

Mesophilic Anaerobic Co-Digestion of Horse Dung, Plantain Peel and Egg Shell at Different Climatic Conditions

Cordelia Nnennaya Mama*, Ugwuja Thankgod Oruchukwu, Eze Chidi Ezekiel and Richard Ifechukwu Nnamdi

Department of Civil Engineering, University of Nigeria, Nsukka, Enugu State, Nigeria

*Corresponding Author: cordelia.mama@unn.edu.ng

Abstract— This study centered on biogas production from locally available animal and kitchen wastes: horse dung (HD), plantain peel (PP) and egg shell (ES) using five 32-Litres metallic prototype digesters. The anaerobic digestion was in the ratio of 3:1 of water to waste for all the samples as follows: Sample A was 100%HD, Sample B; 100% PP, Sample C; 100% ES, Sample D; 50%HD+50%PP and Sample E; 60% HD+30% ES+10% PP. The retention time was 30 days. Parameters like pH, daily biogas production, ambient and slurry temperatures, solar radiation, wind speed, air temperature alongside the physico-chemical properties of wastes were monitored. The cumulative gas production yield was 81.8L, 22.3L, 51.9L, 109L, and 75.2L for samples A, B, C, D and E respectively. The flammable time was 10th, 13th, 16th, 6th, 10th day for samples A, B, C, D and E respectively. The result revealed that sample D: 50%HD+50%PP gave the highest yield of biogas (109L) and flamed earlier than the other samples (6 days) while sample B: 100%PP had the lowest yield of biogas (22.3L). The results also showed that the sample that had the highest composition of methane in the biogas produced was Sample C: 100%ES with 90.3995% while the lowest composition of methane was found in Sample B: 100%PP to be 79.9963%. The TS and VS were seen to be consistently reducing while TVC and BOD reduced (immediately the microbes got acclimatized to the environment) showing the level of waste treatment achieved during the digestion period of 30 days.

Keywords— *Anaerobic, Co-Digestion, Horse Dung, Plantain Peel, Egg Shell, Climatic Conditions.*

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

I. INTRODUCTION

Today, solid waste management and rising energy cost are two major problems facing the world in the recent days. Secondly the issue of global warming and climate change are strongly receiving public attention and have become a major environmental concern both at national and international level. The increasing concentration of atmospheric greenhouse gases as a result of culpable human activities represents the major cause for this problem (Lassey, 2008).

Possible methods to solve these problems are conversion of the solid wastes into methane gas via anaerobic digester. Anaerobic digestion can be used to treat all types of biodegradable waste, including food waste. It is used to stabilize mixed waste after the removal of recycleable materials. The realistic solution to reduce methane emission from manure storage will be using anaerobic digester in a controlled biogas plant so that methane can be collected as biogas (Külling et al., 2002). In this way atmospheric methane emission from the manure storage could dramatically be decreased. Biogas generated can be utilized for various energy services, such as heat, combined heat, and power. In addition, the biogas can be used as vehicle fuel, after removal of carbon dioxide and hydrogen sulphide in an up grading system (Lantz et al, 2007).

Co-digestion for anaerobic digestion means more than one feedstock is used at a time to produce biogas. Co-digestion is used to improve the methane yield from low yield feedstocks. Care must be taken to select compatible feedstocks that enhance methane yields and avoid materials that may inhibit biogas and methane production. Agricultural feed stocks have successfully been co-digested with restaurant bio wastes, food processing and crop residues (EPA 2012). The quantity, availability, and cost of co-digestion feed stocks are important factors to consider. Other factors to consider include: regulations and

permitting; digester capacity; mixing of the feed stocks; and nutrient.

Literature contains substantial biogas production from different wastes in the locality. Nwankwo, 2014 did a research on the digestion of plantain peel (PP) and the codigestion of plantain peel with swine droppings (PP-SD) to observe the biogas production ability in a 50litres metal prototype biodigester. The waste (PP and PP-SD) were subjected to anaerobic digestion for a period of 44days. The cumulative biogas yield for the plantain peels alone (PP) was 80.10dm³ while that of plantain peels mixed with swine droppings (PP-SD) was 163.30m³. The PP-A commenced flammable gas production on the 2nd day while, PP-SD commenced flammable gas production on the 30th day. The PP-SD had the highest cumulative gas yield though with a slow onset of gas flammability. The overall result indicates that the low gas yield of PP could be significantly enhanced by blending it with swine droppings.

