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GENERATION AND PROFILING OF BIOGAS FROM HOUSEHOLD ORGANIC WASTE THROUGH ANAEROBIC DIGESTION

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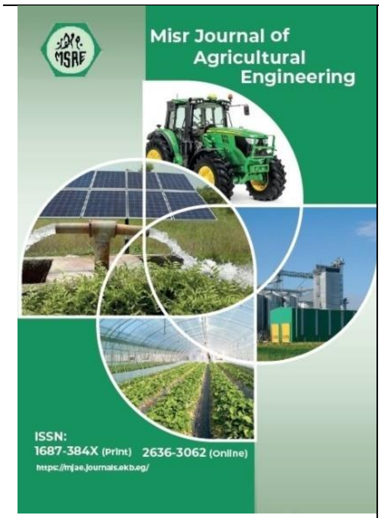

Keywords:
Domestic waste;
Clean energy;
Fossil fuels;
Climate change;
Organic matter

ABSTRACT

Nigeria is presently grappling with a substantial energy crisis due fuel subsidy removal; however, many Households possesses organic waste which has notable potential for biogas energy production owing to its high biodegradability and calorific value, thereby reducing the dependence on fossil fuels. An evaluation of the physical and chemical properties of household organic waste was conducted. The produced Biogas was collected utilizing a compressor and subsequently subjected to Gas Chromatography with Headspace for characterization. The findings from the physical and chemical analysis of the household waste include a moisture content of 59.2%, total solids at 40.8%, volatile solids at 77.3%, and carbon content at 42.9%. The biogas characterization reveals its composition, comprising 63% methane (CH_4), 31% carbon dioxide (CO_2), and 1% hydrogen sulfide (H_2S), with a calorific value of 24.10 MJ/m^3 while the byproduct of the anaerobic process, known as digestate, represents a valuable nutrient source essential for agricultural fertilization. This study proposes that every household in Nigeria has the potential to serve as a supplier of biogas energy and bio-fertilizer by harnessing their organic waste.

INTRODUCTION

Household organic waste encompasses all the biodegradable materials generated in households as a result of daily activities. This type of waste primarily consists of organic matter derived from food scraps, yard trimmings, and other biodegradable materials. They are either discarded or slated for disposal (Saleh & Hassan, 2023). This underutilized energy resource often undergoes decomposition in landfills and dumpsites, resulting in the emission of greenhouse gases into the atmosphere (Ramprasad et al., 2022). Primary sources of food waste generation comprise households, hotels, restaurants, supermarkets, residential complexes, cafeterias, food processing plants, among others. Food waste has the potential for recycling through processes such as anaerobic digestion (AD), composting, and vermicomposting (Somashekar, Rinku, and Manzoor, 2014).

Biogas is typically a gas produced through the decomposition of organic materials in the absence of oxygen. Its primary constituents consist of methane and carbon dioxide (Bhatia, 2015). Biogas, characterized by its lack of odor and color, emits a blue flame when ignited, akin to liquefied petroleum gas (Moses Jeremiah Barasa Kabey and Oludolapo Akanni Olanrewaju,

(2022) . It serves as a viable energy alternative to firewood, agricultural residues, and electricity. Furthermore, converting organic wastes into biogas has been shown to significantly reduce air and environmental pollution (Glivin, et al., 2021) (Lantzet al., 2007).

Biogas stands out as an eco-friendly fuel option, offering an alternative to crude oil and natural gas. Beyond its energy generation potential, the residual byproduct (digestate) can function as an organic fertilizer which offers a sustainable option for soil enrichment, serving as a cost-effective replacement for synthetic fertilizers. The utilization of biogas systems for organic waste removal, treatment, and management contributes to the creation of a cleaner environmental landscape (Kossmann et al., 1999)

As depicted in Figure 1, the production of biogas unfolds in three primary phases: hydrolysis, acidification, and methane generation (Wang et al., 2019). . The initial phase, hydrolysis, involves the breakdown of polymers. The subsequent stage, acidification, encompasses the transformation of the monomers generated during the first phase into various fermentation products, predominantly acids. Within this second stage, referred to as acetogenesis, the fermentation products undergo a conversion into acetic acid. Finally, in the third stage, methane-producing bacteria employ acetate, carbon dioxide, and hydrogen to produce methane and carbon dioxide (Goswami et al., 2016).

