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Batch Investigation of Biogas Production from Palm Oil Sludge, Bambara Nut Chaff and African Wild Mango at Varying Meteorological Conditions

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Abstract**—** *A custom response design study on the biogas production from blends of Palm oil sludge (POS), Bambara nut (VignaSubterranea) chaff (BNC) and African wild mango (AWM) was carried out. The anaerobic digestion was in the ratio of 3:1 and 2:1 of water to waste depending on the nature of the substrates as follows: System A was 100%POS; B: 100%BNC, C: 100%AWM;D: 50%POS+50%BNC and E: 60% POS+20% BNC+20% AWM. The wastes were charged into 32L capacity metal prototype digesters in a batch for 30 days retention period at an ambient temperature range of 26°C - 37°C. The cumulative gas yield from the five treatments systems (digesters) were different: the 50%POS+50%BNC had the highest cumulative gas yield (69.5L); followed by 100%BNC system (54.5L); 60%POS+20%BNC+20%AWM system (39.2L); 100%POS system (14.4L) and 100%AWM system (11.7L). 100%BNC system had the highest methane content (88.056%); followed by 60%POS+20%BNC+20%AWM system (88.007%); 100%POS system (83.025%); and 50%POS+50%BNC system (73.055%).The research has shown that 100% BNC had the least lag days (6 days), highest calorific value (25330.24KJ/Kg) and highest methane content (88.056%). African wild mango needs to be co-digested to produce flammable biogas. The TS, VS, BOD and TVC were seen to be consistently reducing throughout the digestion period. Meteorological conditions like solar radiation, air temperature and wind speed had significant effects on ambient temperature, slurry temperature, pH and daily gas yield.*

Keywords**— *Batch, Biogas production, Palm Oil Sludge, Bambara Nut Chaff, African Wild Mango, Meteorological Conditions.***

Abbreviations: TS=Total Solid, VS=Volatile Solid, BOD=Biochemical Oxygen Demand, TVC= Total Viable Count

I. INTRODUCTION

In this era of industrialization and civilization energy turns out to be one of the bedrocks to achieving national economic status. Hence, the importance of energy cannot be over emphasized as it cuts across virtually every work we do from a little household to the largest cooperation company in the world. Some of the challenging facts facing the energy sector worldwide is the exhaustive nature of the commonly and generally used non-renewable energy sources such as petroleum, and the serious threats (uncontrolled emission of greenhouse gases) the use of such energy sources such as petroleum poses to the environment and mankind in general. Also alarming is the poor waste management strategies in the country; these wastes especially bio-degradable wastes constitute nuisance at the road sides, in our streets and sometimes in our homes. It has also been stated that uncontrolled greenhouse gases (CH_4, CO_2, CO etc) are emitted during the degradation of organic wastes. Subsequent upon these, there have been so many ameliorating technologies employed to ensuring a reduction of the effects such energy sources as it concerns man and his environment; however, biogas production through anaerobic digestion of organic wastes is one of such technologies. Anaerobic digestion is a multistage biochemical process that can stabilize many different types of organic material to produce methane and carbon dioxide by different groups of micro-organisms under anaerobic condition (Joaquin, 2008). Lo et al., (2010) in their work titled "Modelling biogas production from organic fraction

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of MSW co-digested with MSWI ashes in anaerobic bioreactors" stated that anaerobic digestion involves four steps which are: hydrolysis, acidogenesis, acetogenesis and methanogenesis. The activities of micro-organisims present at different stages of anaerobic digestion however depends on various parameters such as temperature, pH, concentration of nutrients agitation, pre-treatment of feedstocks, carbon/nitrogen ratio, hydraulic retention time etc. Hence, in order to improve the overall efficiency of anaerobic digestion process, there have been many works on biogas production through anaerobic co-digestion of different wastes. Anaerobic co-digestion is defined as the treatment of a mixture of at least two different substrates with the aim of improving the efficiency of anaerobic digestion processes (Neczaj et al, 2012).

Oil palm is a common plant in the Southern part of Nigeria. Specifically the south-eastern part believes that it has some traditional values associated with it. Crude palm oil is one of the major products of palm oil processing plants with palm oil effluent as a by-product. This palm oil effluent is often accompanied by palm oil sludge which contains substantial quantities of solids left-over after the liquid must have drained. However, palm oil sludge are sources of pollution to the environment if discharged untreated, this is due to large oxygen depleting capabilities when present in aquatic systems (Hassan et al., 2013). According to Okwute et al., 2007 from their work titled "The environmental impact of palm oil mill effluent (POME) on some physico-chemical parameters and total aerobic bio-load of soil at a dump site in Anyingba, Kogi state Nigeria."studies on POME dump site revealed that the physico-chemical properties of the soil at this dump sites were obviously altered due to its acidic nature. Palm oil sludge are produced and discharged into the environment in millions of tonnes from both milling plants and individual households nationwide, thus, posing a big treat to the environment. Anaerobic digestion is the most suitable method for the treatment of effluents containing high concentration of organic carbon such as POME (Borja et al., 1996a). Projection depicts that 555, 457 and 409 million m^3 of methane gas could be produced under high, low and current status production rates scenario respectively up to 2030, if Nigeria harnesses the energy contained in palm oil mill effluent (Ohimain et al., 2014).

Vigna subterranean (Bambara nut) is a local bean plant commonly grown in the Northern part of Nigeria, but consumed in all part of the country. After it is processed the chaff are either used as blend for poultry feeds or they are thrown away, thus, depleting the environmental harmony. Previous work done on the biogas production potential of Bambara nut chaff showed that it had potentials for biogas production. According to Ofoefule et al. (2010) in their work titled "Biogas production from blends of Bambara nut (Vignasubterranea) chaff with some animal and plant wastes" observed that Bambara nut chaff has the potential for biogas production though the expected increased biogas yield and extended flammable time was not achieved by the co-substrates employed (cow dung, swine dung, cassava peel and field grass wastes). However, they proposed a chemical treatment to increase the pH to neutrality to enhance gas production and extend the retention time.