Ezekoye, 2013 carried out a research on Plantain/almond leaves and pig dung used as substrates in anaerobic bio digester for producing biogas by batch operation method within the mesophilic temperature range of 20.0 to 31.0°C. The study was carried out to compare biogas production potential from plantain/almond leaves and pig dung wastes. The cumulative biogas produced from the plantain/almond leaves was 220.5L while the cumulative biogas from the pig dung was 882.5L. The methane component of gas from pig dung was 70.2% while that for plantain/almondleaves with algae was 72.7%. The biogas from the almond/plantain leaves became combustible on sixteenth day while the biogas from the pig dung was combustible on fourteenth day. Results showed that pig dung produced more biogas than the almond/plantain leaves within the same period.

Kusch et al, 2008 conducted an experiments on methanogenesis from horse dung were conducted in laboratory-scale batch reactors in order to determine the substrate performance in a solid-phase digestion process, more specifically in terms of potential energy recovery and suitable process technology. Dung from a horse stable with straw bedding was used. The temperature was kept in the mesophilic range. In the percolation process (with process water sprinkled over the stacked biomass) a proportion of 10-20% of solid inoculum (pre-digested horse dung) was found to be suitable. Comparative experiments with both percolation and flooding revealed a higher biogas production per volume for the flooded process, as no addition of solid inoculum was necessary. Methane yield from fresh material was similar in both processes: around 170 L(N) CH₄ per kg VS added was obtained in six-week cycles with untreated material under optimized conditions.

Methane production was increased after chopping the substrate. Pre-aeration resulted in decreased methane production.

Hadin and Eriksson, 2016 stated that horse keeping is of great economic, social and environmental benefit for society, but causes environmental impacts throughout the whole chain from feed production to manure treatment. According to national statistics, the number of horses in Sweden is continually increasing and is currently approximately 360,000. This in turn leads to increasing amounts of horse manure that have to be managed and treated. Current practices could cause local and global environmental impacts due to poor performance or lack of proper management. Horse manure with its content of nutrients and organic material can however contribute to fertilisation of arable land and recovery of renewable energy following anaerobic digestion. At present anaerobic digestion of horse manure is not a common treatment. In this paper the potential for producing biogas and biofertiliser from horse manure is analysed based on a thorough literature review in combination with mathematical modelling and simulations. Anaerobic digestion was chosen as it has a high degree of resource conservation, both in terms of energy (biogas) and nutrients (digestate). Important factors regarding manure characteristics and operating factors in the biogas plant are identified. Two crucial factors are the type and amount of bedding material used, which has strong implications for feedstock characteristics, and the type of digestion method applied (dry or wet process). Straw and waste paper are identified as the best materials in an energy point of view. While the specific methane yield decreases with a high amount of bedding, the bedding material still makes a positive contribution to the energy balance. Thermophilic digestion increases the methane generation rate and yield, compared with mesophilic digestion, but the total effect is negligible.

Ofilii et al., 2010 researched on the quantity of biogas yield from anaerobic digestion of rabbit waste and swine dung. The same volume of digester was used in this experiment to accurately compare the volume of the biogas yield. The maximum volume of biogas produced from the 45 litres digester used was 8.2 litres and 6.8 litres respectively for swine dung and rabbit waste. It was observed that the biogas production from swine dung was greater than that of rabbit waste. These studies focused on anaerobic digestion of one substrate and or co-digestion of only two substrates. Co- digestion was not extended to more than two wastes. This necessitated embarking on this study. Hence, the aim of this work is to anaerobically co-digest horse dung,

plantain peel and eggshell. These wastes were chosen in this experiment because they are available within the experimental locations.

II. MATERIALS AND METHODS

The study adopted custom response design. Horse dung was gotten from Obollo-Afor market Udeno L. G. A, egg shell was gotten from Dawuba fast food restaurant behind Ekpo Refectory, University of Nigeria, Nsukka and plantain peels were gotten from Odenigbo Junction Nsukka and some from Ogige market, Nsukka. 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 lbs), plastic water troughs, graduated transparent plastic buckets for measuring daily gas production, the pHep pocket-sized pH meter (Hanna Instruments), thermometers, pressure gauge, thermoplastic hose pipes, metallic beehive stand and biogas burner fabricated locally for checking gas flammability were used.

