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TESTING THE PERFORMANCE OF TWO DIFFERENT DIGESTERS FOR BIOGAS PRODUCTION FROM HOUSEHOLD WASTE CO-DIGESTED WITH COW DUNG

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ABSTRACT

The research was carried out at Mechanical Engineering Department, Federal University Dutsin-Ma, Katsina State, Nigeria. Different researches of bio-digesters have been conducted for biogas production but the physico-chemical properties of wastes, constituents of biogas and volume of digesters were not considered in previous research which resulted to poor performance of digesters by producing low flame. Hence the physico-chemical properties of wastes were determined, constituents of biogas were determined and volumes of digesters were considered for this research work so as to have effective performance of the digesters. This study involved the performance evaluation of two different digesters for the production of biogas from household Wastes co-digested with cow dung to select the best digester among the two suitable for household used. Two different digesters each of 5.5 litres and 90 litres were used for testing the performance of digesters using household Wastes co-digested with cow dung in which anaerobic digestion process at both mesophilic and thermophilic temperatures were employed.After the physico-chemical properties of wastes test, analysis of biogas constituents, Ventilation test and flammability test of both digesters were conducted.The highest volume of biogas produced for Digester 1 was 115 liters/day within a period of 15days and 2537 liters/day within a period of 28days for Digester 2.The Ventilation and flammability tests were conducted of both digesters in which Digester 1 passed Ventilation test and failed flammability test.The Digester 2 passed both Ventilation and flammability tests.The research concluded that, the Digester 2 was more effective because of large volume of Digester, high percentage of cow dung and considering physico-chemical properties of wastes.And it should be recommended to use large volume of digester and high quantity of cow dung than household wastes during the mixing ratio in order to produce high volume of biogas.

Keywords: Biogas, Digester, Wastes, Household, Cow dung

INTRODUCTION

Different researches of bio-digesters have been conducted for biogas production but, physico-chemical properties, constituents of biogas and volume of digesters were not conducted in previous research work to determine the effectiveness of digester which produced low flame. Hence the physico-chemical properties of wastes were determined, constituents of biogas were determined and volumes of digesters were considered for this research work so as to have effective performance of digesters. Therefore, the focus of this research is to test the performance of two different bio-digesters from household wastes co-digested with Cow dung to produce methane rich-gas for household cooking in which anaerobic process would be employed to produce methane rich-gas.

The aim of this research work is to test the performance of two different digesters from household wastes co-digested with cow dung.

The challenges of unstable energy productions and utilization in Nigeria are historical, dated back to 1896 when energy was first introduced into the Nigerian energy market in Lagos. We recalled that this happened fifteen years after it was done in England as reported by Claudius, 2009. But the gap in terms of energy generation, economic growths and social well-being between these two environs are huge today. To achieve rapid growth in any economy means to improve growth of efficiency in the energy sector of such economy. Economic manufacturing is the engine room for poverty alleviation and the only means to attainable development. As energy mix is shifting towards cleaner lower carbon fuels driven by environmental needs and technological advancement, meeting these challenges becomes paramount for Nigeria as a developing nation.

According to (Bank et al., 2011; Ranjeet et al., 2008; Zhang et al., 2007; e.t.c) biogas or methane yield is measured by the amount of biogas or methane that can be produced per unit mass of volatile solids (VS) contained in the feedstock for a given amount of time under a given temperature.

The term "Bio-digester" is any structure that converts organic material (waste) into energy without oxygen. Bio-digester is a technique in which biological degradation of human waste by bacteria takes place. The biodegradation of human waste take place when Inoculums digests the human waste converting it into water and gases in the process as reported by Lou *et al.* (2012). The Chinese fixed dome, the Indian floating drum and the tubular digester are all considered small-scale models as reported by Bond, T., and Templeton, M.R. (2011). Considering the cost of the test, the gas was tested only 3 times during the study period. Each test was done in approximately 3 weeks interval. As the degradation of starch particle continuously increased with the increase of the methanogenic bacteria, the percentage of methane in the outlet gas also increased. Also, as the food waste is mainly starch, which is a hydrocarbon, the gas obtained from the anaerobic digestion of food waste contains an incredibly high amount of methane. From the standpoint of fluid dynamics and structural strength, an egg-shaped vessel is about the best possible solution. The following types of digesters were discussed below [https: //www.Biogas-energypedia.com.].

