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Sustainable biogas: An attempt at blending tradition and innovation for green energy through co-digestion of cow dung and elephant grass

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ABSTRACT

Biogas, a product of anaerobic digestion, presents a promising avenue for renewable energy production, offering a sustainable alternative to traditional non-renewable energy sources. This study explores the potential of biogas production through the co-digestion of cow dung and elephant grass, employing a locally fabricated mild steel biodigester. Through comprehensive physiochemical analysis the moisture content (cow dung–49.64%, elephant grass–74.1%), fiber content (cow dung–6.4%, elephant grass–7.12%), nitrogen content (cow dung–2.03%, elephant grass–0.68%), protein content (cow dung–12.69%, elephant grass–4.26%), fat content (cow dung–5.81%, elephant grass–6.89%), and ash content (cow dung–19.72%, elephant grass–0.73%) were ascertained. They affirmed the suitability of the substrates to ensure effective bio digestion, laying a solid foundation for further exploration. Despite meticulous adherence to standard procedures, biogas production failed to meet expectations, revealing inherent limitations within traditional biogas generation methodologies. This underscores and reiterates the urgent need for a more professionalized approach to biogas production, that integrates advanced technologies and expertise to optimize yields. Beyond mere production metrics, the study underscores broader socio-economic and environmental implications, emphasizing the critical importance of addressing inefficiencies to advance sustainability and resilience within local communities. By transcending traditional paradigms, stakeholders can unlock the full potential of biogas as a renewable energy resource, fostering greater accessibility and contributing to a more sustainable energy future.

Keywords: biogas, green energy, anaerobic digestion, local energy solutions

INTRODUCTION

Biogas could be defined as an end product of anaerobic digestion (AD) where a biochemical process is held during which complex organic matter is decomposed in the absence of oxygen, by various types of anaerobic microorganisms (Mbachu & Alukwe, 2019). It consists of methane (about 65%), carbon dioxide (CO_2), impurities of hydrogen sulfide (H_2S), and water (Adegunloye & Abe, 2020). The gas components of biogas are specific to the plant and substrate type, and the composition of the biogas can only be partially controlled. Biogas is a flammable gas which is obtained by the action of methanogenic bacteria, working in the absence of oxygen through a process of AD (Ojo, 2021). Biogas proffers a very suitable alternative for meeting energy needs without using non-renewable energy, thereby defeating climatic changes, environmental depletion, and health challenges (Rahman et al., 2013). Biogas provides an economical, reliable, and sustainable source of renewable energy that can be generated using domestic, industrial, or agricultural materials engaging cheap technological means while relying on the rich fossil and renewable source deposit of a country like Nigeria (Kwietniewska & Tys, 2014). In the process of AD, microorganisms break down biodegradable materials in the absence of oxygen. Wang (2014) reported that AD can be broken down into three process which are psychrophilic, mesophilic, and thermophilic depending on their temperature range. Also, he claimed that AD processes involve four steps which are hydrolysis, fermentation, acetogenesis, and methanogenesis. In the hydrolysis step, the feedstocks of insoluble large polymers are broken down into soluble substrates by enzymes, after which fermentation of the monomeric products occurs during which sugar, amino acids, and fatty acids are converted into ammonia, organic acids, hydrogen (H_2), CO_2, and volatile fatty acids which are broken down into acetic acids, CO_2 and H_2 in the acetogenesis step and finally in the methanogenesis step acetate, formaldehyde, and H_2 are converted to CH_4 and water, which means in AD carbon of waste is consumed to produce biogas (CH_4, H_2, and CO_2) and digestate. Factors that affect AD include temperature, type of feedstock, and retention time. In AD, it is possible to produce biogas from a single biodegradable substrate however, when AD is carried out on a mixture of two or more substrates, it is known as co-digestion (Ojo & Babatola, 2020), which results in enhanced digestion due to the better carbon and nutrients balance (Adegunloye & Abe, 2020). The global pursuit of sustainable energy solutions has intensified in response to the escalating challenges posed by climate change, environmental degradation, and the depletion of finite fossil fuel resources. In this context, renewable energy sources have emerged as crucial alternatives to traditional, non-renewable energy sources, and as highlighted by (Mbachu & Alukwe, 2019), biogas production through AD offers significant potential for meeting energy demands while mitigating environmental impacts. Biomass-derived biogas offers a cost-effective and environmentally sound solution, utilizing organic waste materials to generate energy while minimizing pollution and greenhouse gas emissions (Rahman et al., 2013). Various works have been done in the line of renewable energy generation through various means and methods, hence varying results have been obtained and conclusions drawn in different instances, Singh et al. (2023) highlighted that with the continuous rise in the overall population of the world, the power requirements have increased drastically which may lead to the depletion of natural resources in the near future. Adegunloye and Abe (2020) investigated the co-digestion of cereal parts with cow dung for the production of biogas, the experiment lasted for about thirty days and the result of the experiment led to the conclusion that biogas can be produced from co-digestion of materials and it enhances digestion process due to the nutritional balance, which is attained by combining substrates, the highest percentage of methane content obtained was 65%. Mbachu and Alukwe (2019) worked on producing biogas from the liquid extract obtained from a plantain pseudo stem, they were inspired by the idea that renewable energy sources have to be available locally and to end users, their work saw biogas of very quality (75%) and this suggested the possibility of using this substrate in synergistic co-digestion for improved biogas quality. Production of biogas has never been in question the big uncertainty always revolves the quality of gas been produced due to the unpredictable output of the experiment. Kanth (2015) carried out a theoretical investigation into the use of biogas as an alternate fuel for internal combustion engines and theoretically validated and proved that biogas quality can be further improved through various techniques including scrubbing, chemical adsorption, pressure swing adsorption, membrane purification, cryogenic separation, which are quite sophisticated and unavailable to the common man. This research endeavors to contribute to the advancement of biogas production through the co-digestion of cow dung and elephant grass, utilizing mild steel biodigester. By exploring the fabrication, and performance evaluation of this biodigester, the study aims to enhance our understanding of biogas production processes and optimize biogas yield and quality all while using traditional cost-effective methods. Ultimately, the findings of this research are expected to inform future efforts to harness biogas as a sustainable and reliable energy source, thereby contributing to the global transition towards a more sustainable energy future.