African wild mango (Irvingiagabonensis) is a plant which produces seeds rich in fat (around 70% on dry matter basis), traditionally used as a soup thickener in central and western African regions. However, it is obvious that much has not been done as it concerns biogas production from African wild mango.

Thus, the major objective of this work is to co-digest these three wastes to: (i) determine their physico-chemical properties and their effects on biogas production as well as waste treatment. (ii) to note the effect of African wild mango as a co-substrate with respect to increased gas production (iii) to determine the optimum mix ratio for optimized gas production. (iv) to have an idea of the level of waste treatment achieved at 30 days retention time.

II. MATERIALS AND METHODS

The study adopted custom response design. Bambara nut shells were collected from Ogige market in Nsukka and also from the university environment. African wild mango was gotten from Ibagwa plantation in Nsukka. Palm oil sludge was collected from a local palm oil processing plant in Ajuona community in Nsukka.

SAMPLE PREPARATION

The African-wild mango was chopped in smaller pieces and soaked in water at 100% level for 2 days. Thereafter, it was sieved to facilitate digestion due to the nature of the waste. The same was done for Bambara nut chaff for effective digestion and on-time gas production. After the soaking period, the feedstocks were then weighed out for charging.

EXPERIMENTAL SET-UP

Metallic model biodigesters (Plate 1) utilized for the study were each of 32.0 L working volume (fabricated locally at the National Centre for Energy Research and Development, University of Nigeria, Nsukka). Materials such as top loading balance (Camry Emperors Capacity 50 kg/110 Ibs), plastic water troughs, graduated transparent plastic buckets for measuring daily gas production, the pHep pocket-sized

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pH meter (Hanna Instruments), thermometers, pressure gauge, thermoplastic hose pipes, metallic beehive stand and biogas burner fabricated locally for checking gas flammability were used.

III. EXPERIMENTAL STUDY

The fermentation of the blends took place for 30 days at the prevailing ambient mesophillic temperature range of 26°C to 37°C. The ratio of the water to waste in each charging is as shown in table 1. This was based on the moisture content of the organic wastes at the point of charging the biodigesters. Palm Oil Sludge, Bambara Nut Chaff and African Wild Mango were co-digested to result to the following treatment blends: A (100%POS), B (100%BNC), C (100%AWM), D (50%POS+50%BNC) and E (60%POS+20%BNC+20%AWM). Table 1 shows details of the blending. Co-digestion is used to increase methane production from low-yielding or difficult to digest materials. Volume of gas produced, ambient and slurry temperatures, relative humidity and wind speed, insolation, pH and slurry pressure were monitored on daily basis throughout the period of digestion. Flammability check was also carried out on daily basis until the system produced flammable biogas and occasionally till the end of digestion period. The study was carried out at the exhibition ground of National Centre for Energy Research and Development, University of Nigeria, Nsukka.

Table.1: Substrates weight

Digesters	Quantity of undigested substrates	Amount of water (kg)	Total volume of slurry (L)	Volume Space for Gas (L)	Total volume of Digester (L)	Mix Ratio of slurry
A (100% POS)	8kg of POS	16	24	8	32	2:1
B (100% BNC)	4.8kg of BNC	19.2	24	8	32	4:1
C (100% AWM)	8kg of AWM	16	24	8	32	2:1
D(50% POS + 50% BNC)	3kg of POS + 3kg of BNC	16	24	8	32	3:1
E(60% POS + 20% BNC + 20% AWM)	4.8kg of POS + 1.6kg of BNC + 1.6kg of AWM	16	24	8	32	2:1

DETERMINATION OF PHYSICO-CHEMICAL PROPERTIES

The methods used in this work to determine the physico-chemical properties of the undigested substrates are clearly defined as follows: The Meynell (1982) method was used to determine the: Total solids and Volatile solids while the A.O.A.C method (1990) was used to determine the: Moisture content, Ash content and Crude fibre content. The Pearson (1976) method was used in the determination of the Crude fat content with the use of Soxhlet extraction apparatus. The Micro-Kjedahl method as described in Pearson (1976) was used in the determination of Crude protein content while the method of surface viable count was used in the determination of the Total viable count (Number of living micro-organisms). The Energy content was determined with bomb calorimeter (model XRY-1A, make: Shanghai Changji, China), using A.O.A.C (1990) method).Walkey-Black (1934) method was used to determine the Carbon content while the ambient and slurry temperature was taken daily using a liquid in glass thermometer and the pH was ascertained using the Hanna instrument pH meter standardized using buffer solutions for pH 7.0.The pressure of the gas produced in the biogas digesters was measured daily using the sphygmomanometer. This water displacement method was used to determine the biogas volume while the Bacharach (PCA2) gas analyzer was used to determine the gas composition. A locally made gas burner was used to carry out the gas flammability tests. The population of the microbes in each of the treatment cases was determined at different times (at charging, flammable, peak of production and end of digestion), during the period of study to monitor the growth of the microbes at the various stages.

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Plate.1: The Anaerobic Biodigesters

Gas Analysis

The flammable gas compositions from the (100%POS), (100%BNC), (50%POS+50%BNC) and (60%POS+20%BNC+20%AWM) were analyzed using BACHARACH (PCA2) Gas Analyzer, made in United States.

Data Analysis

The data obtained for each of the systems were subjected to analysis using Microsoft Excel XP 2007. Meteorological data were obtained from Centre for Basic Space Science, University of Nigeria, Nsukka.

