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Development and Performance Evaluation of Bio-Digester Using Cow Dung and Elephant Grass (*Pennisetum purpureum Schumach*)

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Abstract: *This research work was aimed at determining biogas production from co-digestion of elephant grass and cow dung using batch digester. The study was motivated by the urge to solve the environmental challenges of a local rural community that is blessed with cows in every household. A digester of 30 liters capacity was designed and fabricated to satisfy the need of an average family of 5 using galvanized sheets. Proximate analyses of cow dung and the elephant grass that were used for the study was carried out in order to ascertain the possibility of obtaining gas from the substrates. Biogas was produced at 2 levels of slurry ratios (1:1 and 1:2). The mixture was manually stirred in order to homogenize the substrates. A maximum retention period of 17 days was recorded for all the treatments. While pH values of the substrate before and after the digestion process were 5.6 and 8.13 respectively. Results obtained also shows that the treatment with ratio 1:2 produced the highest amount of biogas of 477.93 g against the 411.98 g from 1:1 ration. This emphasized the importance of adequate moisture in the preparation of the slurry for a conducive microbial activity. The study concluded that the mixture of cow dung and elephant grass has great potential of producing biogas and was able to address the environmental problem of the rural community. The approximate cost of the digester was N20, 800:00.*

Keywords: *Cow Dung, Digester, Elephant Grass, Fermentation, Slurry Ratio*

INTRODUCTION

Energy generation remains one of the biggest challenges of developing counties like Nigeria. About 80 million out of 180 million Nigerians living in villages across the country lack access to conventional energy source (World Energy Council, 2021). Lack of access to energy to stimulate small- and medium-scale enterprises in rural communities is believed to be a major factor responsible for rural—urban migration and the lingering emigration crises across the globe. Due to the fluctuating cost and the environmental effects of conventional sources of energy in Nigeria, especially fossil fuels, there is an emergent interest in the use of renewable energy. As such, the adoption of renewable energy is gradually becoming significant (Perin *et al.* 2020; Vannasinh, 2021; Zhang *et al.*, 2021; Norouzi and Dutta, 2022). In order to fully explore the use of biomass in the generation of energy, several government organizations and researchers have instituted programmes and studies to promote the use of biofuels.

Another driver for the use of renewable energy sources is the issue of sustainability since conventional sources have a lifespan and will be depleted in the near future (Olatunji *et al.*, 2021). However, many initiatives in biogas technology worldwide lacked sustainability as they were implemented in isolation – particularly in developing countries, where cheaper sources of other conventional energy sources is the limiting factor (Zupanˇciˇc *et al.*, 2022). In most Nigerian villages, energy requirements are often dominated by the requirements for cooking, where firewood, charcoal, cow dung and crop residues are the important sources of energy. Of these, firewood is the main source of energy. Indiscriminate cutting of wood in the forests would create environmental problems. Continues depletion of forests would lead to ecological imbalance and climatic changes. Some other human activities bring about such as burning of dung cake which is a source of environmental pollution that decreases inorganic nutrients, untreated refuse and organic wastes that are direct threats to human health. It is estimated that our cattle produce 800 million tonnes of dung and about 70% of it is used as manure while the remaining 30% as fuel in villages (Perin *et al*., 2020). Manure contains large amount of water and organic materials making it suitable for anaerobic fermentation for biogas production, if the manure is not used quick enough it loses the water value and energy (Tonrangklang *et al.*, 2022; Argalis and Vegere, 2021). The abundant availability of animal manure in Nigeria, particularly from livestock enterprises, makes it an attractive and cheap source of raw material for biogas production which could be commercialized and made available to both rural and urban dwellers. However, Manure from ruminants, particularly cattle, is very useful for starting the fermentation process, because it already contains the necessary methanogenic bacteria. On the other hand, the gas yield from cattle dung is lower than that obtained from chickens or pigs, since cattle draw a higher percentage of nutrients out of the fodder and the leftover lignin are resistant to anaerobic fermentation (Norouzi and Dutta, 2022), hence, the need for co-digestion. Tremendous and novel development in biogas production has led to the creation of advanced bio-energy facilities. As such, the biogas facilities are the basis of an economy concept aimed at nutrients recycling, reduction of greenhouse gas emissions and bio-refinery purposes. Conversely, there exist significant logistical challenges related to production of biomass. One of such is the challenge of maintaining a balance between the economic, technical, political, social, and environmental factors involved in the biofuel production processes. Biogas (considered to be the low carbon fuel sources) offers the best opportunities to the rural communities especially in African countries to meet their energy demand.

