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Production and Comparative Analysis of Biogas from Fonio Millet/Cow Dung and Maize Hull/Cow Dung

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A B S T R A C T

This study focused on biogas generation from locally available fonio millet husks (Digitaria exilis) and cow dung, as well as maize hulls and cow dung as a means for developing a low-cost biogas generation system. The objective is to assess the practicality of employing these substrates for biogas production in an eco-friendly manner while minimizing costs. The composition of the substrates was analyzed for total solids (TS), volatile solids (VS), nitrogen (N), and carbon (C). Within a controlled biodigester setting, biogas production from different substrate mixtures was analyzed. Fonio millet husk and cow dung mixture (Substrate A) resulted in an average cumulative biogas volume of 141.78 mL while the cow dung and maize hull mixture substrate (Substrate B) was more productive at an average of 191.61 mL. The biodigesters with these substrates also experienced greater methane production than the control, with Substrate B giving the greatest mean amount of 120.72 mL. Substantial differences were found in the biodigesters' biogas production, with substrate B having the highest variability and mean values for both cumulative biogas and methane production. This study concludes that fonio millet husks and maize hulls are appropriate adjuncts for biogas systems along with cow dung

Keywords: Biogas, Biodigesters, Cowdung, Fonio millet, Methane, Optimum temperature

1. INTODUCTION

Biogas, a renewable energy source, can be generated through anaerobic digestion, where microbial species degrade organic materials without oxygen (Kiran et al., 2016; Sawyerr et al., 2019). Biogas is a mixture of methane (45-75%) and carbon dioxide (25-55%), with the proportion depending on the feedstock and processes used (Monnet, 2003). Methane is a promising feedstock for the chemical industry but is inert due to its high C-H bond energy and symmetric tetrahedral molecular geometry (Qingliang, 2023). Fonio husk, a cereal surrounded by an outer protective covering, can be used for biogas production. Agricultural wastes like fonio husk and donkey dung can be transformed into valuable products for domestic and small industrial use (Ma et al., 2021; Li et al., 2022). Biogas is used in internal combustion engines and boilers for electricity and thermal energy generation, and can be upgraded to bio-methane for injection into the natural gas network or used as vehicular fuel (Whiting & Azapagic, 2014; Huerta-Reynoso et al., 2019).

This research aims to design and implement low-cost biogas generation technology using fonio husks and cow dung as locally sourced and readily available raw materials. Biogas primarily consists of methane and carbon dioxide, with minor amounts of other compounds. Impurities and components can affect the quantity and quality of biogas, affecting its calorific value, corrosion, and potential for various energy services.

Biogas technology converts organic waste into energy, contributing to social and economic benefits, a green environment, and sustainable development. It also provides nutrient-rich organic fertiliser and aids in algae growth, fish production, and seed germination. It offers benefits such as mass reduction, odour removal, pathogen reduction, less energy use, and energy recovery in the form of methane (Mudhoo, 2012) The hydrolysis process breaks down large protein macromolecules, fats, and carbohydrate polymers into amino acids, long-chain fatty acids, and sugars. Acidogenesis ferments these products to form volatile fatty acids, valeric acid, propionic acid, lactic acid, and butyric acid. Factors affecting biogas production include process reactions, mixing, and heat exchangers (Kadam, 2017). The aim of this research is to design and implement low-cost biogas generation technology using fonio (*Digitaria exilis*) husks and cow dung as locally sourced and readily available raw materials.

2. REVIEW OF LITERATURE

Biogas consists of several undesired components, such as H2S, CO2, nitrogen, hydrogen, oxygen, and water vapor, which contribute to lower the calorific value when compared with natural gas(Korbag et al., 2021). Biogas technology converts organic waste into energy, contributing to social and economic benefits, a green environment, and sustainable development (Azhar & Anwar, 2012). It also provides nutrient-rich organic fertiliser and aids in algae growth, fish production, and seed germination (Sakhawat et al., 2013).

Anaerobic digestion is a widely used technology for stabilizing industrial wastewater, urban solid waste, animal manure, and sewage sludge (Mudhoo, 2012). It offers numerous benefits, including mass reduction, odour removal, pathogen reduction, less energy use, and energy recovery in the form of methane (Mudhoo, 2012). Factors affecting biogas production from anaerobic digestion include the hydrogen-ion concentration in the digesting material, the temperature of the MSW, and factors such as process reactions, mixing, and heat exchangers. The optimal pH range for an aerobic digestion system is 7-8.5, with values nearing 7 for optimal activity. The rate of decomposition and gas production is sensitive to temperature, with the optimum temperature being 35°C (Kahaynian et al., 1991).

