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Article

Production and Characterization of Biogas from Domestic Waste by Anaerobic Digestion

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Abstract: Domestic waste can be used to produce biogas due to its high biodegradability and calorific value, which will reduce reliance on fossil fuels. The physicochemical analysis of the domestic waste was determined. The biogas was collected with the aid of compressor into a tube for characterization using a Gas Chromatography with Headspace. The result of the physicochemical analysis of the domestic waste includes; % Moisture (59.2%), % TS (40.8%), % VS (77.3%) and % C (42.9%). The characterization of biogas reveal that it contains CH_4 (63%), CO_2 (31%), H_2S (1%) with a calorific value of 24.10 MJ/ m^3.

Keywords: domestic waste, biogas, characterization, fossil fuels

1. Introduction

1.1. Domestic Waste

Food waste is any food substance, raw or cooked, which is discarded, or intended to be discarded. Food waste is an unexploited energy source that mostly ends up decomposing in landfills, thus releasing greenhouse gases into the atmosphere. Main generators of food waste include households, hotels, eateries, stores, residential blocks, canteens, food processing industries, etc. Food waste can be recycled via anaerobic digestion, composting and vermicomposting [1].

1.2. Biogas

Biogas generally is a gas that is obtained from the degradation of organic matters without the presence of oxygen and its major composition includes methane and carbon dioxide. Biogas is an odourless gas, a gas with no distinct colour which gives a blue flame when it is ignited like that of liquefied petroleum gas [2]. Biogas can be an energy substitute for firewood, agricultural residue and electricity. In addition, it has been observed that air and environmental pollutions are minimized when the wastes are converted to biogas [3]. Biogas is an environmentally friendly fuel that serves as an alternative fuel for compressed natural gas. Beside the use of biogas for generation of energy, the residue can serve as an organic fertilizer; this can replace the costly inorganic fertilizer. Removal, treatment and management of wastes using biogas system help to develop clean state of affairs of the environments [4].

According to Fig. 1 biogas can be formed in three main stages namely; hydrolysis, acidification and methane production. The first stage of biogas formation, that is hydrolysis refer to the polymer degradation stage. The second stage is the method of acidification whereby acid producing bacteria change the monomers formed in the first stage to different fermentation products, mostly acids. In the second step of this stage, known as acetogenesis, the fermentation products will be changed to acetic acid. In third stage, methane producing bacteria utilize acetate, carbon dioxide and hydrogen to form methane and carbon dioxide.

1.3. Anaerobic Digestion

Anaerobic digestion refers to the degradation of organic wastes, naturally by bacteria in the absence of oxygen to produce biogas. It is further explained as the putrefaction of wastes and organic matter through a number of microbiological methods to produce biogas which contains high content of methane and digestate that is rich in both micro and macro nutrients for plant developments[5].

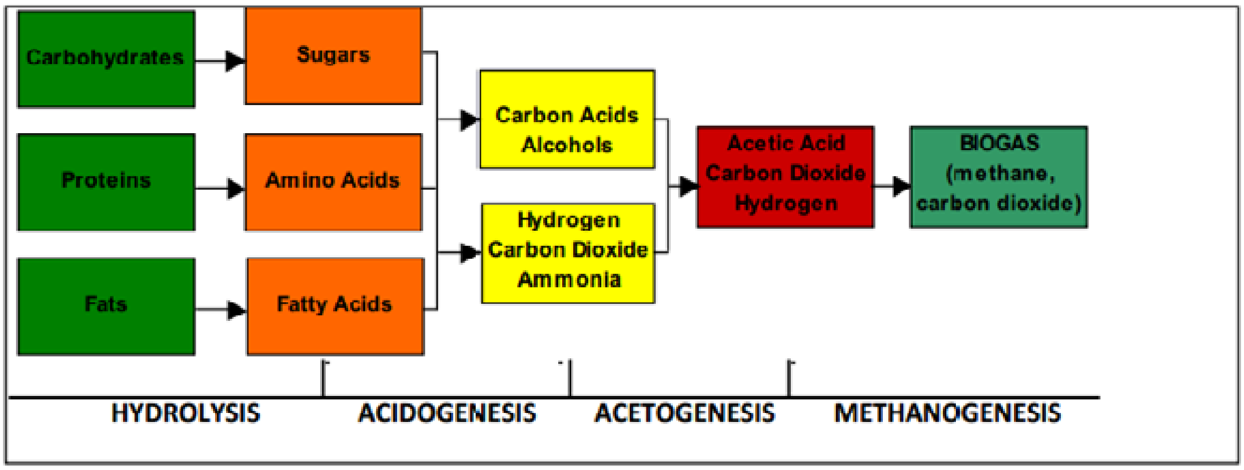

Figure 1: A typical Anaerobic Digestion Process [6]