The abundant availability of animal manure in Nigeria, particularly from cattle enterprises, which could cause health hazards (if not properly handled for effective biodegradation), makes it an attractive and cheap source of raw material for biogas production which could be commercialized and made available to both rural and urban dwellers. However, manure from ruminants, particularly cattle, is very useful for starting the fermentation process, because it already contains the necessary methanogenic bacteria. On the other hand, the gas yield from cattle dung is lower than that obtained from chickens or pigs, since cattle draw a higher percentage of nutrients out of the fodder' and the leftover lignin complexes from high-fibre fodder are very resistant to anaerobic fermentation (Norouzi and Dutta, 2022). Hence the need for co-digestion the grass material (elephant grass) that has a high carbon content but is low in nitrogen content, Strezov*et al.* (2018). With continuous increase of world population and rise in living standards, the demand for energy is steadily increasing. Global environmental issues, such as global warming, early exhaustion of fossil fuel and accompanying potential social uprising in fossil fuel producing areas of Nigeria's Niger Delta region (due to agitation for resource control) poses serious problems for continuous energy generation, consumption and sustenance. In addition, environmental hazards from careless dumping of animal and human wastes will be controlled if these wastes can be converted into biogas. Deforestation will also be reduced if people no longer rely solely on firewood for cooking in addition to creation of employment for most of the rural communities where cows are in abundance. In view of this, environmentally-friendly technology and a shift to non-fossil energy resources that are renewable such as natural energy and biomass are inevitable. Biogas is said to be ideal in deciding alternative energy from the selected bio-materials for rural people in the sense that it is cheap, available and local in origin and production. It is also an energy source that is useful for multiple purposes – heating, lighting, small-scale power generation, and so on, Tambuwal (2002). Hence, the objective of this study.

MATERIALS AND METHODS

Materials Selection

The materials used during the study are: water, cattle dung, elephant grass (the co-substrate mixed with the cow dung), Fig. 1 (a) and (b). Single Super Phosphate fertilizer which served as source of acid added to the slurry during mixing, decreasing the pH of the slurry, and thereby increases the acidity of the slurry. Ash which serves as the source of base to the slurry during mixture, galvanized sheet (used for the fabrication of the bio-digester), 12" bolts and nuts, 1'' control valve and rubber tube (about 5 and 10 mm i.e., internal to external diameters) used as a channel for collecting the gas from the digester.

Instrumentation

Instrumentation materials used are Weigh Balance (Camry 20kg capacity and 0.001g sensitivity). Thermometer, Mortar and Pestle (used for size reduction for better digestion of the slurry), thermometer, pH Meter (HI9610) and a cutlass used for chopping the co-substrate into smaller sizes for better surface area to make mixture easier and digestion faster.

Fig. 1 (a) Dried Cow Dung and (b) Dried Elephant Grass

The construction process of the bio-digester involved cutting, welding, turning and drilling the galvanized iron into the desired cylindrical shape (Fig. 2). Individual components were constructed based on their dimensions and later joined together to form the unit. The top cover was drilled for bolts and nuts to ensure air-tight cover after loading the digester. Control valves and flexible rubber hose of appropriate dimensions were fixed at their proper positions. All joints were sealed using a special gum to avoid chances of leakage. The digester's volume was designed to contain 30 liters of the substrate and the gas formed.