Anaerobic digestion pertains to the decomposition of organic waste materials, facilitated by bacteria in an oxygen-deprived environment, resulting in the production of biogas (Das et al., 2023). It can be elucidated as the natural breakdown of waste and organic substances through various microbiological processes, yielding biogas characterized by significant methane content. Simultaneously, it generates digestate, a nutrient-rich substance encompassing both micro and macro nutrients that promote and facilitates plants growth and development (Ziana & Rajesh, 2015)

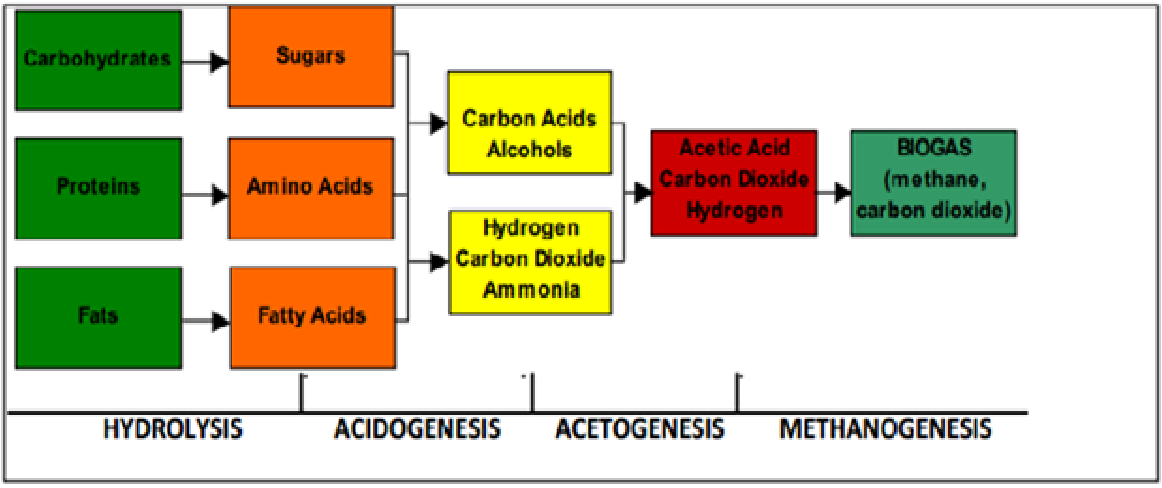

Fig. (1): A typical Anaerobic Digestion Process (Moriarty, 2013)

The composition of biogas is subject to variation contingent upon factors such as the source of raw materials, the duration of retention, and the temperature of the digestion process. Primarily, biogas comprises methane, typically falling within the range of 55% to 80% (Jemmett, 2006). In accordance with Kossman et al. (1999), the composition of biogas encompasses methane (40-70 vol %), carbon dioxide (30-60 vol %) and trace constituents (1-5 vol %), specifically hydrogen (0-1 vol %) and hydrogen sulfide (0-3 vol %). As reported by Ziana & Rajesh (2015), the composition of biogas includes methane (55-60 vol %), carbon dioxide (35-40 vol %), hydrogen (0-1 vol %), water (2-7 vol %), ammonia (0-0.05 vol %), oxygen (0-2 vol %), nitrogen (0-2 vol %) and hydrogen sulfide (2 vol %).