1.4. Composition of Biogas

The composition of biogas varies depending on the raw materials, the retention period and temperature. The gas consists mainly of methane which is generally between 55% - 80% [7]. According to Kossman *et al.* [4] composition of biogas includes methane (40-70 vol. %), carbon dioxide (30-60 vol. %) and trace components (1-5 vol. %) that is, hydrogen (0-1 vol. %) and hydrogen sulphide (0-3 vol. %). Ziana *et al*. [5] reported composition of biogas as 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 sulphide (2 vol. %).

2. Materials and Method

2.1. Sample Collection and Preparation

Samples of domestic waste were collected from Iyalekan restaurant at Tanke Oke Odo, Iya gbadamosi and Mama favour canteens situated in University of Ilorin respectively, and classified as food items such as rice, beans, bread and vegetables. The domestic wastes were blended together with a blender to form paste which is stored at 4ºC [8], diluted with water and fresh sample was taken for physicochemical analysis [1].

2.2. Physicochemical Analysis

The analysis was carried out to determine the changes occurring in the waste during the digestion. The parameters were checked before the fresh slurry was put into the digester [1]. Physicochemical analysis carried out includes; Moisture Content (% moisture), Total Solids (TS %), Volatile Solids (VS %), %Carbon (%C).

2.3. Preparation of the Inoculum

Inoculum was prepared from cow dung, this is because cow is a ruminant and the paunch serves as the primary site for microbial fermentation of ingested feed [8]. A 4kg of cow dung collected from Okeose cattle rearer market in Ilorin suburb, north central Nigeria, was weighed, put into a container and diluted with 4 liters of water in the dilution factor of 1:1 to make slurry. The slurry was fed into the digester from the inlet, which was closed very tightly to prevent any form of leakage and the digester was kept aside for a week [9].

2.4. Requirements and Build-up of the Unique Biogas Digester

The digester (plastic can of 20 liters capacity) consists of CPVC (Chlorinated polyvinyl chloride) pipes, tube, compressor and Multipurpose Sealant which was utilized during the fabrication [1]. The digester consists of inclusions like inlet, outlet, and gasoline.

Figure 2: Set up of the fittings of the laboratory scale digester with compressor

2.5. Biogas Characterization

Characterization of biogas involves the use of gas chromatograph and it is the exact and reliable process of determining the constituents present in the gas. The gas in a sealed tube was connected to the head space vial and later placed in the head space jacket that has been connected to the gas chromatography system. The head space operational conditions include the zone temperature, events time and vial parameters. A detector that detects and measures each constituent is also present in the gas chromatograph [10]. The sample was characterized using a Gas Chromatography HP 6890 Powered with HP ChemStation Rev. A 0901[1206] Software, with Injector temperature of 150ºC, Detector temperature of 300ºC, Initial oven temperature of 35ºC, Final temperature of 100ºC and Rate of 5ºC/minute.

Likewise the calorific value was carried out to determine the heat content of the biogas upon complete combustion, and this was done by Junker's Calorimeter, in which temperature rise of a known volume of water as a result of the combustion of a known volume of gas was determined [11].