Anaerobic digestion is the process of generating biogas from organic materials through insufficient oxygen supply. The organic material is subjected to different stages of degradation. Every degradation step in the anaerobic digestion process is performed by different groups of microorganisms, which place different requirements on their environment. During hydrolysis, polymers (e.g., lipids, carbohydrates, and proteins) are hydrolysed by fermentative bacteria into long chain fatty acids, glucose, and amino acids. Acitogenesis is the second steps of the process where monomers are degraded into volatile fatty acid (e.g., acetate, propionate, and butyrate) along with the generation of by-products. The volatile fatty acids are then converted into acetate and hydrogen by hydrogen-producing acetogenic bacteria. At the end of the degradation chain, two groups of methanogenic bacteria produce methane from either acetate or from hydrogen and carbon dioxide. These bacteria are strict anaerobes. Only a few species of methanogenic bacteria can degrade acetate into methane and carbon dioxide, whereas all methanogenic bacteria are able to use hydrogen to produce methane. The first and second group of microorganisms as well as the third and fourth are linked closely with each other. Therefore, the process can be accomplished in two stages. In a balanced anaerobic digestion process, the rates of degradation in both stages are of equal size. If the first degradation step runs too fast, the acid concentration rises and the PH drops below 7.0, which inhibits the methanogen bacteria. If the second phase runs too fast, methane production is limited by the hydrolytic stage. The rate-limiting step depends on the compounds of the substrate. Cellulose, proteins, or fats are degraded slowly into monomers within several days whereas the hydrolysis of carbohydrates is completed within a few hours as reported by Zhang *et al*. (2014).

They can be spherical, cylindrical and dome in shapes. The materials commonly used for fabrication include plastics, brick, cement, fibre glass for the dome shapes, and metals such as stainless steel and mild steel. Biogas is a good source of renewable energy, composed of 50-70% methane and 30-50% carbon dioxide with other traces of gases reported by Zhang *et al.*(2007). Biogas is an odorless and colourless gas that burns with blue flame. Its caloric value is about 20 MJ/m3 and it usually burns with 60% efficiency in a conventional biogas stove. The methane gas is used as fuel to substitute firewood, cow-dung, petrol, diesel, and electricity depending on the nature of the task and local supply conditions and constraints, as reported by Valijanian et al.(2018).The term "Biogas" is commonly used to refer to a gas which has been produced by the biological breakdown of organic matter in the absence of oxygen. Biogas is one of the products formed during anaerobic digestion process and consist of CO_2, CH_4, H_2S, H_2,H_2O and some other traces of other substances depending on the composition of the substrate as reported by Ishmael *et al*.(2017). According to Weiland, P. (2010). Biogas production from waste biomass has gained significant attention as a sustainable alternative to conventional fossil fuels. This study investigated the potential of using tree waste materials for biogas production and optimizing the process parameters. A lab-scale anaerobic digester was used to evaluate the biogas generation potential of tree trimmings and sawdust. Different process parameters, including the substrate-to-inoculum ratio, temperature, and pH, were varied to optimize the biogas yield. We also analyzed the chemical composition of the feedstock and the digestate to assess nutrient recovery potential. The results showed that tree trimmings and sawdust are suitable feedstock for biogas production, with a maximum biogas yield of 228.4 mL CH_4/g VS added obtained at a substrate-to-inoculum ratio of 2:1 and a temperature of 35°C. The nutrient analysis showed that the digestate obtained from the anaerobic digestion process is a rich source of nitrogen, phosphorus, and potassium, which can be used as fertilizer as reported by Molua et al.(2023).The amount of biogas needed to meet the requirements of one family varies depending on the methane content of the biogas, the pressure in the gas pipe and the stove efficiency. Cultural aspects such as cooking traditions and family size also affect the fuel consumption. Because every family situation is different, it is difficult to determine exactly how much biogas a family requires. The methane content of the biogas is a direct indicator of the quality of the biogas since when burnt; it is the methane that is converted into energy in form of heat. A higher methane content of the biogas means that there is more energy available for creation of heat. The biogas is combustible if the methane content is greater than 50%. Anaerobic digestion (AD) refers to a process where organic matter is synergistically decomposed by a microbial consortium in an oxygen free environment while anaerobic digestion can be operated under liquid (wet) semi solid or solid-state (dry) conditions, when the total solid of substrate are < 10%, 10-15% or >15% respectively. Largely, liquid anaerobic digestion is frequently applied in the full-scale operation, owing to reasons such as easy operation and maintenance, and increasing methane (CH_4,) yields biogas production by anaerobic digestion offers great advantages over other ways of bio energy production. In fact, it is one of the energy efficient and environmentally friendly technologies for the bio-energy production reported by Hussaro *et al*. (2017).