Despite increasing awareness of AD systems globally, their adoption in Nigeria remains limited. This study investigates the feasibility of utilizing household organic waste for biogas production and its potential to address Nigeria's energy challenges. The research objective is to assess household organic waste management for biogas production, focusing on sustainable energy, agricultural utilization, and environmental benefits. By examining both the biogas yield and the nutrient profile of the digestate, the research highlights a sustainable pathway for energy and waste management

MATERIALS AND METHODS

Collection and Preparation of Samples

Household organic waste samples were sourced and gathered from various locations, specifically, Iya Lekan Restaurant at Tanke Oke Odo, Iya Gbadamosi, and Mama Favour Canteens within the University of Ilorin vicinity. These samples encompassed food items such as rice, beans, bread, and vegetables. Subsequently, the organic waste materials were combined and processed into a paste using a blender. The resulting paste was stored at a temperature of 4 degrees Celsius (Dupade Vikrant and Pawar Shekhar, 2013). Prior to physicochemical analysis, the paste was diluted with water, and fresh samples were extracted (Somashekar, Rinku, and Manzoor. 2014)

Physicochemical Analysis

The purpose of this analysis was to assess the alterations occurring within the waste material during the digestion process. These parameters were evaluated prior to introducing the fresh slurry into the digester (Somashekar, Rinku, and Manzoor, 2014). The physicochemical analysis included the determination of the following parameters: Moisture Content (% moisture), Total Solids (TS %), Volatile Solids (VS %), and Carbon Content (%C).

Inoculum Preparation

Inoculum was derived from cow dung due to the fact that cows are ruminants, and their paunch serves as the primary site for microbial fermentation of consumed feed (Dupade Vikrant and Pawar Shekhar., 2013). A quantity of 4 kilograms of cow dung, sourced from the Oke Ose Cattle Rearer Market in the outskirts of Ilorin, North Central Nigeria, was weighed and placed into a container. It was then diluted with 4 liters of water, employing a dilution factor of 1:1, to produce slurry. The slurry was introduced into the digester through the tightly sealed inlet, and the digester was set aside for a duration of one week (Bovas, 2009).

Components and Construction of the Special Biogas Digester

The biogas digester, comprising a 20-liter plastic container, incorporated CPVC (Chlorinated Polyvinyl Chloride) pipes, tubing, a compressor, and a multipurpose sealant during its construction (Somashekar, Rinku, and Manzoor, 2014). The digester was equipped with essential features including an inlet, outlet, and gas line.

Biogas Characterization

Biogas characterization is a precise and dependable procedure for identifying the components present in the gas. This process involves the utilization of a gas chromatograph. Initially, the gas within a sealed tube is connected to a headspace vial, which is subsequently placed into a headspace jacket linked to the gas chromatography system. The headspace operational parameters include zone temperature, event duration, and vial specifications. Within the gas chromatograph, there is a detector responsible for identifying and quantifying each constituent (Kimberly Lynn Bothi, 2007).

Fig. (2): Set up of the fittings of the laboratory scale digester with compressor.

The sample underwent characterization using a Gas Chromatography system, specifically the HP 6890 model, powered with HP ChemStation Rev. A 0901[1206] Software. The system was configured with an injector temperature of 150°C, detector temperature of 300°C, an initial oven temperature of 35°C, a final temperature of 100°C, and a temperature ramp rate of 5°C per minute.