Experimental Study

The fermentation of the blends took place for 30 days at the prevailing ambient mesophilic temperature range of 24°C to 34°C. The ratio of the water to waste in each charging was 3:1. This was based on the moisture content of the organic wastes at the point of charging the biodigesters. Horse dung, plantain peel and egg shell were co-digested to result to the following treatment blends: A (100%HD), B (100%PP), C (100%ES), D (50%HD+50%PP) and E (60%HD+30%ES+10%PP). Table 1 shows details of the blending. Co-digestion is used to increase methane production from low-yielding or difficult to digest materials. The moisture content of the respective wastes determined the waste to water ratios used. 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

DIGESTER	Horse Dung (kg)	Egg Shell (kg)	Plantain Peel (kg)	Water (kg)
A (100%HD)	6	-	-	18
B (100%PP)	-	-	6	18
C (100%ES)	-	6	-	18
D (50%HD+50%PP)	3	-	3	18
E (60%HD+30%ES+10%PP)	3.6	1.8	0.6	18

The ratio of water to waste is 3:1

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.



Plate.1: The Anaerobic Biodigesters

Gas Analysis

The flammable gas compositions from the 100% HD, 100% PP, 100% ES, 50%HD+50%PP and 60%HD+30%ES+10%PP 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.

III. 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
Moisture Content %	88.33	84.48	87.93	88.46	85.19
Ash Content (%)	2.60	2.10	3.40	3.7	1.80
Crude Fibre(%)	3.80	3.40	4.10	4.60	2.51
Crude Fat (%)	0.50	0.80	0.60	0.55	0.90
Crude Protein (%)	1.75	1.23	1.40	0.96	2.01
Crude Nitrogen (%)	0.175	0.196	0.224	0.154	0.18
Carbon Content (%)	4.2	4.15	4.55	4.63	4.3
Magnesium (ppm)	0.5710	0.5742	0.7383	0.9286	0.7285
Calcium (ppm)	3.7753	1.8090	5.1124	4.4045	3.8539
Volatile Solid (%)	8.70	11.07	8.73	7.13	11.03
Total Solid (%)	10.33	12.87	9.93	8.77	13.40
B.O.D (mg/l)	59.2	73.6	62.4	51.2	68.8
Phosphorus (%)	0.60	0.90	1.40	1.10	1.00
Total Viable Count (TVC) (cfu/ml)	41.67×10 ⁵	56.67×10 ⁵	46.67×10 ⁵	37.50×10 ⁵	50.83×10 ⁵
C/N	24.0	21.174	20.313	30.065	23.889

Table 3 shows the gas compositions for the various substrates.

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

Sample	Flammable Time/Lag Time (days)	Retention Time (days)	Cum vol of Biogas (L)	Composition of Biogas (%)				
				CO ₂ (%)	CO (ppm)	CO converted to (%)	CH ₄ (%)	Others
A	10	30	81.8	17	10	1×10 ⁻³	79.999	3
B	13	30	22.3	17	37.3	3.7×10 ⁻⁴	79.9963	3
C	16	30	51.9	6.6	5	5×10 ⁻⁴	90.3995	3
D	6	30	109.0	14.4	8	8×10 ⁻⁴	82.5992	3
E	10	30	75.2	9.6	8	8×10 ⁻⁴	87.3992	3