3. MATERIALS AND METHODS

3.1 Sampling site

This was conducted in Plateau State Polytechnic, Barkin Ladi. Seeded Cow dung (CD) substrate available in a float drum biogas digester at Abattoir market in Jos, Plateau State and was collected in plastic containers for the research. Acha Hulls (AH) was procured from processors in Heipang, Plateau State and sundried for 1 week. The dried hull was subjected to sieve analysis according to ASTM E-11 (Graves, 2006) using a Gilsonro-top shaker (serial no.064438). One hundred grams of the hulls retained on British Sieve Size (BSS) 14 (1.2 mm) with large surface area was collected for the co-digestion experiment.

3.2 Sample collection and preparation

Determination of the Total Solids (TS) and Volatile Solids (VS) of samples:

The determination of total solids and of volatile solids of CD and Ah was modelled after DIN EN 15935 (2012–11) as described by (Zhou, 2014)

3.3 Proximate analysis of samples

To determine the elemental composition (carbon hydrogen nitrogen and sulphur) of CD and AH substrates, triplicated samples was analysed using a CHNS analyser Model Thermo Flash EA12 series. Prior to this, samples was oven dried at 105℃ for 24 hours and then 5 g of the individual samples were analysed and the results were used to determine the C: N ratio for the substrates.

3.4 Experimental procedure

Cow dung inoculums and AH particles were used in co-digestion experiments. Fifteen grams of CD inoculums were placed in a 500 mL bioreactor made from a plastic wash bottle, and 5 g of AH was added to the CD inoculum. The bioreactor was sealed with a butyl cock stopper and a thermometer. PVC tubing was connected to a valve to control biogas flow. The biogas was liberated in a guard solution, removing impurities and displacing the guard solution. The CH4 gas volume was estimated by measuring the daily difference in the guard solution height. The experiment was repeated with co-digesting blends (10:10 and 5:15) and a control.

3.5 Biogas measurements

The Biogas yields were measured using the liquid displacement method. A calibrated glass burette was filled with a solution of 5 % citric acid 20 % NaCl and a hose connected to the gas hose on the lid of the biodigester was inverted in the liquid. As biogas is produced and passed through the solution vessel, CO and H2S wasdissolved in the solution and CH4 was displace an equivalent volume of water to its volume. The displaced volume was presumptive CH4. The biogas quality was determined using an infrared hand-held multi gas analyser (Drager x-am 5600, Germany).

3.6 Statistical analysis

Data as analysed in a three-way factorial design and optimized under a single constraint of high CH4 yield using the computer software Design Expert (ver. 12) at 0.05 level of significance

4. RESULTS

The composition of the substrates used in this study are in Table 1 and the average composition of TS (%), ash (%), VS (%), N (%), C (%)and volatile percentage of total solids (V %TS, %) were82.40, 17.55, 64.85, 3.16, 37.60, 12.01 and 78.67 for CD respectively. The mean composition for AH is 92.62, 7.38, 85.24, 1.67, 49.44, 29.56 and 92.04 for TS (%), ash (%), VS (%), N (%), C (%) and V %TS (%)respectively. The average C:N ratio of the two substrates was (12.01 + 29.55/2) 20.78, which is within the best range for optimal biogas yield (Surra *et al*., 2018). The range of the degradability of the substrate and inoculum is at 85 and 65 % based on the concentration of VS of the CD and AH.

The Descriptive statistics of the cumulative biogas volume (mL) produced by the co-digestion of AH and CD in Biodigesters A, B, C and the control is in Table 2 The mean (±SD) values were141.75 (±171.27), 191.58 (±228.46), 108.43 (±133.31) and 114.37 (±141.92) for Digester A, B, C and the control respectively. The maximum biogas volumes for digesters A, B, C and the control were 462.24, 574.06, 359.64, and 384.52 respectively. The high standard deviations (SD) are a manifestation of the high fluctuations in biogas volumes during different stages of the AD process. Digester B recorded the highest average and maximum biogas volumes and Digester C had the least average and maximum biogas volumes. The Descriptive statistics of the cumulative CH4 volume (mL) produced by the co-digestion of CD and AH in Biodigester A, B, C and the control is in Table 3.