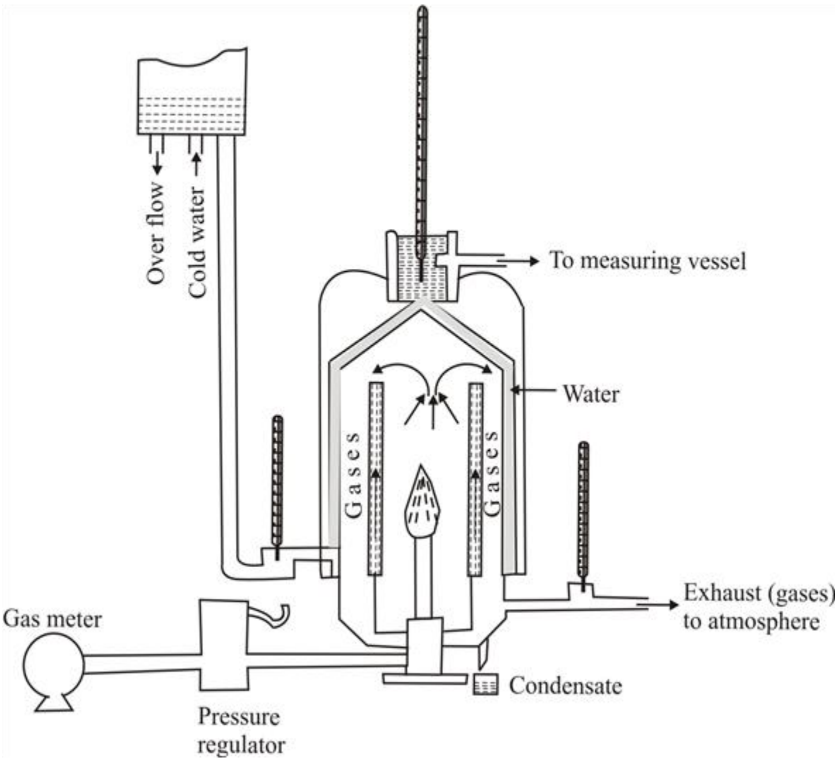

Fig. (3): Diagram of a Junker gas calorimeter (Imam et al., 2024).

Similarly, the calorific value assessment was conducted to ascertain the heat content of the biogas when completely burned. This measurement was accomplished using Junker's Calorimeter, wherein the temperature increases of a known volume of water resulting from the combustion of a known gas volume was determined (Imam et al., 2024).

Examination of the Digested Waste

An analysis of the digested waste was conducted to assess its elemental composition for fertilizer quality. This analysis was carried out utilizing X-ray fluorescence spectrometry (XRF) (Wastowski et al., 2015).

RESULTS AND DISCUSSION

Analysis of the Physical and Chemical Properties of Household Waste

The outcomes of the physicochemical analysis conducted on the composite domestic waste sample utilized in the experiment were compared with findings from a previous study, as presented in Table 1 below.

As asserted by Sharada, Surendra, and Hema. (2016), moisture plays a pivotal role in influencing the anaerobic digestion process of domestic waste. This influence can be attributed to two primary reasons: first, water facilitates the mobility of both microorganisms and nutrients, thereby enhancing the decomposition process; secondly, water reduces the constraints on the bulk transfer of non-homogeneous substrates. In general, the moisture content in the digested state tends to increase with higher levels of volatile solids and a reduction in total solids. The final moisture content obtained in this research, amounting to 59.2%, closely aligns with a study conducted by Maxwell (2011), which reported a moisture content of 65%. Furthermore, the domestic waste sample exhibited an average total solids content of 40.8%. The determination of total solids in food waste is a valuable method for assessing the quantity of nutrients available for bacterial activity during the digestion process. In this study, the total solids fell within the range conducive to biogas production when compared to findings by Dupade and Pawar (2013). Nevertheless, it's worth noting that the total solid percentage is likely to decrease due to the active performance of microorganisms decomposing the food waste, facilitated by the ample availability of moisture content in the digester. Additionally, the domestic waste exhibited a high volatile solids content of 77.3%. It's important to emphasize that the quantity of methane generated is contingent upon the quantity of volatile solids, which represents the amount of solids present in the waste and their degradability (Ofoefule, Uzodinma and Anyanwu, 2010).

Table 1: **Results for physicochemical analysis of domestic waste**.

Parameter	This Study	Maxwell (2011)	Dupade and Pawar (2013)
Moisture Content (%)	59.2	65	55
Total solids (% TS)	40.8	35	45
Volatile solids (% of TS)	77.3	Nd	80
Percent Carbon (%C)	42.9	Nd	Nd

Nd: Not determined

According to findings by Achinas, Achinas and Euverink (2017) and Somashekar, Rinku and Manzoor (2014), volatile solids play a pivotal role in biogas production, indicating that domestic waste holds significant potential as raw material for biogas generation

Biogas Production, Collection, and Analysis

Evidently, biogas production became noticeable during the fourth week following the initiation of the research. Subsequently, the digester was agitated to facilitate the even distribution of nutrients for microbial activity and to prevent the materials from settling at the bottom. Biogas samples were collected under pressure in a tube using a compressor. The biogas obtained underwent characterization to assess its composition, including H_2S, CH_4, CO_2, CO, and NH_3.

