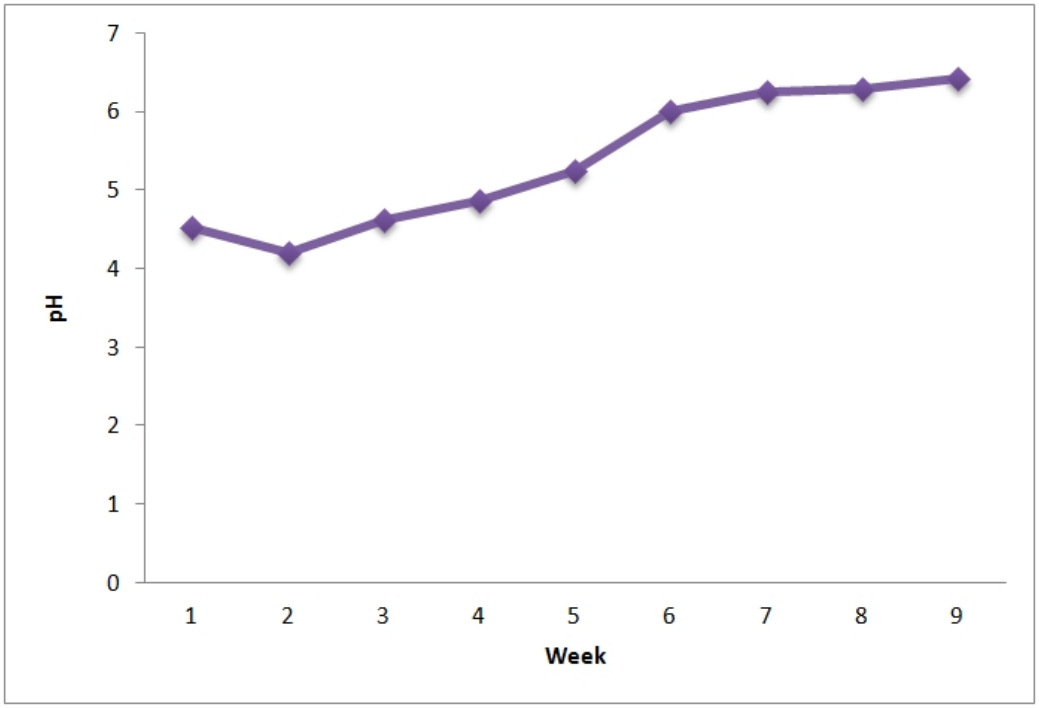

Fig. 3. pH changes during digestion

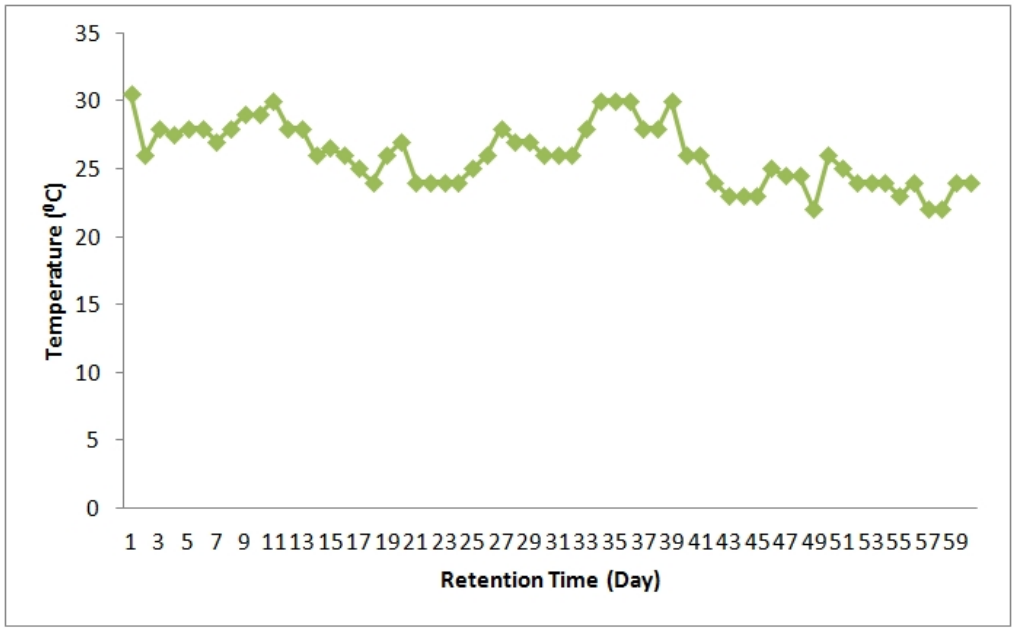

Fig. 4. Daily temperature of digester feedstock

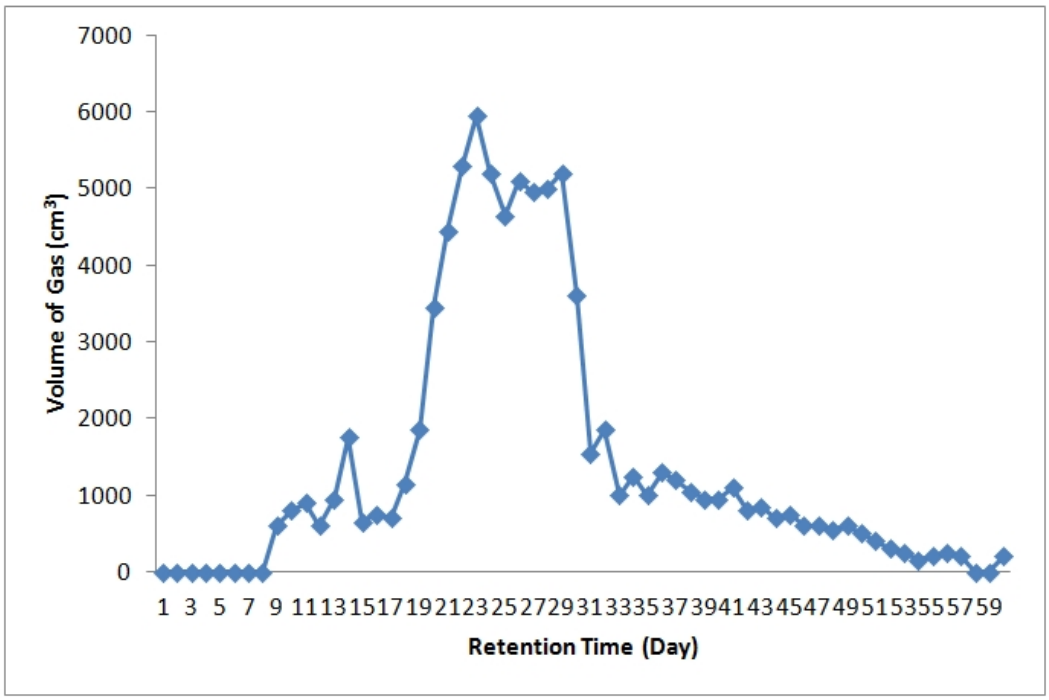

Fig. 5. Daily gas production

Fig. 6 gives the percentage distribution of the micro flora of the digester feedstock during the period of digestion. Aerobic organisms were top in the digester with 40% followed by anaerobic bacteria and fungi with 28% and 24% respectively while methanogenic bacteria were the least populated in the digester having 8%.

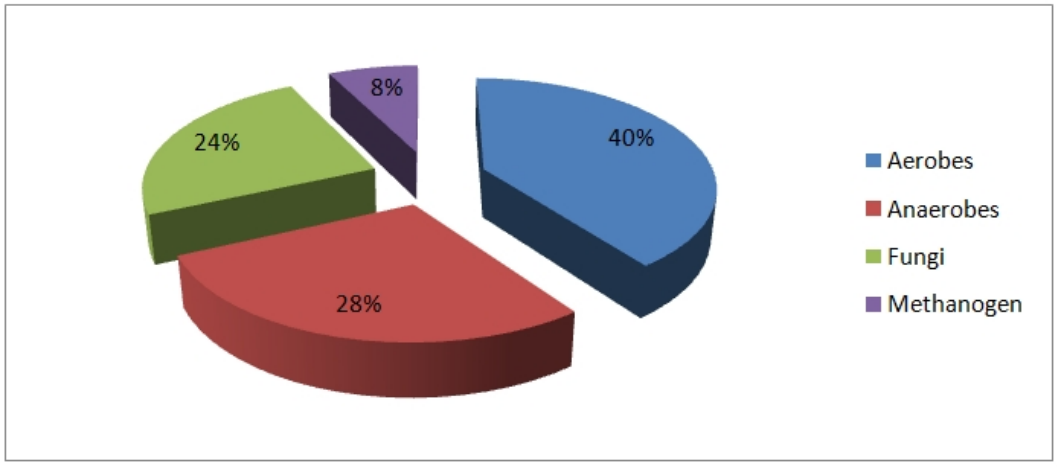

Fig. 6. Percentage distribution of microorganisms in the digester

4. DISCUSSION

The result of the physico-chemical analysis of the feedstock before and after anaerobic digestion reveal that there is reduction in BOD, COD and the ash content indicating that anaerobic digestion is a potent way of reducing these parameters from sludge or wastewater. The reduction in BOD observed in this study agrees with [48] that treating human waste through anaerobic digestion is a credibly ethical sanitation technology and removes Biochemical Oxygen Demand (BOD) from sewage, conserves nutrients (especially nitrogen compounds) and most importantly reduces pathogens. The value obtained for C/N ratio was far exceeding the optimum of between 20:1 and 30:1 for biogas generation from biomass. Too much of carbon may have retarded effective gas generation at some point during the digestion.