Table 4 shows the energy content/ calorific values of the substrates

Table.4: Energy Contents/Calorific Values of substrates

Egg shell	13938.63KJ/Kg
Plantain peel	20634.86KJ/Kg
Horse dung	21351.17KJ/Kg

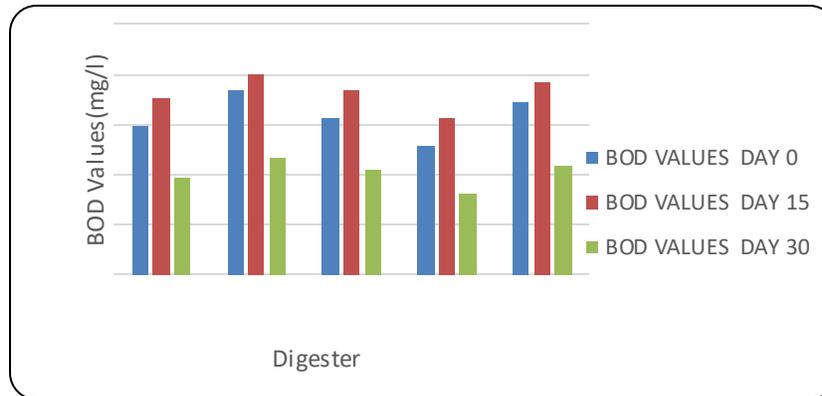


Fig.1: Weekly BOD Values

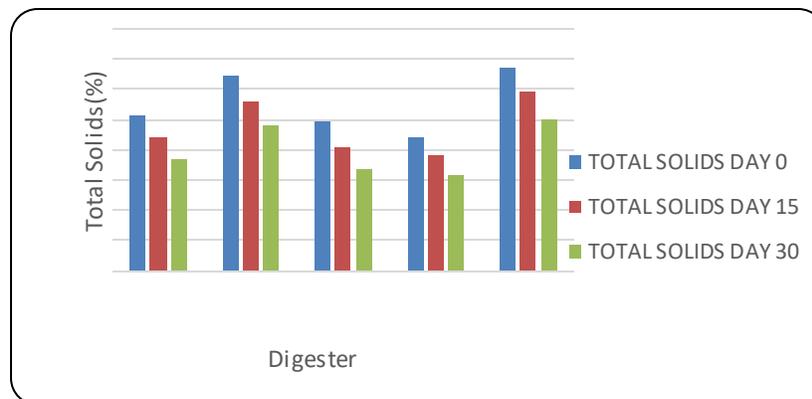


Fig.2: Weekly Total Solids

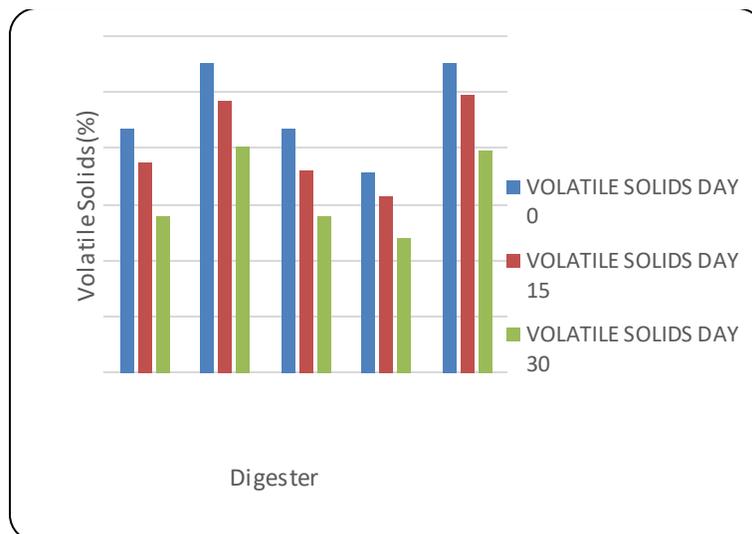


Fig.3: Weekly Volatile Solids

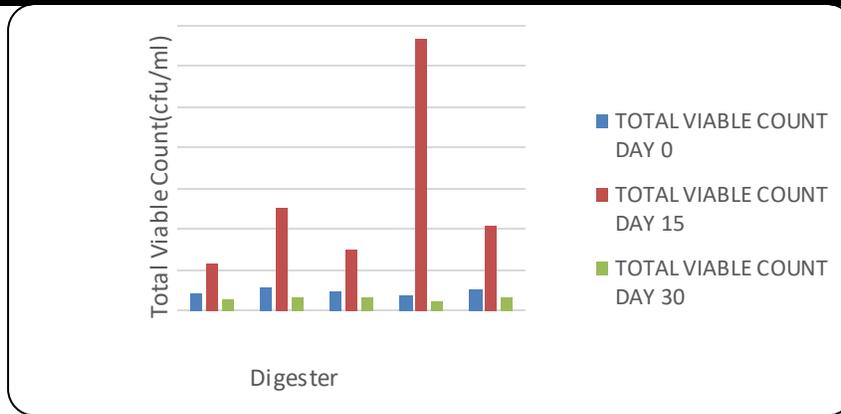


Fig.4: Weekly Total Viable Count

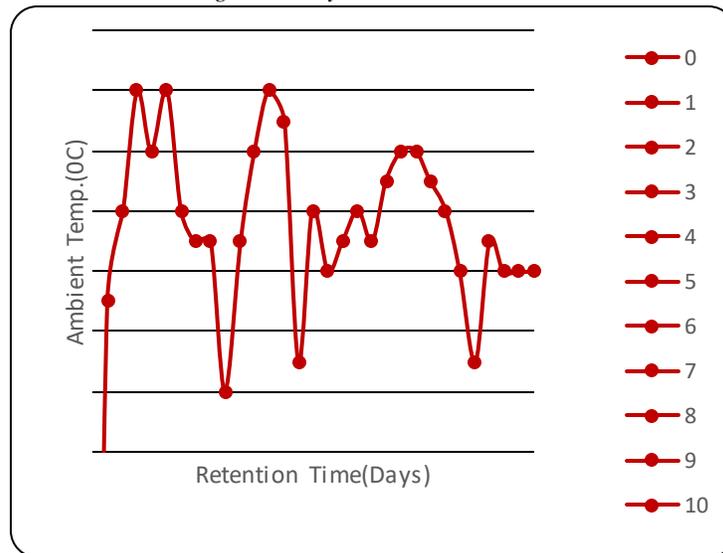


Fig.5: Ambient Temperature versus Retention Time

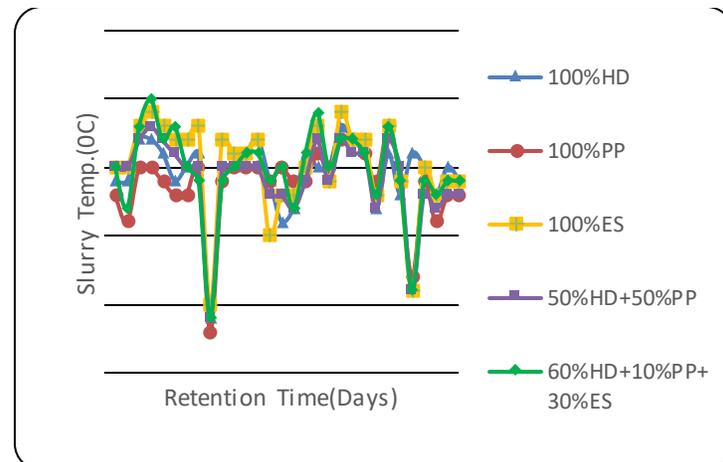


Fig.6: Slurry Temperature versus Retention Time

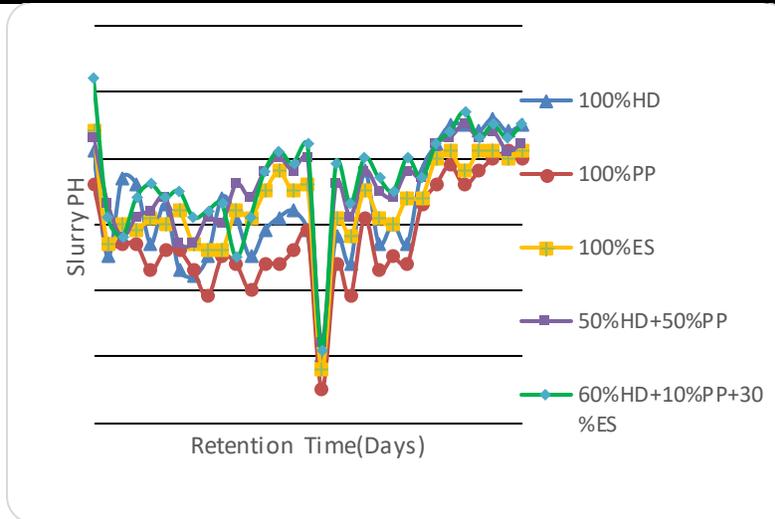


Fig.7: Slurry pH versus Retention Time

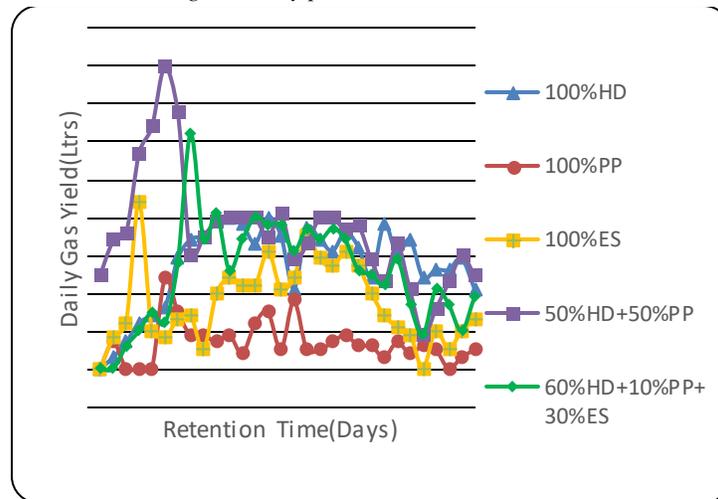


Fig.8: Daily Gas Yield versus Retention Time

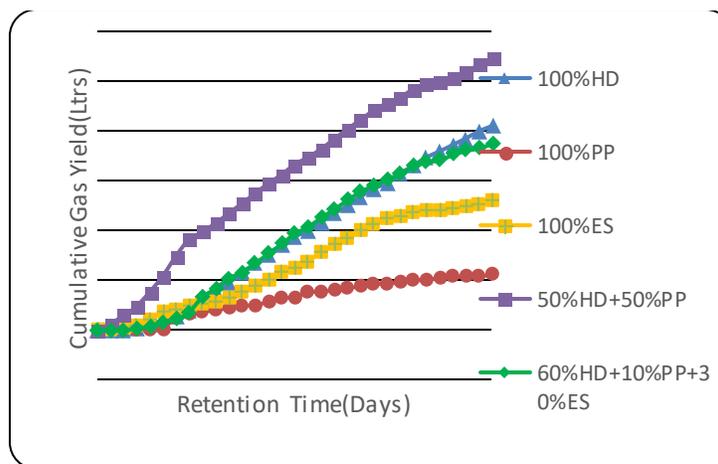


Fig.9: Cumulative Gas Yield versus Retention Time

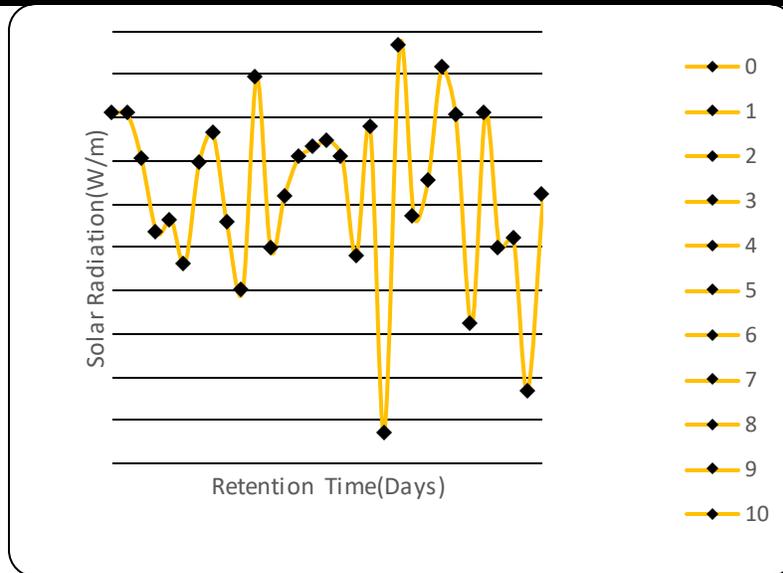


Fig.10: Solar Radiation versus Retention Time



Fig.11: Air Temperature versus Retention Time

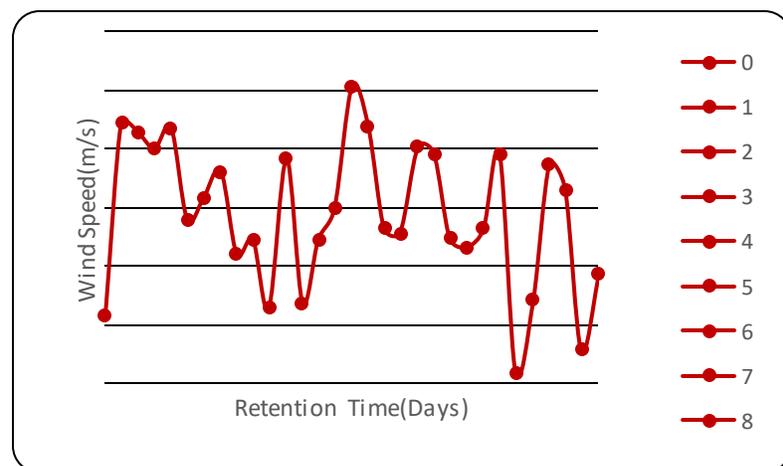