IV. RESULTS AND DISCUSSION

Table 2 shows the physicochemical properties of undigested wastes.

Table.2: Table of the physicochemical properties on the charging day (Day 0)

PARAMETERS	Sample A	Sample B	Sample C	Sample D	Sample E
Crude Fat (%)	0.7	0.75	0.6	0.95	0.6
Crude Protein (%)	1.4	1.14	1.31	1.45	1.44
Crude Nitrogen (%)	0.224	0.182	0.21	0.232	0.23
Carbon Content (%)	4.5	4.31	2.23	4.7	4.68
Total Solid (%)	8.46	9.3	7.37	10.4	9.5
Volatile Solid (%)	6.3	6.9	5.5	7.43	6.93
Ash Content (%)	3.9	4.7	3.2	6	5.3
Moisture Content (%)	89.29	88.68	88.24	85.19	89.47
Crude Fibre (%)	2.89	5.4	5.1	3.8	4.6
B.O.D (mg/l)	80	86	65.6	96	89.6
T.V.C (cfu/ml)	40×10^5	45×10^5	34×10^5	63.33×10^5	50×10^5
C/N	20.09	23.68	10.62	20.26	20.35

Table 3 shows the gas compositions for the various substrates.

Table.3: Table of gas composition of the flammable gas from experiment

Digester (Treatment)	**Retention Time(Day)**	**Cumulative Volume of Biogas(L)**	**Flammable Time(Day)**	**Component of Biogas (%)**			
				CO_2 (%)	**CO (%)**	**CH_4 (%)**	**Other components**
POS (100%)	30	14.4	23	20	0.0246	83.0246	3
BNC (100%)	30	54.5	5	15	0.0555	88.0555	3
AWM (100%)	30	11.7	-	-	-	-	3
POS (50%)+BNC (50%)	30	69.5	23	30	0.0055	73.055	3
POS(60%)+BNC(20%)+AWM(20%)	30	39.2	23	15	0.0065	88.0065	3

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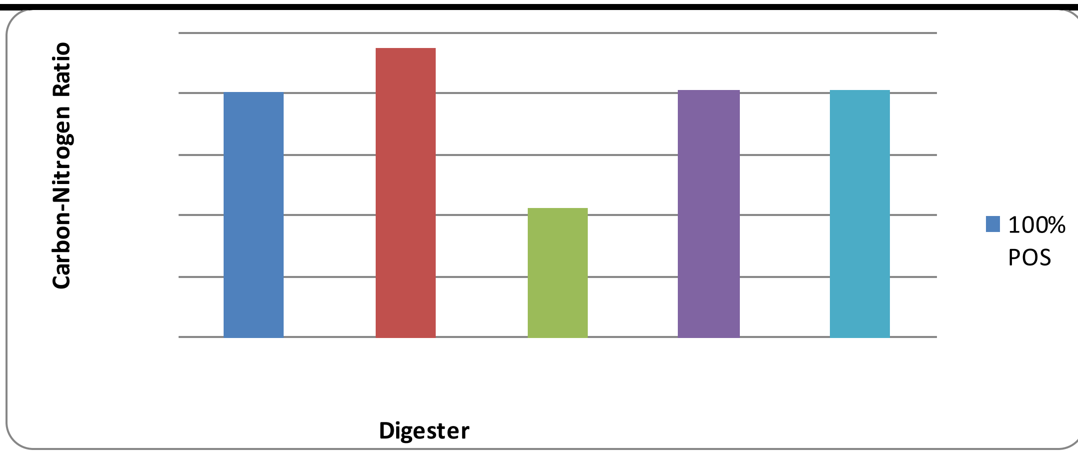