Figure 1. Research set up (Source: Authors' own elaboration)

MATERIALS AND METHODS

The research was designed to be observational to ensure ecological validity, without interfering or manipulating variables (**Figure 1**). It was conducted in a natural setting to be observed for at least a period of 21 days, ensuring no intentional external intervention to the setup while using locally sourced materials, The sample size was 27 kg, in a ratio 1:1. Random sampling was employed for the cow dung and elephant grass ensuring natural conditions. Cow dung and elephant grass were used because of their availability, also because while cow dung provides a source of readily available organic matter and microorganisms, elephant grass adds structural biomass and cellulose content and the complementary nature of these materials can improve process stability and biogas yield compared to using them individually and because both elephant grass and cow dung are agricultural residues or byproducts that require proper management to prevent environmental pollution and odor issues. The material used for the biodigester was mild steel due to specific considerations such as durability (Azman, 2021), high strength, readily available, easy to fabricate, and cost-effective (Hosseini, 2017). Likely limitations such as corrosion, lifespan, and environmental impact were considered and steps were taken to reduce its likelihood such as coating the steel with paint (Nkoi et al., 2018).

The thought that the shape of the biodigester could affect the overall efficiency led to careful considerations in its cylindrical choice (Ojo & Babatola, 2020), like volume-surface ratio, mixing efficiency, ease of construction, and maintenance. The gas chamber was designed in cone shape (Torbira & Ebigenibo, 2021) to ensure efficient gas collection, greater structural stability, and ease of construction and maintenance.