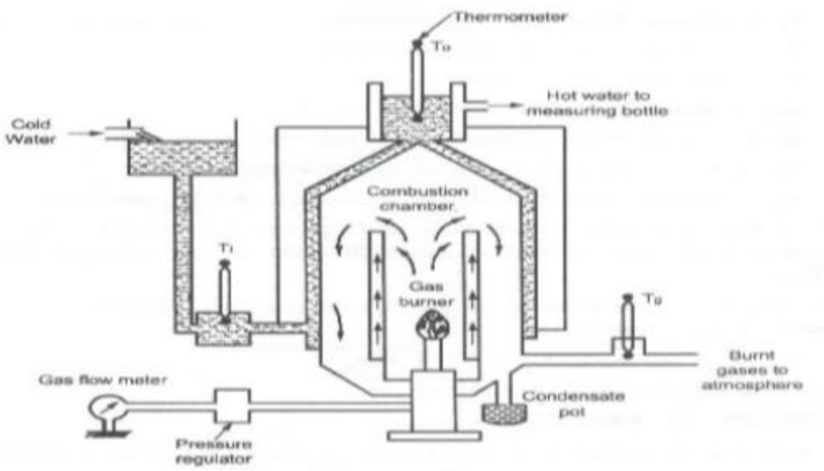

Figure 3: Diagram of a Junker gas calorimeter [11].

2.6. Analysis of the Digested Waste

The digested waste was analyzed to evaluate the elemental composition for fertilizer quality and this was done using X-ray fluorescence spectrometry (XRF) [12].

3. Results and Discussion

3.1. Physicochemical Analysis of Domestic Waste

The results of the physicochemical analysis carried out on the blended domestic waste sample used in the experiment were related to previous study done and this is shown in table 1 below.

Table 1: Results for physicochemical analysis of domestic waste

Parameters	This study	Maxwell [14]	Dupade *et al.* [8]
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 Sadaka *et al.* [13], moisture is a significant factor that affects anaerobic digestion of domestic wastes, there are two main reasons for this, that is mobility of water together with microorganisms growth which enhance the breakdown and passage of nutrient and also, water lessens the restriction of bulk transfer of non-homogenous substrate. In general, the amount of water in the digest state increases with increase in the amount of volatile solid and total solid reduction. The final % moisture (59.2%) obtained from this research, almost corresponds with study conducted by Maxwell [14] which recorded 65 % moisture content. Furthermore the domestic waste recorded an average of 40.8% total solids. Determination for total solids of food waste is an effective way of finding out the amount of nutrient that will be available for bacterial action during digestion. The total solids in this study are within the range for biogas production when compared with Dupade *et al.* [8]. However, the total solid percentage is likely decreased due to active performance of microorganisms decomposing the food waste, because of the sufficient availability of moisture content in the digester. Also from the study domestic waste contains high volatile solids (77.3%); the amount of methane produced depends on the quantity of volatile solid, which is an amount of solids present in the waste and their degradability [15]. As reported by Somashekar *et al*. [1] volatile solids are accountable for production of biogas, with this domestic waste has high prospect of being use as raw materials for production of biogas.

3.2. Biogas Production, Collection and Characterization

From all indication production of biogas were observed on the fourth week after commencing of research, afterward shaking of the digester was introduced to allow even circulation of nutrients for the microbes and avoids the possibility of the materials getting settled at the bottom. Biogas sample was collected in a tube with pressure using a compressor. The biogas obtained was characterized for H_2S, CH_4, CO_2, CO and NH_3.

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

According to Pellerin *et al*., [16] biogas from dairy manure digesters comprises mainly of CH_4 (50-60%), CO_2 (40-50%), and H_2S (< 1%). Vishwanath [17] review biogas as a mixture of gases with the composition as follows CH_4 (50-75% vol.), CO_2 (25-45% vol.), H_2S (20-20.000ppm), NH_3 (< 1% vol.). According to Demirbas *et al*., [18] biogas is composed of CH_4 (55-75%), CO_2 (25-45%), H_2S (0-1%), and O_2 (0-2%).

In this research work, the data obtained from the characterization of produced biogas indicate consistency with data obtained from previous study and it contains CH_4 (63%), CO_2 (31%), H_2S (1%), CO (3%), NH_3 (1%). Figure 4 represent chromatogram obtained from the characterization of produced biogas.