Fig.1: Carbon-Nitrogen Ratio of Digesters

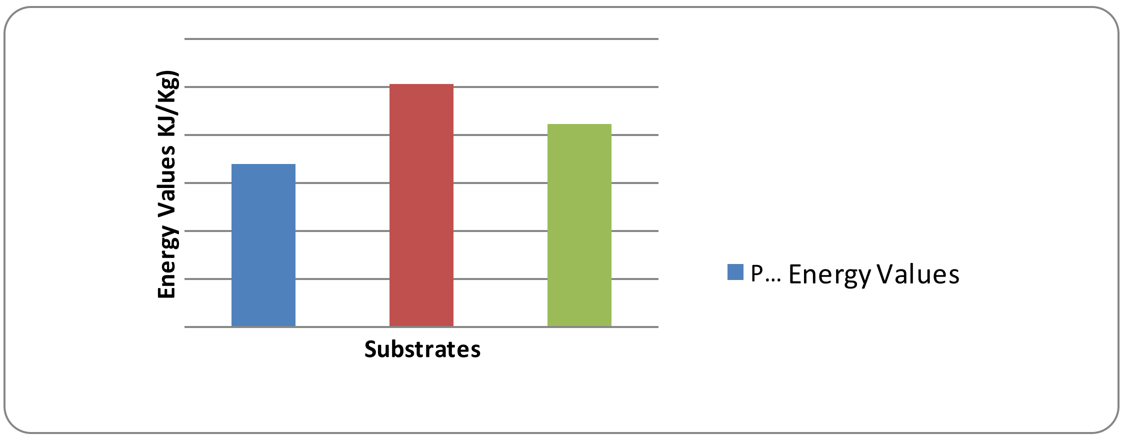

Fig.2: Energy values of Substrates

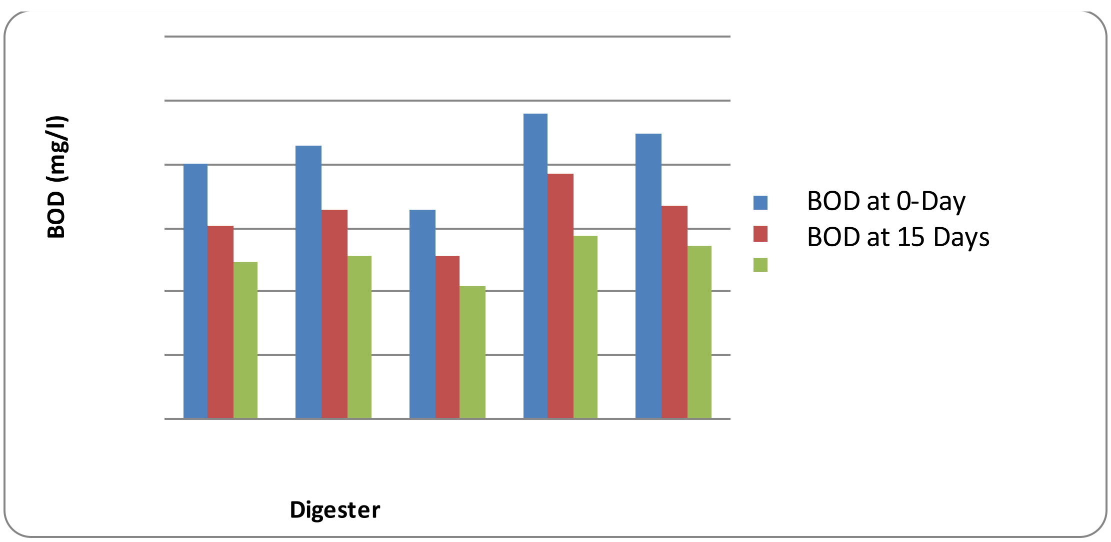

Fig.3: Weekly BOD Values

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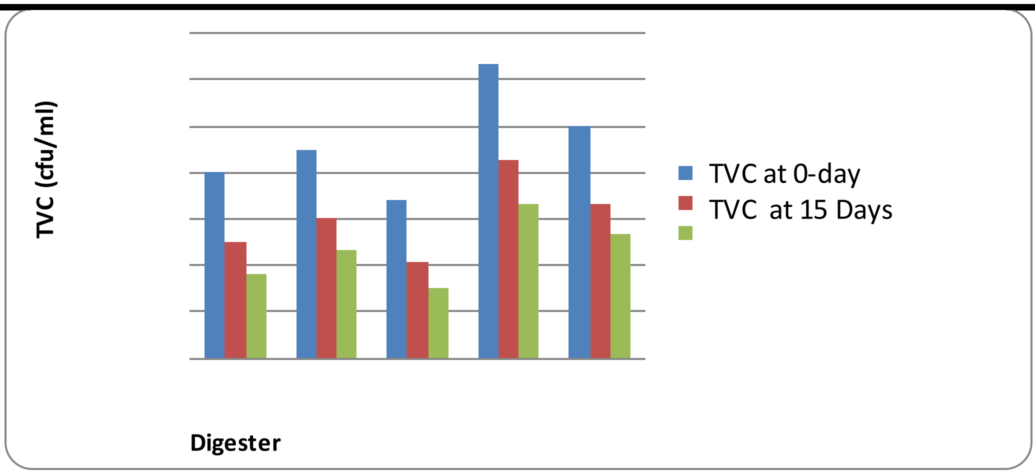

