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Production and purification of biogas from poultry dropping at mesophilic temperature

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ABSTRACT

Biogas is a mixture of gases produced during the breakdown of biodegradable organic matter in the absence of oxygen. To improve its quality, impurities such as carbon dioxide (CO_2), hydrogen sulfide (H_2S), and moisture must be removed. This study aimed to upgrade biogas produced from poultry droppings. The poultry droppings (PD) used as the substrate were collected from the Ladoke Akintola University of Technology (LAUTECH) poultry farm in Ogbomoso. Biogas production took place in a Continuously Stirred Tank Reactor (CSTR) located in the Agricultural Engineering Laboratory at LAUTECH. The produced biogas was analyzed using gas chromatography, both before and after purification. Chemical absorption was employed for purification, utilizing distilled water, silica gel, and iron fillings as scrubbers to remove CO_2, moisture, and H_2S, respectively. Before purification, the biogas composition was 61.42% CH_4, 35.83% CO_2, and 0.67% H_2S which improved to 89.81% CH_4, 8.22% CO_2, and 0.54% H_2S after purification. These results indicate that purified biogas is more advantageous for cooking compared to raw biogas.

INTRODUCTION

Energy is an essential prerequisite for accelerated economic development and improved quality of life for citizens of any country. Due to rapid industrialization and urbanization in the last few decades, there is a huge pressure on depletable crude oil, coal and other fossil fuels (Vijay *et al.*, 2006). Complex polymers are broken down into soluble compounds during the manufacture of biogas by enzymes produced by bacteria that digest substrate into short-chain fatty acids, hydrogen, and carbon dioxide (Adebayo *et al*., 2015). Methane and carbon dioxide make up the majority of the biogas produced by anaerobic digestion, which is a potential replacement for conventional energy sources (Jekayinfa *et al.*, 2020). As seen by the rise in bio-digester development, biogas is taking on greater significance as a source of energy for rural areas in developing nations (Vij, 2011).

The rising cost and associated problems with the combustion of fossil fuel have necessitated the need to develop and utilize cleaner renewable. Anaerobic digestion (AD) is a biological process of breaking down organic matter by microorganisms in the absence of oxygen (Sawatdeenarunat *et al.*, 2015; Zhang *et al.*, 2016). AD of agricultural residue can provide clean and renewable energy in the form of biogas (Shah *et al*., 2024). It is considered a widely accepted and well-studied technology for the treatment of organic wastes (Kamalinasab *et al.*, 2016). Waste management practices like incineration, landfills, animal waste, and wastewater treatment account for poisonous gas emissions and serious public hazards (Kowalska *et al.*, 2024).

The effects of organic loading rate on biogas yield in a continuously stirred tank reactor experiment at mesophilic temperature shows the improvement in the biogas production (Adebayo *et al.*, 2015). Studies have investigated the economic viability of the utilization of biogas as an alternative source of energy in rural parts of Nigeria (Okonkwo *et al.*, 2018). Carbon /nitrogen (C/N) ratio, Organic loading rate (OLR), Hydraulic retention time, pH, Alkalinity, Toxicity, Dilution, Agitation and Temperature were the following factors affecting the production of biogas. The biogas produced from different mass agricultural residues have different component gases where methane and carbon dioxides are the major components, where the percentage composition of CH_4 ranges from 50-60% and 30-40% of carbon dioxide (Ray *et al*., 2013).H_2S in the biogas produced is highly toxic and can gradually destroying the equipment used Also, the reduction of heat is caused as a result of high content of CO_2 (Islamiyah *et al*., 2015).

These impurities such as carbon dioxide, hydrogen sulphide and moisture present in biogas have to be removed to improve its quality. Biogas is a renewable energy that has the potential candidates to meet global energy requirements in a sustainable way (Kawo and Shamsuddeen, 2024. The purification process focuses on increasing the methane content and removing contaminants. Certain techniques of purification, such as water scrubbing and cryogenic separation, demand a significant amount of energy, which might lower the biogas manufacturing process's overall energy efficiency. This study aimed to purify the biogas produced from poultry dropping.

MATERIALS AND METHOD

Sample collection and equipment used

The materials used for this study are inoculum (which enhances the micro-organism in biogas production) substrate PD (Figure 1), Gas bag (LINDE), silica gel, distilled water and iron filling. The digestates of the past experiment set up for biogas production were used as inoculum for the research. The chemical and thermal characteristics of the substrate and inoculum were taken to the Chemistry Laboratory Department (LAUTECH) for determination according to (AOAC) 2019 standard and the properties that were determined included; Dry matter, Organic dry matter, pH, total nitrogen, organic carbon, moisture content, crude protein, crude lipid and carbohydrate content, phosphorus, potassium and ash content. Equipment used were the CSTR Reactor, Gas Detector (RITTER) and water tank.