The significance of this research work is to test the performance of two different digesters and select the most effective for household use. Hence, this will enable the researcher to consider physico-chemical properties of wastes, constituents of biogas and volume of digester to be considered thereby provide effective performance of digesters for household cooking.

MATERIALS AND METHODS

Materials

i. High Density Polyethylene drum (90 Litres)
ii. Polyvinylchloride Pipe (5 feet)
iii. Galvanized Zinc Sheet (4x8 feet)
iv. Black paint spray (400 militres)
v. Araldite gum (17 militres)
vi. Well water (25 Litres)

Method

Collection of Samples

The household wastes were collected at Late Ambassador Magaji, Dustsin-Ma, Katsina State using direct waste analysis to determine waste characteristics and this method includes sampling, sorting and weighing the sample of Wastes were analysed by Peter *et al*. (2003). After the sample was obtained, it was blended and thoroughly mixed in a container in which 1kg was taken out for proximate analysis. Fresh cow dung samples (CD1, CD2 and CD3) of different breeds were collected in the same residence according to the recommended method of manure analysis experimented by Tchobanoglous *et al*.(1993).After the samples were obtained, they were thoroughly mixed in a container. From the container single composite sample of approximately 1kg was taken out for proximate analysis reported by Peter *et al.(*2003).

Physico-Chemical properties of the household waste

The physico-chemical properties of household wastes such as; Percentage of Moisture Content (PMC), Volatile Solid, Total Solid, Slurry Retention Time (SRT), Carbon-Nitrogen ratio (C/N), Fixed Carbon (PFC), Nitrogen Content, Organic

Loading Rate, Calorific Value of Waste were determined using the work of Boe *et al.(*2012).

Experimental Procedure of Digesters

Experimental procedure of Digesters 1

This type of digester is fixed dome digester of 5.4L. The experiment took place within the period of 14 days. The household wastes (60%) and cow-dung (40%) were poured into small plastic cylinder (Digester1) after blended with the aggregate of 2kg cow dung and 3kg household waste. It then mixed with water in the ratio 1:1 (waste/water) to ensure that the total solid is less than 10% reported by Obileke *et al*. (2020). And put into the digester using funnel through the inlet pipe. The biomass was stirred with a stirrer of 5m height to ensure homogenous mixture. The mixture of the household wastes, cow dung and well water were sealed with nylon sheet to provide anaerobic digestion process. The gas produced inside the digester was connected with a hose and a control valve. The control valve was opened to allow the gas to flow for the collection of gas for constituent analysis using blood bag. However, the gas hose from the digester was then channeled to the burner for household cooking.

Experimental procedure of Digesters 2

Another type of digester called fixed dome digester was fabricated using 90L Cylindrical plastic drum made up of High-density polyethylene (HDPE) materials. The experiment took place within the period of 28 days. The household wastes for this digester was changed to 8kg (40%) and 12kg of Cow dung (60%) respectively. The slurry was poured into the cylindrical drum (Digester 2) using funnel through an inlet pipe after blended and weighed in the ratio of 1:1 (waste/water) to ensure that the total solid is less than 10% reported by Obileke *et al*. (2020). And put into the digester through inlet pipe. The biomass was stirred with a stirrer of 5m height to ensure homogenous mixture. The mixture of the household wastes, cow dung and well water were sealed with nylon sheet to provide anaerobic digestion process. The gas produced inside the digester was connected with a hose and a control valve. The control valve was opened to allow the gas to flow for the collection of gas for constituent analysis using blood bag. However, the gas hose from the digester was then channeled to the burner for household cooking.