Fig.4: Weekly TVC Values

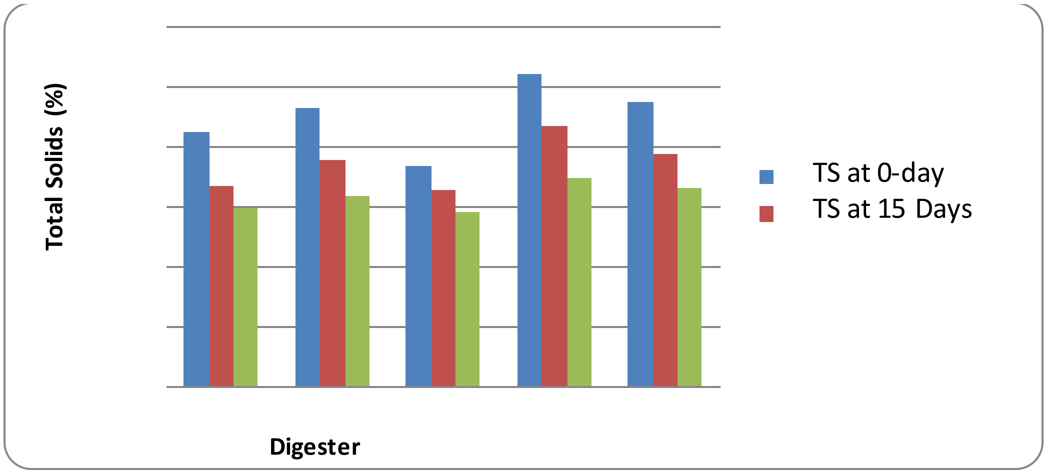

Fig.5: Weekly Total Solids

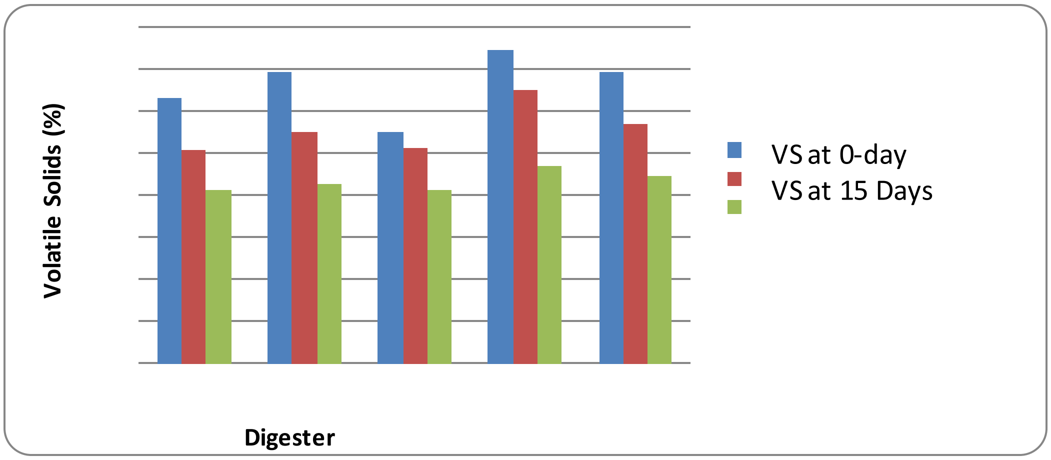

Fig.6: Weekly Volatile Solids

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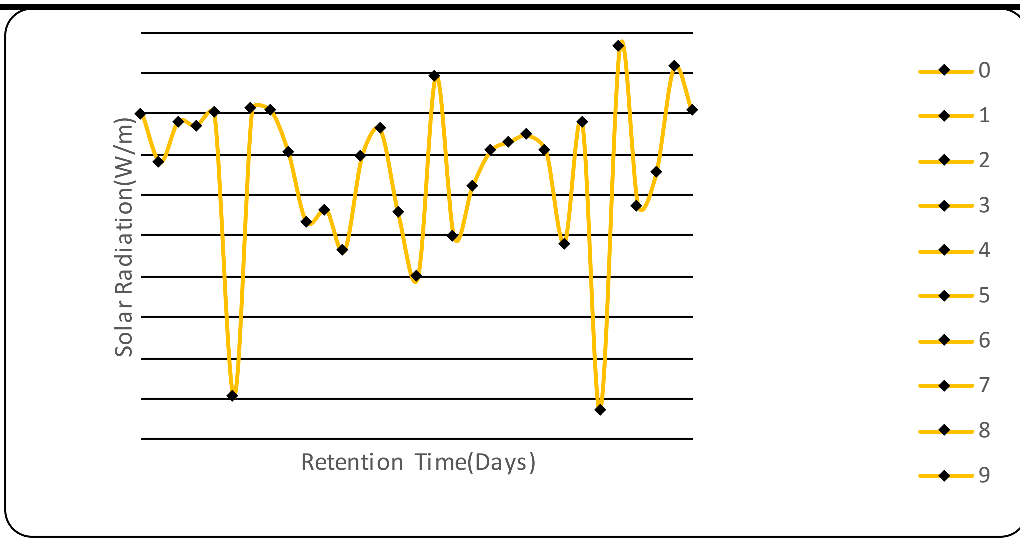