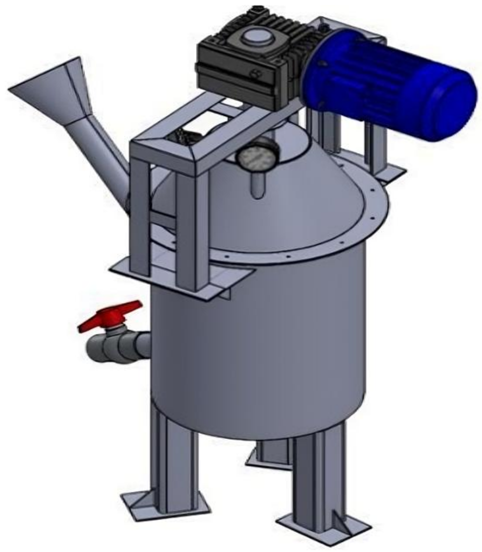

Figure 2. Biodigester in 3D (Source: Authors' own elaboration)

Figure 3. Cow dung and elephant grass undergoing pretreatment (Source: Authors' own elaboration)

The biodigester constructed also included a pressure gauge, thermometer for temperature and pressure monitoring as well as a stirrer shaft and reducer electric motor assembly to aid unform mixing of slurry in the chamber (**Figure 2**). After construction, the biodigester was pressure tested to check for leakages (Pandey, 2021).

Collection of Substrates

Manual collection of substrates was done, this is to ensure consistency in the work's aim to explore localized means of production, avoiding while possible high precision devices, materials or methods and reducing cost. The cow dung used was collected from Federal University of Technology, Akure (FUTA) livestock farm, Maalu Road, Akure while the elephant grass was collected from around School of Engineering and Engineering Technology Central Workshop, FUTA. The materials used for this collection included sacks, wheelbarrows, cutlass, and buckets. After collection, the substrates were prepared for digestion. The cow dung collected was sundried for 4 days, after which it was pulverized to increase the surface area. The grass collected was also cut into smaller pieces for easy ingestion and digestion. Samples of each substrate were taken for proximate analysis to determine basic physiochemical properties to ascertain their potential suitability for digestion. **Figure 3** shows cow dung and elephant grass undergoing pretreatment.

Figure 4. Mixing of substrates in preparation for digestion (Source: Authors' own elaboration)

Proximate Analysis of Digestion Substrate

The individual substrates were subjected to analysis by the standard of Association of Official Agricultural Chemists and expressed in percentages at the Animal Production Husbandry Laboratory at School of Agriculture and Agricultural Technology, FUTA for proximate analysis in order to affirm their basic physiochemical properties. The moisture content, fiber content, nitrogen content, protein content, fat content and ash content were all determined.

Mixing of Substrates and Ingestion

The mixture of pretreated cow dung and elephant grass were weighed using a weigh scale to be 27 kg and mixed with water of 27 kg in ratio 1:1 (Adelekan & Bamgboye, 2009). The mixture was stirred to attain homogeneity then, ingested equally into both biodigesters to undergo the bio digestion process. The automated stirrer in the biodigester ensured continuous mixing, preventing formation of clogs on the slurry surface (**Figure 4**).

Collection of Biogas

Biogas generated was collected in a tube, which was well sealed and placed to avoid puncture and ensure its movement.

RESULTS AND DISCUSSION

Results

Table 1 shows result from analysis of cow dung. **Table 2** shows result from analysis of elephant grass. **Table 3** shows representations and their meanings.

The determination of physiochemical properties holds significant importance in the bio digestion process, serving as critical indicators of substrate suitability and potential microbial activity within the biodigester (Kwietniewska & Tys, 2014). The average dry moisture content of the substrate mixture (49.64%, 74.1%) is conducive to optimal microbial activity, facilitating nutrient dissolution, microbial enzyme transport, and organic matter degradation.