Ventilation test of Digesters

The ventilation test involves the use of blowing air into the digester to ensure that the digester is leak free. For these digesters, the Ventilation tests were conducted after fabrication. Manual air pump was used which blew air inside the digester with a maximum pressure of 35Psi through the gas hose in which liquid soap was applied to the body of digester. The digesters were leak free due to absence of bubbles on the digesters body.

Biogas produced per day

Using the work of Hamed and Zhang. (2012), daily biogas was produced using.

$VB=(P\times Vhead\times C) / (R\times T)$

VB=Volume of biogas (Liters/day)/L/day

Vhead = Volume head space (Liters)/L

T=Absolute temperature difference (Kelvin)/K

P=Absolute pressure difference (Millibar)/mbar

C=Molar Volume of gas ($22.4x10m^3$ /l) R=83.143KJ/Mol

Highest biogas produced per day for Day 7 in Digester 1

P=38-2=36mbar

$T=40.3-36=4.3^{oC}+273=277.3K$

Vhead=3.3Litres

VB= (36×3.3×22.4×103) / (83.1×277.3)

=2661120/23043.6

VB=115Litres/day

Highest biogas produced per day of Day 22 for Digester 2

P=70-38 = 32mbar

T= 46.4-29.8=16.6 +273 = 289.6K

VB= 32×64×22.4×103/ 83.1×289.6

VB=1906Litres/day

Flammability test of the Digesters

The flammability test involves the use of lighter or matches to ignite the burner when the gas valve was opened in order to determine the colour and stability of flame.

For Digester 1, flame test was conducted after the gas has been accumulated on day 7 (38mbar). Lighter was ignited on the burner when the gas valve was opened, the flame produced was not stable and disappear immediately for just 1minute.Hence the pressure gauge dropped drastically due to a low volume of pressure.

The flammability test of Digester 2 was conducted after the gas has been accumulated on day 22 (71mbar), lighter was ignited on a burner when the gas valve was opened, the gas produced was a reddish yellow in colour with slightly blue which indicate high volume of methane and the flame last for more than one hour.

RESULTS AND DISCUSSION

Results and discussion of Physical Properties of Household waste 1, Household Wastes 2 and Cow dung.

The physical properties of wastes in Test 1 and Test 2 were summarized in Table 3.1 below with their corresponding values.

Table 1: Physical Properties of Test 1, 2 and cow dung

S/N	Parameters	Household waste 1 (%)	Household waste 2 (%)	Cow Dung (%)
1	Moisture Content	81.5	93.1	89
2	Ash Content	4.6	5.1	5.7
3	Total Solid	18.5	6.9	11
4	Volatile Solid	80.6	92.4	90.1
5	Slurry Retention Time	15.0	28.0	-
6	PH Value	5.7	7.8	8.2
7	Organic loading rate 1	3	-	2
8	Organic loading rate 2	-	8	12