Fig. 2 Developed Bio-Digester coupled with Gas Chamber, hose and control valve

Preparation of Samples

The cow dung being the raw material for the production of biogas was obtained from Zango Abattoir, Zaria while the elephant grass was sourced from around Institute for Agricultural Research (IAR) farm of the University. Both were dried by spreading in an open air at ambient temperature. After drying, it was taken the Processing Laboratory of the Department of Agricultural and Bio-Resources Engineering of the Ahmadu Bello University, Zaria-Nigeria where it was grinded in order to reduce it into smaller size thereby increasing the surface area for better solubility and ease of digestion. Before loading, the substrate with water and the other co-substrate (elephant grass) into the digester, foreign materials were carefully removed. The pH of the fresh cow dung as well as the slurry was determined using a digital pH Meter (HI96107). The substrate was formed in two treatments. The first mixture contained 5 kg each of the elephant grass, cow dung and 10 kg of water were mixed thoroughly in order to homogenize the substrates (ratio 1:1 of the substrate and water). The mixture was introduced into the digester. In other to catalyze the anaerobic digestion of the slurry, 1 kg of Single Super Phosphate (SSP) fertilizer, which is acting as the acid with a pH value range of (1.0-1.5), was added in the ratio. Similarly, ½ kg of ash (acting as the base/alkali) was also added in the ratio. In the second treatment, 2½ kg each of the elephant grass, cow dung and 10 kg of water were mixed thoroughly (ratio 1:2 of the substrate and water). However, the ratio of SSP and ash were kept constant. The mixture was also introduced into the digester (Fig. 3) that was properly to ensure air-tightness. The pH and temperature (Table A1, Appendix A) of the slurry in digester was observed daily. After loading, the substrate was not stirred since the digester was sealed. This was because opening the digester would give way for air to enter the system, thus truncating the gas formation process.

Fig. 3 Substrate (Mixture of cow dung, elephant grass and water)

Biogas Collection

A car inner tube (175/185 - 13/14) was weighed with the aid of a digital precision weighing balance (2000 g capacity and 0.01 g sensitivity) to determine its initial weight. It was then connected to the gas outlet valve of the digester, Fig. 4. When the valve was opened, biogas produced in the digester flowed into the tube as a result of pressure difference between the digester and the tube. The inflammation of the tube was observed for about 10 minutes to ensure that the tube size remain constant. The tube is then disconnected and weighed to determine the new weight. The difference in weight was the weight of the gas produced. This process was repeated every 24 hours until no change in weight is observed, i.e., when the gas ceases to flow. The contents of the tubes were periodically discharged into the gas collection tank.

Fig. 4 Biogas Sample Being Collected in a Tube

RESULTS AND DISCUSSION

Proximate analyses of cow dung and the elephant grass that were used for the study was carried out in order to ascertain the possibility of obtaining gas from the substrate. Table 1 below shows the values of the parameters tested.

Table-1 Proximate Analyses of the Substrates

Characteristics	Cow Dung	Elephant Grass
Carbon C (%)	17.06	27.70
Nitrogen N (%)	0.48	0.67
Volatile Solid Vs (%)	17.69	28.32
Total Solid Ts (%)	29.41	14.71
Moisture Content (%)	65.22	75.93
C/N Ratio	35.54	41.34

The bio-digester was designed and constructed. Results obtained shows that the daily values of the biogas produced from the various treatments were observed and recorded as indicated in Table A2, Appendix A as well as the graphical representations in Figs. 5 and 6. Comparison of these results revealed that gas production in treatments 1:1 on the 4th day after charging the digester while treatment 1:2 starts on the 3rd day. The period it took for gas production to start was in line with the finding of Baron (2007) that biogas formation is a slow process. While treatments 1:1 have same volume of water contents as the substrate, early gas formation in treatment 1:2 may be attributed to the fact that there was enough water to enable the substrate dissolve and allow microbial activities to facilitate ferment easily than treatment 1:1 that has less water content. It could thus be seen that biogas production increases with increasing quantity of water. Similarly, increase in water quantity changes the sample pH in addition to decreasing total solid ratio.