Table 1. Result from analysis of cow dung

%M_C	%F_C	%N_C	%P_C	%FT_C	%A_C
49.64	6.40	2.03	12.69	5.81	19.72

Table 2. Result from analysis of elephant grass

%M_C	%F_C	%N_C	%P_C	%FT_C	%A_C
74.10	7.12	0.68	4.26	6.89	0.73

Table 3. Representations in table and their meanings

Properties key	Meaning
M_c	Moisture content
F_c	Fiber content
N_c	Nitrogen content
P_c	Protein content
FT_c	Fat content
A_c	Ash content

The low fiber content of the mixture (6.4%, 7.12%) is favorable for digestion, as excessive fibrous content can prolong the retention time (Okewale et al., 2018). Additionally, the presence of fiber enhances substrate structural integrity, promotes effective mixing, and supports microbial colonization, ensuring a stable digestion process.

The presence of nitrogen and protein (14.72%, 4.94%) indicates suitability for digestion, albeit at a slower degradation rate. With nitrogen and protein content below 25%, risks associated with excess nitrogen, such as ammonia accumulation or volatile fatty acid production, are mitigated.

Moderate values of fat content (5.81%, 6.89%) contribute to biogas production without impeding mixing or causing scum formation, as excessive fat content may do (Ojo & Babatola, 2020).

The ash content (< 20%) signifies the presence of predominantly biodegradable minerals, rendering the substrates highly suitable for digestion. Excessive ash content would pose risks of clogging, fouling, and nutrient imbalance, negatively impacting protein production (Ojo, 2021).

In summary, the substrates exhibit favorable physiochemical properties for bio digestion, thus validating their suitability for use in the process.

Discussion

Following 21 days of feedstock ingestion into the biodigester, no discernible changes were observed in both temperature and pressure within the system. Consequently, there was no noticeable alteration in the volume of the collection tube connected to the gas outlet of the biodigester. Extended observation until the 30th day revealed a subtle change in the volume of the collection tube; however, no measurable gas production was detected. Despite adhering meticulously to standard bio digestion procedures, the quantity of biogas generated from the biodigester was notably minimal relative to its capacity. The ingestion of a 0.028 m^3 feedstock mixture comprising cow dung and elephant grass into the 0.061 m^3 metallic biodigester resulted in only 45.90% filling of the slurry chamber, consequently leading to insufficient biogas production. The cumulative volume of biogas generated, in conjunction with that of the feedstock, failed to surpass 60% of the slurry chamber capacity. This shortfall in volume led to inadequate pressure buildup within the slurry chamber, impeding the propulsion of biogas toward the conical gas chamber and subsequently through the gas outlet to the collection tube.

CONCLUSION/RECOMMENDATION

The research findings highlight a considerable disparity between the projected and actual biogas production outputs, underscoring a substantial shortfall in performance. This disparity serves to illuminate the inherent limitations of employing traditional methods for biogas generation, particularly when executed without rigorous professional supervision and strategic planning. Consequently, it becomes increasingly apparent that an overreliance on conventional practices, devoid of expert input, undermines the potential for achieving optimal biogas yields. Moreover, this revelation prompts a critical examination of the broader implications for local biogas production endeavors aimed at fostering accessibility and sustainability within communities. By recognizing the inadequacies inherent in traditional approaches, stakeholders are compelled to reassess existing strategies and embrace a more holistic and professionally guided approach to biogas production. This entails integrating advanced technologies, employing best practices, and leveraging specialized expertise to maximize efficiency and output.

Furthermore, the implications extend beyond mere production metrics, encompassing socio-economic and environmental considerations. Inefficiencies in biogas production not only hinder progress towards energy independence and environmental sustainability but also impact the economic viability of local initiatives. Addressing these challenges necessitates a multifaceted approach that combines technical innovation with capacity-building initiatives to empower local communities to effectively harness the potential of biogas as a renewable energy resource. In essence, the findings underscore the imperative of transcending traditional paradigms and embracing a more professionalized approach to biogas production. By doing so, stakeholders can unlock the full potential of this renewable energy source, fostering not only greater accessibility but also resilience and sustainability within local communities.

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Declaration of interest: No conflict of interest is declared by the authors.

Data sharing statement: Data supporting the findings and conclusions are available upon request from corresponding author.

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