Table 1: The Composition of Inoculums and Substrate for Biogas Production

Substrates	TS	ASH	VS	N	C	C:N	VS %TS
CD	82.43	17.54	64.82	2.84	37.64	13.32	78.66
82.37	17.56	64.88	3.48	37.56	10.70	78.68	
Mean	82.40	17.55	64.85	3.16	37.60	12.01	78.67
AH	92.60	7.38	85.26	1.78	49.45	28.10	92.02
92.64	7.37	85.22	1.56	49.43	31.02	92.06	
Mean	92.62	7.38	85.24	1.67	49.44	29.56	92.04

S-total solids, VS- volatile solids, N- nitrogen, C- carbon, VS %TS -% VS divided TS, CD- cow dung, AH- acha hulls

Table 2: Descriptive Statistic of Cumulative Biogas Volume (mL)

Statistics	A	B	C	Control
Mean	141.78	191.61	108.47	114.40
Standard Error	28.96	38.64	22.55	24.01
Median	42.00	25.50	16.20	18.19
Mode	0.00	0.00	0.00	0.00
Standard Deviation	171.28	228.47	133.35	141.93
Sample Variance	29330.00	52190.00	17774.00	20139.00
Kurtosis	-0.98	-1.33	-1.02	-0.96
Skewness	0.78	0.64	0.78	0.81
Range	462.27	574.09	359.68	384.53
Minimum	0.00	0.00	0.00	0.00
Maximum	462.27	574.09	359.68	384.53
Sum	4961.50	6705.55	3795.60	4003.35
Count	35	35	35	35

Table 3: Descriptive Statistics of Cumulative Methane Volume (mL)

Statistics	A	B	C	Control
Mean	89.33	120.72	68.35	72.08
Standard Error	18.26	24.35	14.22	15.13
Median	26.48	16.08	10.21	11.48
Mode	0.00	0.00	0.00	0.00
Standard Deviation	107.91	143.95	84.02	89.43

Statistics	A	B	C	Control
Sample Variance	11642.00	20715.00	7055.00	7994.00
Kurtosis	-0.98	-1.33	-1.02	-0.96
Skewness	0.78	0.64	0.78	0.81
Range	291.24	361.70	226.60	242.26
Minimum	0.00	0.00	0.00	0.00
Maximum	291.24	361.70	226.60	242.26
Sum	3125.78	4224.50	2391.25	2522.10
Count	35.00	35.00	35.00	35.00

89.33 (±107.91), 120.72 (±143.95), 68.35 (±84.02), 72.08 (±89.43), for Biodigester A, B, C, and the control, respectively.

4.2 Discussion

This study examines the biogas production from cow dung (CD) and acha hulls (AH) in anaerobic digesters. The composition of these substrates, particularly the high volatile solids (VS) content of AH, plays a crucial role in determining biogas production efficiency. The average levels of total solids (TS), volatile solids (VS), nitrogen (N), and carbon (C) for both CD and AH were within acceptable ranges for anaerobic digestion, aligning with previous research. The total biogas production from the combined digestion of CD and AH exhibited noticeable variability among different digesters. Digester B displayed the highest average biogas volumes, followed by Digester A and then the control group. In contrast, Digester C had the lowest yields. These findings align with Nnokwe et al. (2024), who pointed out that co-digesting multiple substrates can boost biogas output due to improved nutritional balance and heightened microbial activity. The results demonstrate that combining CD and AH enhances performance compared to using single substrates alone, as evidenced by Digester B achieving a peak biogas volume of 574.06 mL.

Methane (CH_4) volumes showed a trend similar to the biogas outcomes. Digester B recorded both the highest average and peak CH_4 volumes, reinforcing that co-digestion can enhance methane production. This aligns with findings by Abouelenien et al. (2015), which highlighted increased methane yields from co-digestion due to synergistic substrate interactions. Conversely, Digester C exhibited the lowest CH_4 output, potentially attributable to higher ash content or other inhibitory elements in its substrate mix that may have impeded microbial activity and reduced methane generation.

Optimum biogas yields occur at a total volatile solid (TVS) concentration of 6 g VS/mL, an ambient temperature of 25.5°C, and a hydraulic retention time (HRT) of 26 days. The regression model formulated in this research (Equation 17) pinpointed TVS as the most critical factor affecting biogas yield, while temperature and HRT had less significant impacts on outcomes.

4.3 Conclusion

The study reveals that anaerobic digesters can significantly increase biogas production by co-digestion of carbon dioxide and aqueous hydroxyl (AH). The efficiency of anaerobic digestion is influenced by substrate composition, with high AH content being crucial. The optimal biogas yield was achieved at a total VS concentration of 6 g/mL, 25.5°C ambient temperature, and 26 days hydraulic retention time.

4.4 Recommendations

Based on the findings, recommendations for future biogas production systems include:

1. The findings endorse co-digestion, especially by combining substrates with high volatile solids content such as AH, to enhance biogas and methane production.

2. Operators must diligently manage the OLR, keeping it below 6 g VS/mL to prevent inhibition of microbial activity and maintain stable biogas production.

3. Maintaining a mesophilic range of 25-30°C supports optimal microbial digestion.

4. Conducting further studies on various combinations of organic waste materials and their effects on biogas production could enhance the co-digestion process, tailored to diverse regions and specific waste management requirements.

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