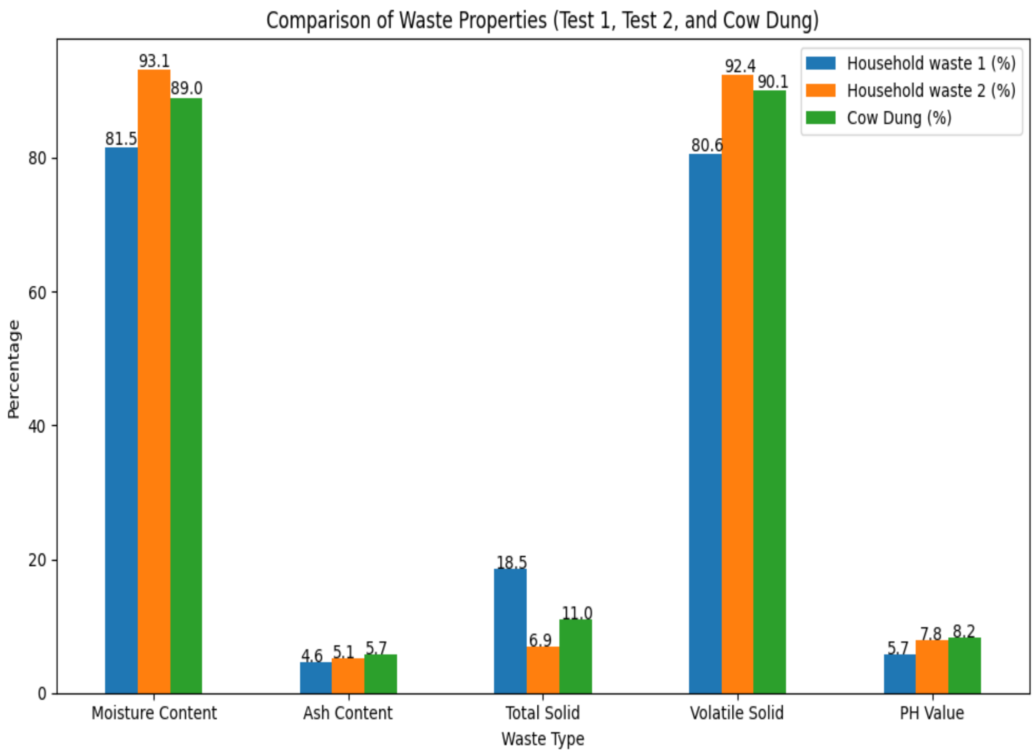

Figure 1 Physical properties of wastes

From Figure 1, it is evident that the moisture content of Household waste 2 (93.1%) is higher than household waste 1 (81.5%) and cow dung (89%) which increased anaerobic digestion. The same results were reported by Sadaka and Engler.(2012) and Yadav *et al. (2014)*. The higher moisture content of the wastes (77.04%) before digestion would encourage the movement and growth of bacteria and reduce the limitation of mass transfer of non-homogenous or particulate substrate. The ash content of Test 2 is higher than that of Test 1(4.6%), indicating that Test 2 has higher calorific value. Ordinarily, 6% - 9% solids concentration is best suited for biogas production, as reported by Okewale *et al. (2016)*. The total solid (TS) of household waste 1 (18.5%) is higher than household waste 2 (6.9%) and Cow dung (11%). Hence, the combination of household waste 1 and cow dung produced poor mixing ratio. These results were compared with the values (18.5%,6.9% and 11%) obtained in the present study as household waste 1 mixed with cow dung produced 8.95 Total solid content within the range of 6-9% as reported by Okewale *et al.(2016)*. The volatile solid (VS) for household waste 2 (92.4%) is greater than that of cow dung (90.1%) and household waste 1 (80.6%) due to high blending of household waste 2 which increased the anaerobic digestion. The values of VS (80.6%, 90.1% and 92.4%) obtained in the present study were compared with 92.73% as reported by Nand (1994) .The PH value of household waste 1 was very low around 5.7 (Table: 3.1) which implies high acidic content due to high amount of orangepeels present in the waste as compared to household waste 2 and cow dung, hence PH was adjusted by interchanging the ratio of household waste and cow dung from (3kg of household wastes and 2kg of cow dung) to (8kg of Household and 12kg of cow dung). . The organic loading rate (OLR) measured in kilogram (kg) of both Test 1 and Test 2. The Organic Loading Rate of digester 1 is 5kg (3kg of Household waste+2kgof Cow dung) and increased to 20kg (12kg Cow dung + 8kg Household waste) in Test 2 due to small volume of biogas in Digester 1.

Chemical Properties of Wastes in Test 1, 2 and Cow Dung

The results of chemical properties of wastes were obtained were presented in the Table 2 with their corresponding values.