Substrate and Inoculum Preparation

The fresh PD was collected from Ladoke Akintola University of Technology (LAUTECH) poultry farm, with the help of a shovel and bucket, one kilogram (1 kg) of poultry dropping was mixed with five litres (5 L) of distilled water and thoroughly stirred together to form a particle in preparation for the experiment which was transferred into the reactor (Jekayinfa *et al*.,2020).

Figure 1: Substrate used (Poultry droppings)

Description of the bioreactor

The experimental set-up was carried out at the processing laboratory, Department of Agricultural Engineering LAUTECH. The volume of the digester was 26 L vessel with a dimension of 47 cm height and 31 cm inner diameter. The body material for the reactor was made from galvanized steel. The digester body consists of a feedstock inlet, effluent and narrow gas outlet. The diameter for the feedstock inlet, effluent and gas outlet will be 25 mm, 50 mm of 10 mm respectively. The CSTR was equipped with a stirrer, the stirrer consists of two finned blades connected to a shaft in the center of the reactor. The stirrer was powered with the use of a 0.5 hp electric motor (Labor Technik ziege) which determines the motion in revolution of the stirrer that ranges from 50-2000 rpm. The temperature of the system was controlled using a water incorporated with a heater and water pump.

Experimental set-up for biogas production

The CSTR was cleaned in preparation for the experiment. The prepared substrate was loaded into the CSTR. 6 liters of pre-cultivated, modified seeding sludge (inoculum) were added to the stirred tank reactor. The reactor was operated in the fill-and-draw mode and stirred slowly for 20 minutes per hour at a speed of roughly 100 rpm, the substrate was then added at a modest loading rate of 0.5 to 2.0 goTSl-1d-1. Equation 1 was used to calculate the substrate mass supplied into the reactor (Adebayo *et al*., 2015). The amount of substrate fed into the digester was also calculated using Equation 2 (Adebayo *et al*., 2013)

The temperature of the water was controlled using the water tank heated at 37^{o}C and the heated water was circulating through the CSTR body using a 0.5 hp electric pump. The gas bag was connected to the outlet of the CSTR to collect the biogas produced. The sample of produced biogas was taken for analysis after a few weeks of production.

$$M_s = \frac{OLR \times V_g}{C_s} \qquad 1$$

Where

M_s = mass of the substrate (g)

OLR = Organic Loading Rate (goTSl$^-$ d$^-$)

V_r = Volume of the reactor in (litres)

C_s = Concentration of substrate (%)

$$\frac{oTS\ substrate}{oTS\ seeding\ sludge} \leq 0.5 \qquad 2$$

Where

$oTS_{substrate}$ = organic total solid of the substrate and;

$oTS_{seeding\ sludge}$ = organic total solid of the seeding sludge (the inoculum)

Equation (2) can be modified to read

$$P_i = \frac{Mi.Ci}{MsCs} \qquad 3$$

Where

P_i= mass ratio=2;

M_i= amount of inoculum, g

C_i=Concentration of inoculum, oDM in % Fresh mass

M_s= amount of substrate,g

C_s= Concentration of the substrate, oDM in % fresh mass

Biogas Purification Process

Raw biogas from the digester was made to pass through the container containing 1 liter of distilled water, as the biogas entered into the water, it produced small bubbles to sufficient contact with water to reduce the percentage of CO_2 present in the biogas. The resulting biogas was collected over water and passed into the container containing 50g of silica gel, the reaction reduced the percentage of moisture in the raw biogas because it has a good moisture-absorbing capacity. The biogas was then passed through a container filled with 70g of Iron-filling metal, the reaction was then used to remove the amount of H_2S present in the biogas, H_2S is poisonous and corrosive as well as environmentally hazardous. Therefore, the presence of iron filling reduced the environmental hazard. This procedure is in line with Lien *et al.(*2014) where water was used as one of the scrubbing units. This purification method was used because it is available and moderate cost to achieve. Figures 2 and 3 show the biogas production and purification setup

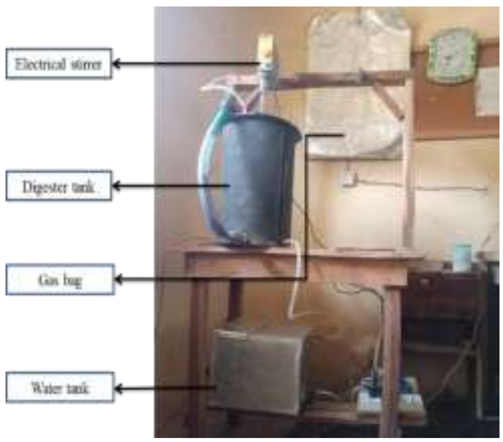

Fig .2: biogas production set-up

Figure 3: Purification set up of the biogas produced.