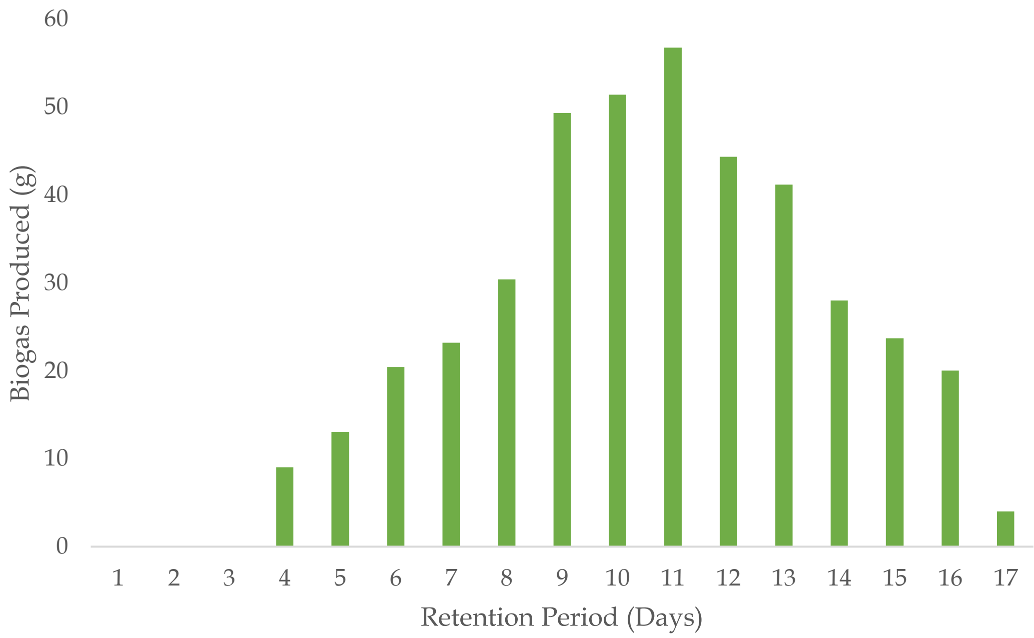

Fig. 5 Graphical Representation of Biogas Produced from Ratio 1:1

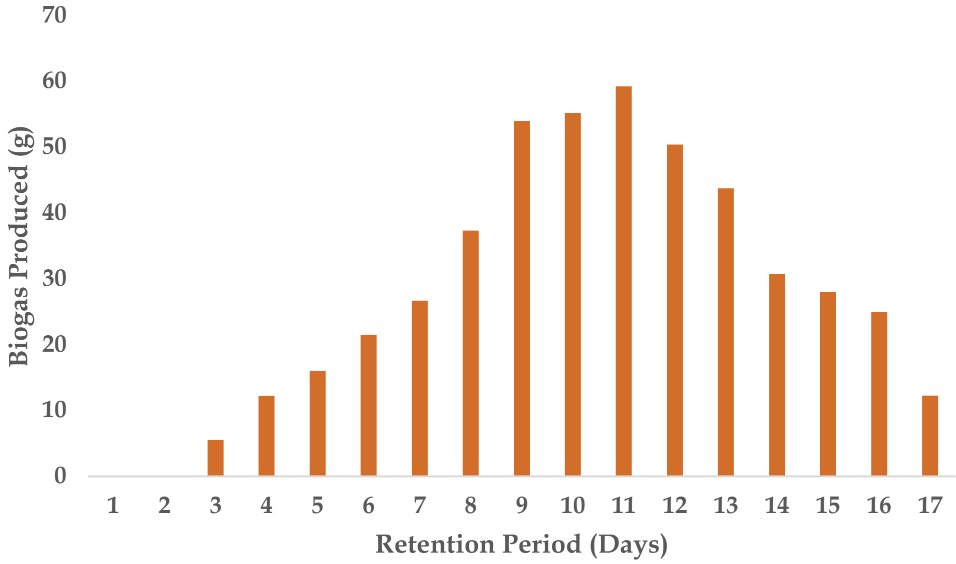

Fig. 6 Graphical Representation of Biogas Produced from Ratio 1:2

Results obtained also shows that the treatment with ratio 1:2 produced the highest amount of biogas of 477.93 g with the shortest retention period of 17 days; however, biogas formation was actually for 15 days only. Its peak production day was the 11^{th} with 59.23 g and steadily dropped to the 17^{th} day when biogas production ceased. It was followed closely by the treatment 1:1 which has the same ratio of substrate and water whose total produced gas weight was 411.98 kg at the same retention period of 17 days. The retention period of 17 days falls within the acceptable range of 15 to 30 days (Adrian, 2007). The longer retention period could also be attributed to the high percentage of TS as suggested by Kossmann *et al*. (2006). However, gas formation lasts for 14 days while its peak production was 56.79 g also at the 11^{th} day of retention. This shows that although the constituents of the two treatments are the same, their retention time and total gas production differs due to the variation in the ratio of the substrate. This emphasizes the importance of provision of adequate moisture in the preparation of the slurry for a more conducive microbial activity in order to achieve satisfactory digestion which results in more gas production. This finding is in agreement with the results obtained in the earlier studies of Mattock (1994), Steffen *et al*. (1998) and Thy (2003) that wetter the material are likely to produce more gas. Generally, the higher gas obtained from the two treatments could as be attributed to the high percentage of VS observed. The presence of VS represents the fraction of the solid material that may be transformed into biogas as observed by Matinez, (2005).