Fig.7: Solar Radiation Versus Retention Time

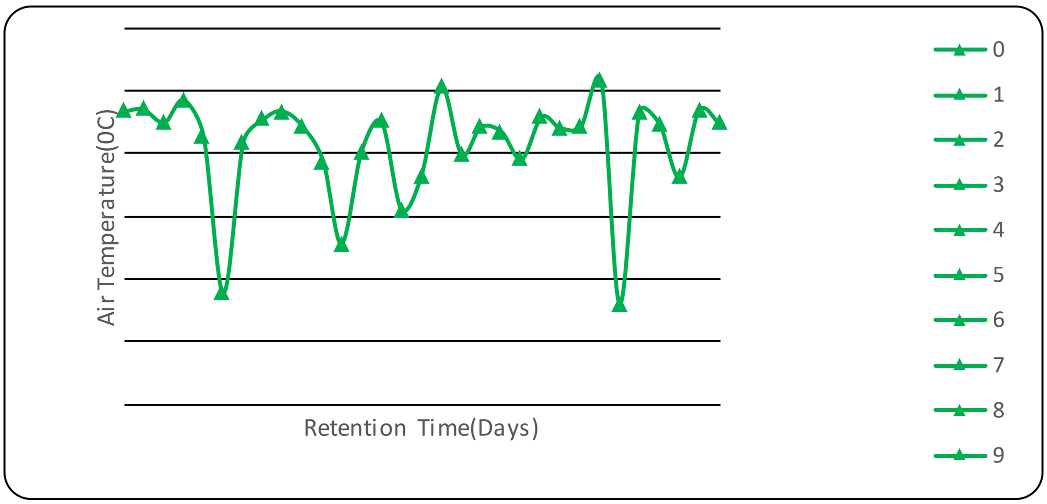

Fig.8: Air Temperature Versus Retention Time

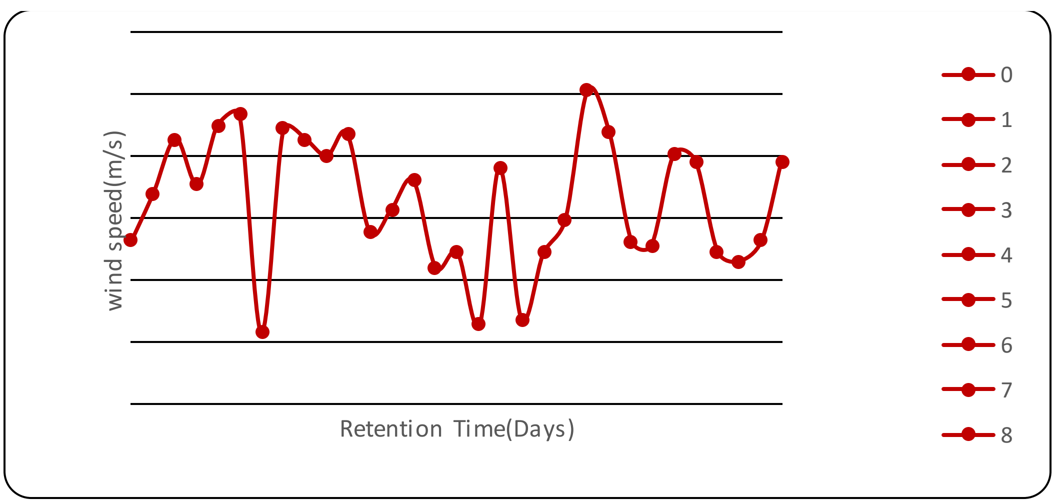

Fig.9: Wind Speed Versus Retention Time

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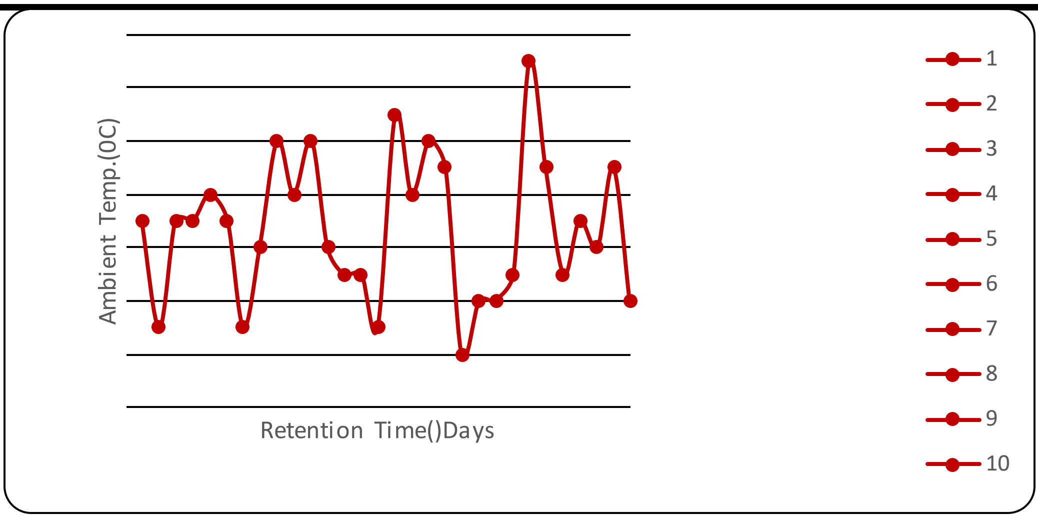