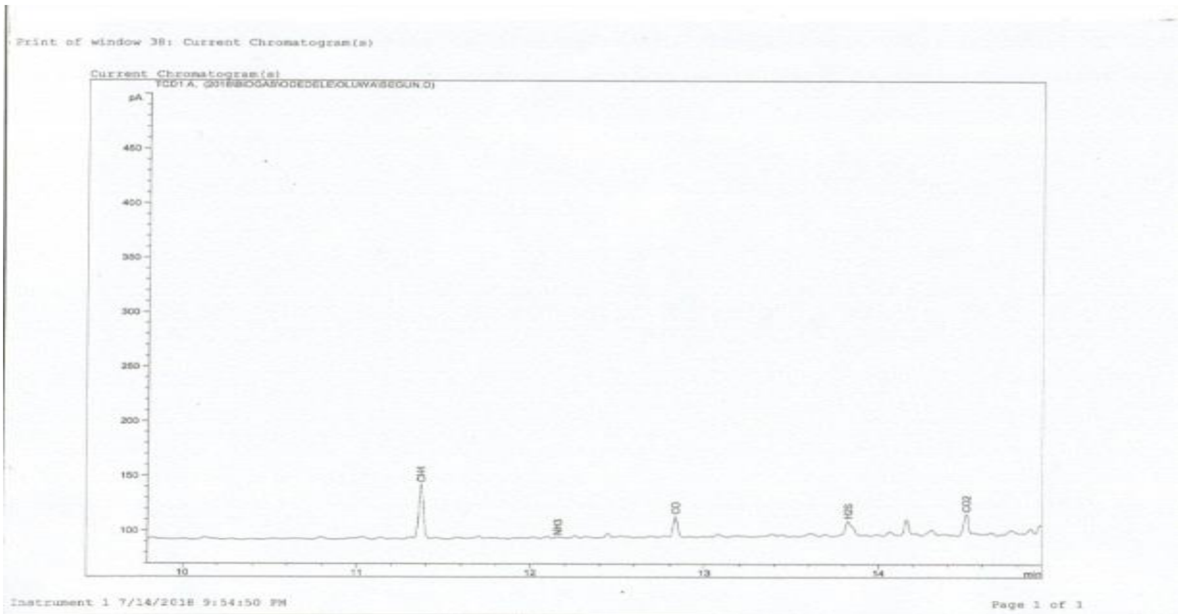

Figure 4: Chromatogram peaks

3.3. Biogas Calorific Value

Calorific value is defined as the amount of heat energy produced on complete combustion, the higher the calorific value, the more the efficiency. Methane percentage (%) is a major determinant of the total calorific value of the biogas, high% methane will give high calorific value. From this study, calorific value of the biogas obtained is 24.10 MJ/ m^3.

Table 3: Results of the biogas analysis for calorific value

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

From the calorific point of view, the most important component of biogas is methane (CH_4). Vishwanath [17] reported that calorific value of biogas can be in the range of 20-25 MJ/ m^3 based on the % methane (50-75% vol.). According to Ziana *et al*., biogas is an odourless and colourless gas that burns with blue flame similar to LPG gas and the reported caloric value is 20MJ/m^3 with % methane (55-60% vol.)[5]. Hence from this study methane of approximately 63.8 % gives 24.10 MJ/ m^3calorific value.

3.4. Mineral Composition of Digested Waste

This study also intensified focus on the correct disposal of digested residues so that besides ceasing to be an environmental problem, they can become economically feasible alternatives for plant development. In this context, the elements concentration in digestate from anaerobic digestion of municipal waste was determined using X-ray fluorescence spectrometry (XRF).

In the characterization of the digestate, conducted using the XRF technique, a total of 15 chemical elements were detected including Calcium (Ca) and Potassium (K), Phosphorous (P), Magnesium(Mg) and others as shown in table 4. Elements Ca, K, S, Fe, Si and P were found in higher concentrations making it possible for the digestate to be used as nutrients for plant development.

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 %

4. Conclusions

This study assesses biogas production from domestic waste through anaerobic digestion of 20L capacity built and designed in the laboratory. Production of biogas was observed on the fourth week which span through a period of two months. From this study domestic waste contains high volatile solids, indicating that it has high prospect of being use as raw materials for production of biogas. In addition, the production and use of biogas help in achieving sustainability through access to affordable, reliable, modern, clean energy and combats climate change and its impacts by regulating emissions.

Likewise digested waste from anaerobic digestion contains nutrient elements, making it possible for the digestate to be used as nutrients (fertilizer) for plant development.

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