Table 2: Chemical Properties of Test 1 and 2 wastes

S/N	Parameter	Householdwaste 1 (%)	Householdwaste 2 (%)	Cow Dung (%)
1	Fixed Carbon content **(%)**	40.6	61.2	63
2	Nitrogen Content **(%)**	2.8	1.9	2.1
3	Carbon/Nitrogen ratio **(%)**	14.5	32.2	30.0
4	Calorific Value **(**MJ/KGK**)**	20	22	23.5

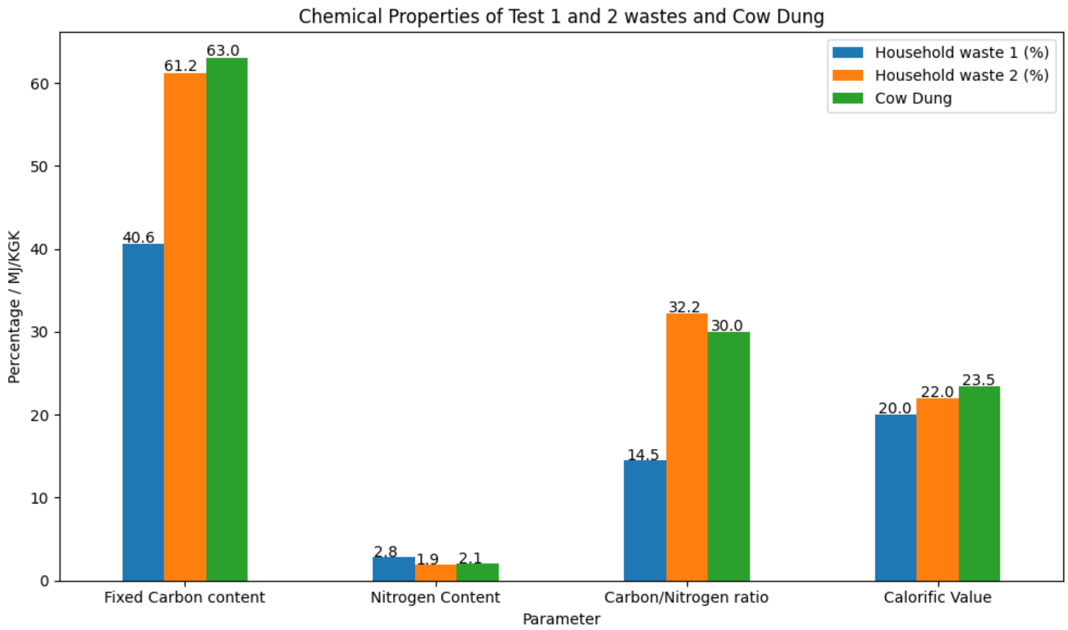

Figure 2: Chemical properties of wastes

From Fig 2, high quantity of fixed carbon content (63 %) was observed in cow dung as compared with (61.2 %) of Household waste 2 and (40.6 %) in Household waste 1.The high C/N (32.2%) ratio of household waste 2 implies that the waste can produce gas due to anaerobic digestion facilitated by bacteria activity. However, low C/N ratio (14.5%) was discovered in Household waste 1 due to high nitrogen content resulting from high amount of orange peels present in Household waste 1. In addition, higher calorific value of cow dung (23.5MJ/Kg) implies that Cow dung can burnt easier than Household waste 1 and Household waste 2 similar to 21-23.5MJ/m^3 reported by Mungwe *et al.(2021)*.

Performance of Digesters (1 and 2)

The performance of the digesters were summarized in Table 3 which includes highest andlowest biogas produced per day for both digesters.

The Table 3: Summarized the volume of biogas produced per day for both Digesters 1 and 2

Number of days	Volume of Biogas for Digester 1(L/day)	Volume of Biogas for Digester 2(L/day)
1	0.0	0.0
2	0.0	0.0
3	0.0	0.0
4	0.0	0.0
5	0.0	0.0
6	0.0	0.0
7	115	0.0
8	3.4	0.0
9	37.0	0.0
10	56.7	0.0
11	0.0	0.0
12	0.0	0.0
13	18.5	0.0
14	50.8	0.0
15	0.0	0.0
16	-	0.0
17	-	0.0
18	-	0.0
19	-	0.0
20	-	1906
21	-	35.9
22	-	520
23	-	1164.8
24	-	241
25	-	59.7
26	-	1680
27	-	605