Fig.10: Ambient Temperature Versus Retention Time

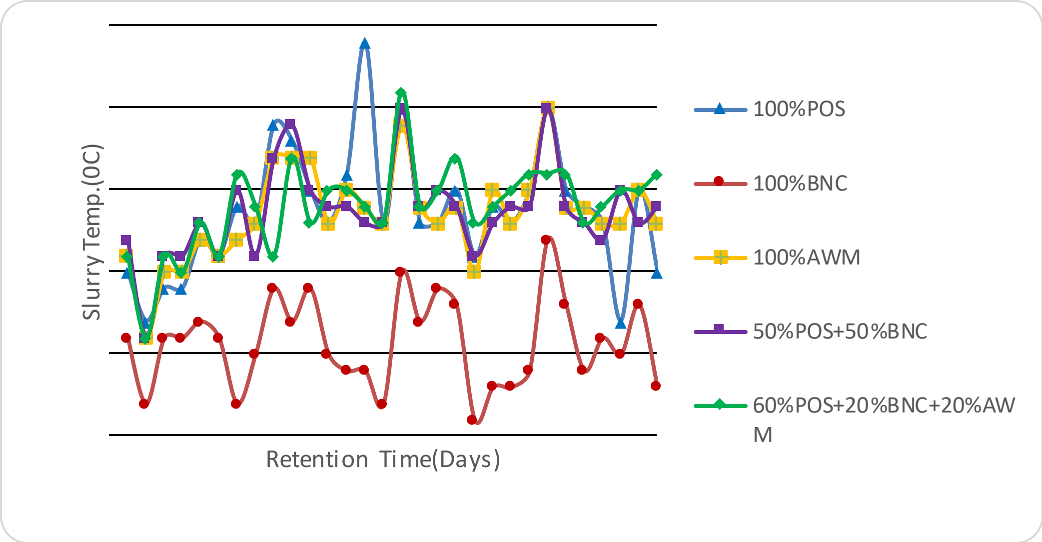

Fig.11: Slurry Temperature Versus Retention Time

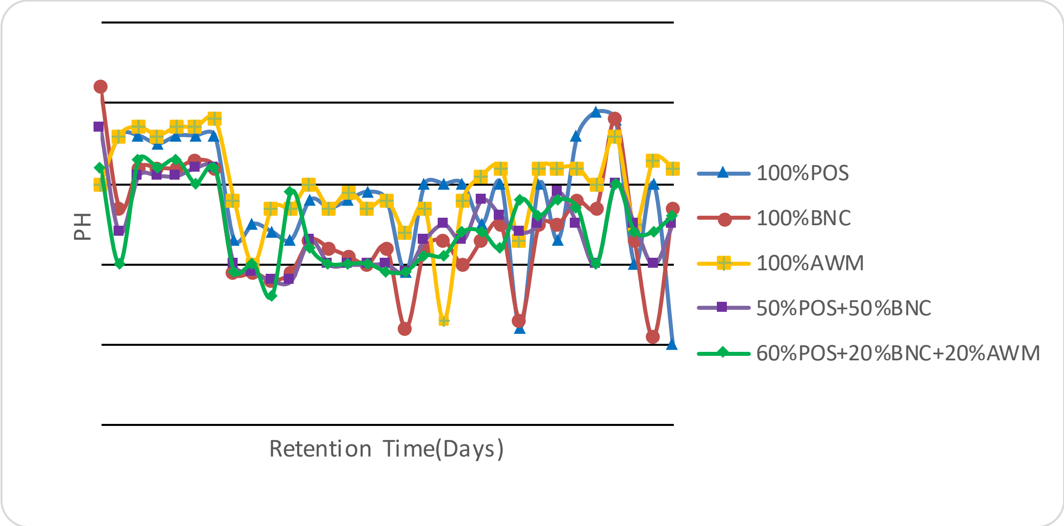

Fig.12: pH versus Retention Time

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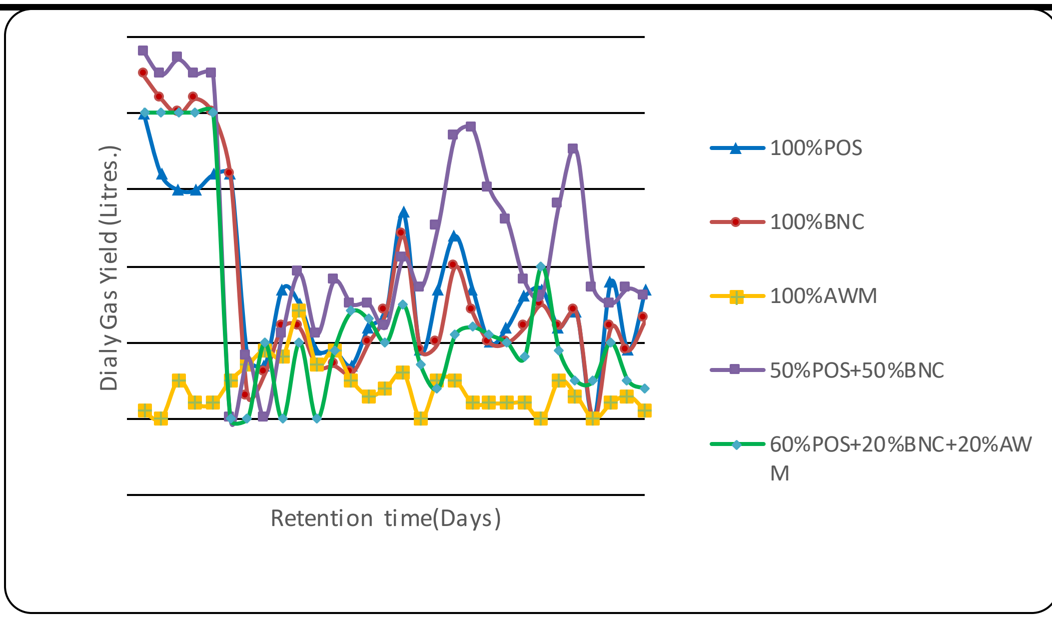

Fig.13: Daily Gas Yield Versus Retention Time

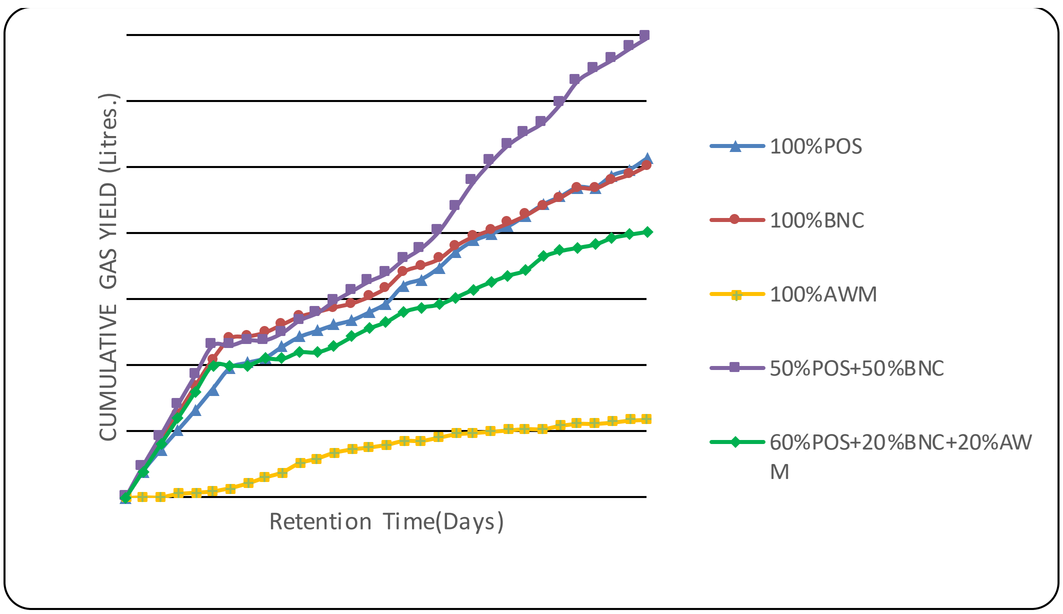

Fig.14: Cumulative Gas Yield Versus Retention Time

PROXIMATE ANALYSIS OF THE SYSTEMS

The proximate composition includes the ash, moisture, crude fibre and crude fat contents of the wastes. From table 2, The ash content of the 50%POS+50%BNC system was highest (6%) while that of 100%POS was least (3.9%).The 100%BNC system had the highest crude fibre content (5.4%) while the 100%POS had the least crude fibre content (2.89%). Each of the wastes for the systems had optimum moisture content because of the mix. Biological activities are increased when digester fluid are mixed to provide homogenous temperature and nutrient condition throughout the digester (Lay et al., 1997). The crude fat for each of the wastes was appreciable.