Fig.12: Wind Speed versus Retention Time

DIGESTERS' PERFORMANCE

The results of digester performances (from Table 3) indicated that 100% HD system flamed on the 10th day; 100%PP system flamed on the 13th day; 100%ES system flamed on the 16th day, 50%HD+50% PP system flamed on the 6 day while 60%HD+30%ES+10%PP system flamed on the 10th day. By having lesser number of lag days, the 50%HD+50% PP system is better in biogas production technology (Nagamani and Ramasamy, 1999). The cumulative gas yield from the five treatments were different: the 50%HD+50%PP had the highest cumulative gas yield (109L); followed by 100%HD system (81.8L); 60%HD+30%ES+10%PP system (75.2L); 100%ES system (51.9L) and 100%PP system (22.3L) during the 30 days retention period. 100%ES system had the highest methane content (90.3995%); followed by 60%HD+30%ES+10%PP system (87.3992%); 50%HD+50% PP system (82.5992%); 100%HD system (79.999%) and 100%PP system (79.9963%).

EFFECT OF C/N RATIO ON THE SYSTEMS

From the results of table 1, the C/N ratio of 100%HD, 100% PP, 100%ES, 50%HD+50%PP and 60%HD+30%ES+10%PP were seen to be within the range of optimum C/N ratio. Consequently all the digester systems flamed. 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 (table 4) show that the substrates are good feedstock for biogas production if properly utilized. Horse dung had the highest calorific value, followed by plantain peel and then eggshell.

EFFECT OF WEEKLY TOTAL SOLIDS AND VOLATILE SOLIDS

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. There was generally a reduction in the weekly trend for total solids and volatile solids for each of the systems (figures 2 and 3).

EFFECT OF WEEKLY BOD AND TOTAL VIABLE COUNT

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. The BOD and TVC on 0-day were lower than those on the 15th day since the microbes needed to acclimatize with the environment because there was no seeding. However, the values of BOD and TVC for the 30th day were lower than those of the 15th day; indicating stabilization. These trends were generally observed for each of the digester systems (figures 1 and 4).

THE EFFECTS OF SOLAR RADIATION, WIND SPEED AND AIR TEMPERATURE

There was variation in solar radiation resulting to highest solar radiation (582.604W/m) on the 20th day and least (135.655W/m) on the 19th day. Air temperature had highest (30.309°C) on the 18th day and least (23.196°C) on the 19th day. Wind speed had highest (1.813m/s) on the 15th day and least (0.84m/s) on the 25th day (figures 10, 11 and 12). The variation in these climatic conditions gave rise to variations in ambient temperature, slurry temperature, pH, and daily volume of gas produced (figures 5, 6, 7 and 8).

IV. CONCLUSION

This study has shown that wastes such as horse dung, plantain peel and egg shell which 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 three substrates and their combinations are excellent in producing flammable biogas; capable of being utilized for any purpose such as cooking. The research has shown that even though egg shell had the lowest calorific value; it had the highest methane content. 50% HD+50%PP had the least lag time (6 days).

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.

V. 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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