Also, the reduction in COD is in agreement with [49] who reported a high COD removal from supernatant of hydrothermally treated municipal sludge by up-flow anaerobic sludge blanket reactor (UASD). In a similar finding, Yoneyama et al. [50] reported the recovery of bioenergy from hydrothermally heated cow manure with COD removal rate reaching up to 75.9%.

The groups of bacteria isolated from the digester feedstock include *Bacillus, Escherichia, Clostridium, Klebsiella, Proteus and Bacteroides* some of which are acid-formers and a methane former *Methanococcus* species, the correct balance between these two groups of microorganisms determines the successful operation of anaerobic digesters for biogas production. The methane formers however multiply at a slower rate than acid formers and are very sensitive to environmental changes as seen in this research. Fungal isolates includes *Aspergillius, Rhizopus, Penicillium and Mucor* whose source could be the feedstock. Pritchard et al. [51] reported a similar result when he isolated *E. coli, Aspergillius, Clostridium botulinum, C. chavoie* and others from water contaminated by human excreta in Malawi. The decreasing trend seen in the aerobic count could be attributed to the increasing anaerobiosis. The acidic nature of the feedstock over the first four weeks of digestion could have supported the growth of acid-producing organisms despite the anaerobic condition. Increase in fungal isolates over the first three weeks even as the digestion becomes more anaerobic is in contrast with fungal general physiology and metabolism which is known to be purely aerobic and this calls for further research on this subject, however, the acidic condition of the digester could be a support for fungi which are known to be acid-loving.

The pH data obtained showed an initial fall to a more acidic level before assuming stable values toward neutrality, by the sixth week, a pH of 6.0 was obtained and remained within 6.0-6.41 throughout the fermentation period thus accounting for the sparce population of methanogens as well as reduced gas production. The initial drop in pH is important since activities of aerobes and facultative aerobes are essential to produce relevant acidic metabolites, which are acted on by methanogenic bacteria to produce methane. Methanogenesis occur best within a pH range of about 6 and 7.8 as seen in the present study which is in conjunction with the findings of [17,52] where the highest biogas yields were observed at digester pH 8.

The temperature of the digester remained constant at mesophilic range (22.0ºC-30.5ºC) throughout the fermentation period. Temperature has been observed by most workers to be quite critical for anaerobic digestion, since methane – producing bacteria operate most efficiently at temperatures 30.0 – 40.0ºC or 50.0 – 60.0ºC [53]. Temperature does not seem to have any significant effect on the amount of gas produced daily as revealed in this study, daily gas generation tend not to follow a specific and this is indicative of the fact that other

parameters apart from temperature could be responsible for the quantity of biogas generated per day. The temperature of below 30ºC in which this experiment was operated, during the harmattan season of December to January, could have contributed to the slow development of methanogens and consequently low methane production. This is similar to the report of [53] that the recovery time for biogas production as well as the quality and quantity of biogas produced from agricultural materials are a function of the nature, and composition of the digester feedstock.

Gas generation commenced on the ninth day, it kept a steady increase rate and reached the peak on the twenty third day before dropping. This result agrees with the findings of [49] who reported an increasing trend of biogas production from commencement and a drop after 300 days from supernatants of hydrothermally treated municipal sludge by up-flow anaerobic sludge blanket reactor. Alkan-Ozkaynak and Karthikayan, [18] also reported a high rate of biogas production from treated thin sillage with a drop towards the end of the experiment.

5. CONCLUSION

The results of this study have shown clearly that food wastes and human excreta, when used in combination are good substrates for biogas generation. These two wastes are the commonest in every home and usually end up in the dustbin or septic tank. Moreover, in a nation like Nigeria where there are no central waste treatment /recycling plants in her cities thus leading to the use of underground septic tanks in individual house, which are serving storage purposes only without any provision for the conversion of such wastes into energy forms like biogas which can then be used for cooking and other domestic purposes. The outcome of this research has given us a clear direction as to how to tackle this issue of domestic waste bioconversion especially food wastes and excreta. As the world and especially developing nations are changing direction from over reliance on fossil fuels because of its attendant pollution problems, the investment into alternative energy sources such as biogas would help arrest energy scarcity as well as militating against ecological disaster in addition to elimination and/or control of deforestation and erosion of the soil surface. Therefore, for developing countries of Africa and especially, Nigeria to survive her current energy crisis, the anaerobic digestion process could provide the much awaited solution if given the desired attention.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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