DIGESTERS' PERFORMANCE

The results of digester performances (from Table 3) indicated that 100% BNC system flamed on the 6th day while 100%POS, 50%POS+50%BNC and 60%POS+20%BNC+20%AWM systems flamed on the 23rd day. By having lesser number of lag days, the 100% BNC system is better in biogas production technology (Nagamani and Ramasamy, 1999). The cumulative gas yield from the five treatments were different: the 50%POS+50%BNC had the highest cumulative gas yield (69.5L); followed by 100%BNC system (54.5L); 60%POS+20%BNC+20%AWM system (39.2L); 100%POS system (14.4L) and 100%AWM system (11.7L) during the 30 days retention period. 100%BNC system had the highest methane content (88.056%); followed by 60%POS+20%BNC+20%AWM system (88.007%); 100%POS system (83.025%); and 50%POS+50%BNC system (73.055%).

EFFECT OF C/N RATIO ON THE SYSTEMS

From the results of Table 2 and figure 1, the C/N ratio of (100%POS), (100%BNC), (50%POS+50%BNC) and (60%POS+20%BNC+20%AWM) CD, were seen to be within the range of the optimum C/N. Consequently, each of these digesters flamed. Digesters 100% AWM 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. During anaerobic digestion, microorganisms utilize carbon 25 to 30 times faster than nitrogen (Yadvika et al., 2004). To meet these requirements, microbes need 20 to 30:1 ratio of C to N.

CALORIFIC VALUES OF SUBSTRATES

The energy contents (figure 2) show that palm oil sludge and bambara nut chaff are good feedstock for biogas production if properly utilized while African wild mango has to be co-digested to produce biogas. Bambara nut chaff had the highest calorific value (25330.24 KJ/Kg); followed by African wild mango (21053.77JJ/Kg) and then Palm oil sludge (16935.98KJ/Kg).

EFFECT OF WEEKLY BOD, TOTAL VIABLE COUNT, TOTAL SOLIDS, VOLATILE SOLIDS; AND ANAEROBIC DIGESTION AS A WASTE MANAGEMENT TECHNOLOGY

Biochemical Oxygen Demand (BOD) is the amount of dissolved oxygen needed (i.e. demanded) by aerobic biological organisms to breakdown organic materials present in a given water sample at certain temperature over a specific time period. This is a quantitative expression of the ability of microbes to deplete the oxygen in waste water. It is also the amount of oxygen required for the biological decomposition of organic matter in wastewater by bacteria under aerobic conditions. This depletion is caused by the microbes consuming organic matter in the water via aerobic respiration. Total Viable Count (TVC) gives a quantitative idea about the presence of microorganisms such as bacteria, yeast and mould in a sample. The count actually represents the number of colony forming units (cfu) per gram (or per ml) of the sample.Total solid shows the total solid matter constituent of the entire organic waste both degradable and non-degradable. The volatile solid is the true organic matter available for bacterial action during digestion. Figures 3, 4, 5 and 6 show reductions in weekly BOD, TVC, TS, VS respectively. This is expected as the wastes stabilized. Anaerobic digestion is the most important method for the treatment of food waste because of its techno-economic viability and environmental sustainability. The use of anaerobic digestion technology generates biogas and preserves the nutrients which are recycled back to the agricultural land in the form of slurry or solid fertilizer. The relevance of biogas technology lies in the fact that it makes the best possible utilization of food wastes as a renewable source of clean energy since there is always reduction in BOD, TVC, TS and VS.

THE EFFECTS OF SOLAR RADIATION, WIND SPEED AND AIR TEMPERATURE ON AMBIENT TEMPERATURE, SLURRY TEMPERATURE, PH AND DAILY BIOGAS YIELD

There was variation in solar radiation resulting to highest solar radiation (582.604W/m) on the 26th day and least (135.655W/m) on the 25th day. Air temperature had highest (30.309^{o}C) on the 24^h day and least (23.196^{o}C) on the 25^h day. Wind speed had highest (1.813m/s) on the 21st day and least (1.035m/s) on the 6th day (figures 7, 8 and 9). The variation in these climatic conditions gave rise to variations in ambient temperature, slurry temperature, pH, and daily volume of gas produced (figures 10, 11, 12, 13 and 14).

V. CONCLUSION

This study has shown that wastes such as palm oil sludge, bambara nut chaff and African wild mangowhich have been termed nuisance to the environment can be utilized to produce biogas which can be used as an alternative to the widely known and used fossil fuel. The digestate after biogas has been produced can also be used as fertilizer to improve plant growth and enhance soil capability in producing.

From the results, it can be seen that the palm oil sludge and bambara nut chaff substrates are excellent in producing flammable biogas; capable of being utilized for any purpose such as cooking. African wild mango if co-digested can produce flammable biogas. The research has shown that 100% BNC had the least lag days, highest calorific value and highest methane content.

This study has shown a new source for wealth creation and at the same time a means of decontaminating the environment by waste recycling and transformation. This wastes that are consumed in large quantities in homes can be used to produce biogas, this will help them lose the name attached to them as being nuisance to the environment.

VI. RECOMMENDATIONS

The following has been recommended as a result of findings from this work:

- The gas produced should be further purified to enhance its scope of utilization such as in welding and automobiles.
- A method of gas collection which is safe and highly reliable should be enhanced.
- Highly advanced technological equipment should be constructed for the storing the gas separately from the digesters.
- Equipment that can purify and utilize the biogas that has been produced can be fabricated; this will encourage people to use biogas.
- Researches should be carried out to discover means of improving the methane quality produced and also the quality of the bio-fertilizer left after digestion.

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