The performance of the digester was effective when it passed leak test and flammability test. The ventilation tests were conducted for both digesters after designed and fabrication in which manual air pump was used to supply air inside the digester under high pressure through the gas hose while applying liquid soap to the body of digester maintained it shape. Due to the absence of bubbles on the digesters body, the digesters were confirmed that it was leak free. The flammability test of Digester 1 after the gas has been accumulated on Day 7 (38mbar) with a biogas yield of 115L/day was failed after passing the leak test. The gas valve was opened immediately and then setting fire on the gas burner to check its flammability. It was confirmed that the gaswas reddish yellow for 2 minutes and disappear immediately. The pressure was dropped drastically on Day 15 which indicates small capacity digester leading to a low volume of pressure.For Digester 2, the pressure was 70mbar on Day 22 when the biogas yield was 1906L/day. Lighter was set on a burner when the gas valve was opened, the gas produced was a reddish yellow in colour with slightly blue which indicate the high percentage of methane and the flame last formore than one hour.

Constituents in Biogas

The Table 4 shows that the constituents of biogas from Test 1 and Test 2 with their corresponding values were obtained after passing through Gas analyser (B1000).

Table 4: Constituents of Biogas Produced in Test 1 and Test 2

S/N	Substances	Formula	Test 1 (%)	Test 2 (%)
1	Methane	CH4	59.2	61.5
2	Carbon dioxide	Co2	33.0	33.3
3	Nitrogen	N2	0.9	0.6
4	Hydrogen	H2	6.1	4.2
5	Oxygen	O2	0.1	0.1
6	Water Vapour	H_2O	0.2	0.1
7	Hydrogen sulphide	H_2S	Traces	Traces

It is clear that the biogas constituents obtained with co-digestion of 60% cow dung in Test 2 has higher methane content than that of Test 1 (40%). The methane (CH_4) content has a highest percentage (61.5%) in Test 2 as compared with Test 1 (59.2%). The methanecontent obtained (61.5% and 59.2%) is similar to Voegeli *et al. (2014)*. Hence, high quality of biogas was fond in Test 2 as the Household waste (60%) and Cow dung (40%) were interchanged to be Household waste (40%) and Cow dung (60%). though the quantity has been increased. Hence the increased in methane yield recorded in Test 2 was due to the digester being associated with the presence of readily biodegradable organic matter in the Household waste 2 and Cow dung. The value of Co_2 (33.3%) in Test 2 is higher as compared with Test 1 indicating that the gas can burn vigorously to produce flame.

CONCLUSION

Based on the results obtained after proximate analysis of physico-chemical properties of waste in Test 1 and Test 2, the ratio of household wastes to cow dung (3:2) kg of Test 1 was changed to 8kg:12k for Test 2.And this is as a result of biogas constituents analysis where there is high percentage of methane content as well as calorific value than household wastes 1 and household wastes 2 . Hence, the percentage of methane increased from 59.2% (Test 1) to 61.5% (Test 2). Therefore, it was concluded that Digester 1 passed the leak test and failed flammability test due to poor mixing ratio and small digester volume which produced low volume of biogas.Digester 2 was more efficient since it passed leak test and flammability test and when the burner was ignited with a lighter in an air free space (empty room), it produced stable flame.

RECOMMENDATION

Hence, it should be recommended to use large digester volume (above 90L), high percentage of cow dung (above 12kg) and analysis of biogas constituents to produce biogas rich in methane content.

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REFERENCES

Banks, C.J., M., Chesshire, S., Heaven. and Arnold, R. (2011). "Anaerobic digestion of sourc segregated domestic food waste", Bioresource Technol.vol.102, pp.612–20.

Boe, K., Kougias, P.G., Pacheco, F.,Thong, O.S., Angelidaki, I.(2012),"Effect of Substrates and Intermediate Compounds on Foaming in Manure Digestion Systems", Water Science and Technology, vol.66, pg.2146.

Bond, T., and Templeton, M.R. (2011). "History and Future of domestic Biogas Plants in the developing World", Energy for Sustainable Development, vol.15, pp. 347-354.