As reported by Pellerin et al. (1987), biogas originating from dairy manure digesters primarily consists of CH_4 (50-60%), CO_2 (40-50%), and H_2S (< 1%). Vishwanath (2018) describes biogas as a gas mixture with the following composition: CH_4 (50-75% vol), CO_2 (25-45% vol), H_2S (20-20,000 ppm), NH_3 (< 1% vol). According to Demirbas, Taylan and Kaya (2016), biogas typically comprises CH_4 (55-75%), CO_2 (25-45%), H_2S (0-1%), and O_2 (0-2%).

In this research study, the data obtained from the characterization of the produced biogas aligns consistently with previous findings, and it includes CH_4 (63%), CO_2 (31%), H_2S (1%), CO (3%), and NH_3 (1%).

Table 2: **Results for composition of biogas sample.**

Components	% Composition
CH_4	63.8
CO_2	31.2
H_2S	1.09
CO	2.65
NH_3	1.17

Calorific Value of Biogas

Calorific value signifies the quantity of heat energy generated during complete combustion, with higher values indicating greater efficiency. The methane content (%) serves as a significant factor in determining the overall calorific value of biogas; a higher methane percentage results in a higher calorific value. In the present study, the biogas obtained exhibited a calorific value of 24.10 MJ/m^3.

From a calorific perspective, the primary constituent of utmost significance within biogas is methane (CH_4). Bhatt and Tao (2020) indicated that the calorific value of biogas typically falls within the range of 20-25 MJ/m^3, contingent upon the methane content, which typically ranges from 50-75% by volume. In accordance with Ziana and Rajesh (2015), biogas is an odorless and colorless gas that burns with a blue flame, akin to LPG gas. The reported calorific value is approximately 20 MJ/m^3, with a methane content ranging from 55-60% by volume. Consequently, in this current study, a methane content of approximately 63.8% yields a calorific value of 24.10 MJ/m^3.

The study also placed significant emphasis on the proper disposal of digested residues, aiming to transform them from being an environmental concern into economically viable alternatives for promoting plant growth. To accomplish this, the concentration of chemical elements in the digestate resulting from the anaerobic digestion of municipal waste was assessed using X-ray fluorescence spectrometry (XRF).

The characterization of the digestate through XRF analysis revealed the presence of a total of 15 chemical elements, including Calcium (Ca), Potassium (K), Phosphorus (P), Magnesium (Mg), and others, as outlined in Table 4. Notably, elements such as Ca, K, S, Fe, Si, and P were found to be present in higher concentrations, rendering the digestate a valuable source of nutrients for facilitating plants growth and development. This approach holds the potential to address environmental concerns while also providing a sustainable solution for plant growth enhancement.

Table 3: **Results of the biogas analysis for calorific value.**

Parameter	Biogas
Calorific value (MJ/ m^3)	24.10

Table 4: **Analyte Concentration table for the digested waste.**

Element	Concentration	Element	Concentration	Element	Concentration
Na_2O	0.663 wt %	SO_3	7.328 wt %	Cr_2O_3	0.032 wt %
MgO	1.935 wt %	Cl	12.028 wt %	Mn_2O_3	0.579 wt %
Al_2O_3	3.920 wt %	K_2O	10.656 wt %	Fe_2O_3	7.182 wt %
SiO_2	30.230 wt %	CaO	14.531 wt %	ZnO	0.373 wt %
P_2O_5	9.583 wt %	TiO_2	0.858 wt %	SrO	0.101 wt %

CONCLUSIONS

This study confirms the potential of household organic waste as a resource for biogas production and nutrient recycling. The findings emphasize the feasibility of adopting AD systems at the household level in Nigeria, providing clean energy and sustainable agricultural inputs. Implementing such systems could mitigate climate change impacts, reduce reliance on fossil fuels, and promote environmental sustainability. Future research should focus on scaling up the process and evaluating economic viability for widespread adoption

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