It was also observed from the results obtained that biogas production for all the treatments went on smoothly with limited disruption, perhaps due to the fact that the experiment was conducted in a relatively constant condition where no significant temperature changes were noticed throughout process thereby permitting an approximate stability of micro-organisms activities within the system. The retention periods of all the treatments were not beyond 17 days. The ability to maintain relatively constant temperature and pressure also helped in stabilizing the biogas production in all the treatments. This was done by keeping the digester in an enclosure where temperature can be controlled and maintained as much as possible as the ambient to minimize temperature migration (Table A1, Appendix A) as suggested by Green (2005). The relatively high biogas production may be attributed to the available nutrient in the digestrates. The 35. 54 and 41.54 carbon-nitrogen and the initial favourable pH of 5.6 in of the substrate was an indication of obtaining a fair amount of gas. Similarly, the substrates contained adequate amount of carbon and nitrogen and a number of trace elements. There was also has higher volatile solids content that aids higher biogas formation. Finally, the pH values of the substrate before and after the digestion process were 5.6 and 8.13 respectively.

These results were good in that anaerobic digestion would take place when the pH value of the slurry was neutral, that is, 7.0; indicating that methane-producing bacteria lived well under neutral to slightly alkaline conditions. After the digestion process, the medium turned alkaline, given a pH of 8.13. The pH values obtained agrees with Bouallagui *et al*. (2005) who determined the optimum pH requirement for the survival microbes ranging from 6.8 – 7.4.

CONCLUSION

A batch-type bio-digester was designed and constructed for production of biogas for economic and waste management. Cow dung and elephant grass were used as feed stocks in varying ratios of 1:1 and 1:2. Proximate analyses of the feed stocks was done to ascertain their suitability for gas production. Maximum gas production of 414.98 g was obtained from 1:2 slurry ratio suggesting the importance of moisture in facilitating fermentation. The peak production of biogas of 56.79 and 59.23 g were respective obtained from ratios 1:1 and 1:2 in the 11th day of the retention period of 17 days for all the treatments. The abundant availability of animal manure in Nigeria, particularly from cow dung, makes it an attractive and cheap source of raw material for biogas production which could be commercialized and made available to both rural and urban dwellers.

CONTRIBUTION TO KNOWLEDGE

This study has established the use of cow dung and elephant grass as suitable feedstocks for biogas production, waste management and cost-saving enterprise.

DECLARATION OF CONFLIT OF INTERST

The authors declare no competing interest

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APPENDIX A

Table-A1 Daily Temperature of the Substrate after loading

DAY	TEMPERATURE ^{O}C
1	26.4
2	27.8
3	28.5
4	30.7
5	35.5
6	33.3
7	28.6
8	29.7
9	30.5
10	28.6
11	29.1
12	29.8
13	28.8
14	30.7
15	31.2
16	32.2
17	33.2

Table-A2 Daily Biogas Production

Day	Gas Yield (g)	
	1:1 (With zero agitation)	1:2 (With zero agitation)
1.	-	-
2.	-	-
3.	-	5.51
4.	9.02	12.20
5.	13.06	16.01
6.	20.43	21.50
7.	23.20	26.70
8.	30.40	37.35
9.	49.36	54.01
10.	51.42	55.20
11.	56.79	59.23
12	44.35	50.43
13.	41.18	43.74
14.	28.01	30.76
15.	23.70	28.02
16.	20.04	25.01
17.	4.02	12.26
Total (g)	414.98	477.93

Table-A3 Estimated Cost for Constructing the Bio-Digester

S/N	Description of Items	Quantity	Amount (₦)
1	Galvanized sheet	½	7,500
2	Control Valve	1	1,500
3	Gas Chamber	1	1,750
4	Electrodes	12	1,800
5	Cutting/Grinding Disc	1	2,000
6	Burner	1	2,000
7	Cow Dung	25 kg	300
8	Body Filler	-	150
9	Rubber Hose (¾)	1 m	1,500
10	Pipe (¾)	1 m	500
11	Gasket	1	300
12	Workmanship		1,500
Total:			20,800