Laboratory Analysis for Raw and Purified Biogas

The produced biogas from the continuous reactor was analyzed using a gas analyzer (GCMS-2000) to know the composition of NH_3, CO and H_2S**.** The biogas composition CO_2 and CH_4 were determined using a gas chromatograph (Shimadzu, GC-8A) equipped with a thermal conductivity detector (GC-TD) as described by Zhu *et al.*2021.

RESULTS AND DISCUSSIONS

The chemical and thermal characteristics of the substrate and inoculum

Table 1 shows the chemical and thermal properties of the substrate (Poultry dropping) and the inoculum. The dry matter, organic dry matter (%DM), organic dry matter (%FM), Conductivity (mS/cm), protein, and Kejahdaj Nitrogen of poultry droppings were 22.40%, 60.16%, 15.27%, 8.68% 1.75% and 3.17 kjel.g/kgFM respectively. while the inoculum had respective contents of 10.48%, 71.24%, 8.02%, 7.26%, 40.51%,8.14% and 4.07 kjel.g/kgFM of dry matter, organic dry matter, fresh matter, Conductivity (mS/cm), protein and Kejahdaj Nitrogen.

Figure 4: shows the result of biogas production. The figure shows that biogas yields and the rate of biogas production increased with increasing hydraulic retention time. The highest value of production of biogas yield and biogas rate were 0.65g/kgoTS and 0.003g/g.day. The figure revealed that, as the organic loading rate (OLR) increased from 1.0 oTSg/l.d, the yields were found to increase till OLR of 2.0 goTS/l.d after which a decrease in yields was noticed. The decrease in production occurs as a result of weather changes that cause bacteria to become less active due to low temperatures. Also, there was a slight increase in the biogas rate of production with the same amount of organic loading rate at the Hydraulic retention time (Day) due to the change in temperature during the biogas production.

Table 1: Chemical and thermal properties of the substrate (PD) and the inoculum

Parameter	Poultry dropping	Inoculum
Dry Mater DM	22.40	10.48
Organic dry matter, oDM (%DM)	60.16	71.24
Organic dry matter (% FM)	15.27	8.02
N_{kjel}, g/kgFM	3.17	4.07
K (%)	1.75	1.02
Conductivity (mS/cm)	8.68	7.29

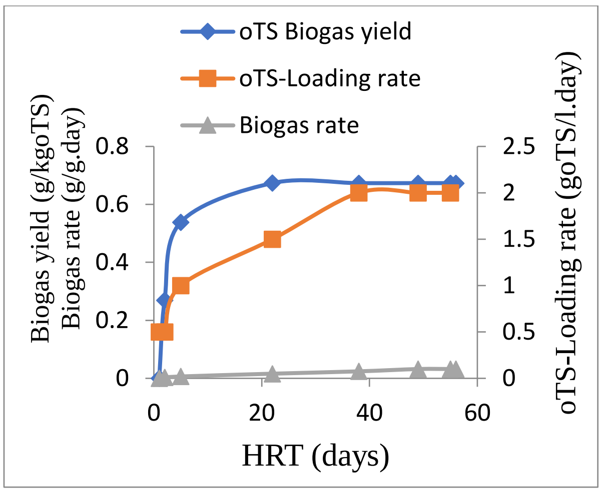

Figure 4: Continuously stirred tank reactors performance data for poultry dropping at mesophilic temperature.

Result of biogas purification (Removal of CO_2 and H_2O with distilled water)

Table 2 shows the result of purification by using distilled water, the removal efficiency of CO_2 and H_2S were reduced by 77.1% and 19.4% at the same temperature and pressure. The removal efficiency of H_2S content for biogas was decreased due to the concentration of dissolved hydrogen sulphide being saturated with the increased water scrubbing time. This is in agreement with Lien *et al.*(2014) where the average removal efficiency of H_2S was 51% at the scrubbing time and water level of 30 sec and 70 cm. The result of purified biogas shows that the methane concentration of the biogas increased from 61% to 89% whereas, NH_3, CO_2 H_2S decreased from 0.48%, 1.59%, 0.67% and 35.83% to 0.39% 1.02 0.54 and 8.22 respectively.

Table 2: Composition of Raw and Purified Biogas

Constituents	Raw biogas (%)	Purified biogas (%)	Efficiency (%)
CH_4	61.42	89.81	
NH_3	0.48	0.39	18.8
CO	1.59	1.02	35.9
H_2S	0.67	0.54	19.4
CO_2	35.83	8.22	77.1

CONCLUSION

Biogas produced from poultry droppings as substrate has a high potential for biogas generation by anaerobic generation due to the volume of biogas produced. This study also established the comparison of raw and purified biogas where the methane composition of biogas produced was upgraded from 61.42% to 89.91%.

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