Claudius A. Awosope, (2009) Nigeria electricity industry: issues, challenges and solutions. Electrical and Electronics Engineering. School of Applied Engineering College of Engineering, Covenant University, Ota.

Hamed, M. and Zhang, R. (2012). "Biogas production from Co-digestion of diary manure and food waste", Bioresource Technology, vol.101, pg.4021-4028.

Hussaro, K., Intanin, J. and Teekasap, S. (2017). "Biogas production from food waste and vegetable waste for the sakaew temple community International journal, vol.11, pp.82-89.

Ishmael, M.R, Esther, T.A, Daniel, M.M and Robert, H. (2014), "Design of the Bio-digester for Biogas Production", vol.2, pg.22-24. [107] Mungwe, J., Asoh, D. and Mbinkar, E. (2021), "Design considerations of flexible Biogas Digester system use in Rural communities of Developing countries", Journal of sustainable Bioenergy systems, vol.11. pg. 260-271.

Lou, X.F., Nair, J. and Ho, G. (2012). "Field Performance of Small-Scale Anaerobic Digesters Treating Food Waste", Energy for Sustainable Development, vol.16 (4), pp.509-514.

Molua, O.C., Ukpene A.O., Ighrakpata, F.C., Nwachuku, N.D., Ogwu, D.A., and Edobor, M.(2023).Optimization of Biogas Production From Tree Waste Materials for Bioresource Recovery, FUDMA JOURNAL OF SCIENCE, vol.7, no.6

Nand, K. (1994). "Indian Food Industry", vol.3, pg.23-24.

Obileke, K., Mamphweli, S.,Meyer, E.L., Makaka, G.N.and Onyeaka,H. (2020), "Comparative study on the performance of aboveground and underground fixed-dome biogas digesters," Chemical Engineering and Technology, vol. 43, pg. 68–74.

Okewale, A.O., Omoruwuo, F. and Ojaigho, R.O. (2016), "Alternative Energy Production for Environmental Sustainability".British Journal of Renewable Energy, vol.1, pg.18-22.

Peters, J., Combx, S., Hoskins, B., Jarman, J., Kovar, M., Watson, A., Wolf, A.and Wolf, N. (2003),"Recommended methods of manure analysis, University of Widconsin, pg.1-57.

Ranjeet, S., Mandal, S.K. and Jain, V. K. (2008). "Development of mixed inoculum for methane enriched biogas production", Indian Journal of Microbiology, vol.50, pp. 20-34.

Sadaka, S.S. and Engler, C.R. (2003). "Effect of initial total solids on composting of raw manure with biogas recovery", Compost Sci. Util, vol.11, pg.361-369.

Tchobanoglous, G., Thesen, S.A. and Vigil, E. (1993), Integrated Solid Waste Management, Engineering Principles and Management, New York.

Valijanian, E., Tabatabaei, M., Aghbashlo, M., Sulaiman, A. and Chisti, Y. (2018). "Biogas production systems", Biogas springer, pp.95-116.

Vogeli, Y., Lohri, C.R., Gallardo, A., Diener, S.and Zurbrugg, C. (2014),"Anaerobic Digestion of Biowaste in Developing Countries", Eawag-swiss Federal Institute of Aquatic Science and Technology, Dubendorf, vol.8, pg.7

Weiland, P. (2010). "Biogas production: current state and perspectives", Apply Microbial Biotechnology, vol.85, pp. 849-860.11.

Yadav, N., Kumar, R., Rawat, L.S. (2014). "Physico-Chemical Properties of waste before and after anaerobic digestion of Jatropha seed cake and mixed with pure Cow Dung", Journal of Chemical Engineering Processing Technolology, vol.5, pg.186-190.

Zhang, R.H.M., El-Mashad, K., Hartman, F., Wang, G., Liu, C.C. and Gamble, P. (2007). "Characterization of Food Waste as Feedstock for Anaerobic Digestion", Bioresource Technology, vol. 98, pp.929–35.

Zhang, C., Su, H., Baeyens. and Tan, J. T. (2014). "Reviewing the anaerobic digestion of food waste for biogas production", Sustainable energy, vol.38, pg. 383