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Evaluation of Biogas Production Potential and Energy Conversion Efficiency of Some Animal Dungs

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Abstract: *The increasing global demand for sustainable and renewable energy sources has intensified research into biogas production from animal wastes. This study evaluates the biogas production potential and energy conversion efficiency of different animal dungs, including cow dung, poultry manure, pig dung, and sheep/goat dung, through anaerobic digestion. The substrates were digested under mesophilic conditions for a defined retention period, and the volume of biogas produced was measured daily. Results revealed that cow dung yielded the highest biogas volume of 0.070 m³/kg, followed by poultry manure (0.055 m³/kg), pig dung (0.045 m³/kg), and sheep/goat dung (0.040 m³/kg). Energy conversion efficiency was assessed based on the methane content and calorific value of the biogas obtained. Cow dung exhibited the greatest energy potential, indicating its suitability as an efficient feedstock for bioenergy generation. The findings highlight the significant role of animal waste in renewable energy development and environmental sustainability, offering an eco-friendly solution for waste management and rural electrification.*

Keywords— Biogas production, Animal dungs, Anaerobic digestion, Energy conversion efficiency, Renewable energy

1. INTRODUCTION

The increasing global demand for energy, coupled with the rapid depletion of fossil fuel reserves and the adverse effects of greenhouse gas emissions, has intensified the search for sustainable and renewable energy sources (Akinbami et al., 2019). Biogas, a mixture of methane (CH4) and carbon dioxide (CO2) is produced through the anaerobic digestion of organic materials such as animal dungs, agricultural residues, and food waste (Mao et al., 2015).

Animal waste, particularly dung, represents one of the most abundant and under-utilized bioresources in many developing countries including Nigeria (Abubakar & Ismail, 2012). Different type of animal dungs- such as cow, pig, poultry, and goat-vary in their physicochemical properties, microbial composition, and nutrient content, which consequently influence their biogas yield and methane concentration (Igoni et al., 2008). The efficiency of biogas production depends on several factors including substrate type, carbon-to-nitrogen (C/N) ratio, temperature, and retention time (Nwankwo et al., 2021). However, there remains a need to comparatively evaluate the biogas potential and energy conversion efficiency of locally available animal dungs under similar anaerobic conditions, especially within the context of tropical developing regions where these resources are abundant. Therefore, this study aims to evaluate the biogas production potential and energy conversion efficiency of selected animal dungs, with a view to identifying the mist efficient substrate for sustainable bioenergy generation. The findings will contribute to optimizing biogas technology for rural energy supply and waste management in Nigeria and other developing nations.

2. LITERATURE REVIEW:

2.1 Overview of Renewable Energy from Biomass

Energy generation from renewable sources has gained global attention due to the depletion of fossil fuels and environmental concerns. Biomass energy, derived from organic waste materials, represents one of the most sustainable alternatives to fossil energy (Demirbas, 2017). Among biomass sources, animal dung offers significant potential for renewable energy generation through anaerobic digestion processes (Awe et al., 2017). Anaerobic digestion converts organic waste into biogas, a mixture primarily composed of methane (CH_4) and carbon dioxide (CO_2), which can be used for electricity, cooking, and heating. Biogas is typically comprised of 60% methane and 40% carbon dioxide (IEA Bioenergy).

2.2 Animal Dungs as Feedstock for Biogas Production

According to Igoni et al. (2008), cow dung remains one of the most efficient and stable substrates for biogas production due to its balanced nutrient composition and microbial activity. However, poultry droppings and pig dung have been reported to produce higher methane yields under optimal conditions (Adebayo et al., 2020; Arthur et al., 2011).

Goat and sheep dung produce relatively lower gas volumes because of their fibrous content and lower moisture level (Nwankwo et al., 2021). Thus, the selection of suitable animal dung is critical to improving energy conversion efficiency and biogas yi

The efficiency of energy generation from animal dungs depends on several operational parameters, such as temperature, pH, retention time, and substrate mixing (Kumar et al., 2018). Optimal biogas production occurs under mesophilic conditions (30–40°C), while extreme temperatures or improper C/N ratios reduce microbial activity (Mshandete & Parawira, 2009).

Studies also indicate that co-digestion of animal dung with agricultural residues (such as cassava peels or crop waste) enhances methane yield by balancing nutrient content (Adekunle & Okolie, 2015).

Several comparative studies have been conducted to evaluate different animal dungs for biogas production. Bamgboye and Oniya (2012) compared cow, pig, and poultry dungs, and found that poultry dung produced the highest methane concentration, while cow dung showed more stable and longer gas production. Similarly, Ismail et al. (2020) observed that the efficiency of biogas generation varied depending on the substrate type and digestion duration, with pig dung yielding higher biogas per unit of volatile solids.

These studies highlight the need for localized evaluations to determine the most efficient dung type for energy production under specific environmental and climatic conditions.

Utilization of animal dungs for biogas production not only generates renewable energy but also reduces environmental pollution, greenhouse gas emissions, and health hazards associated with open dumping of wastes (Kemausuor et al., 2014). Furthermore, the use of digestate as organic fertilizer improves soil fertility, promoting circular economy and sustainability (Minale, 2014).

Hence, evaluating the efficiency of animal dungs for energy generation contributes to achieving sustainable development goals (SDGs), particularly affordable clean energy and climate action.

Despite the growing need of sustainable and renewable energy sources, the potential of various animal dungs as feedstock for anaerobic digestion remain underexplored and inadequately quantified. This gap limits the optimization and adoption of biogas technology. Therefore, there is a need to evaluate and compare the efficiency of different animal dungs in energy generation through anaerobic digestion to identify the most effective substrate, improve biogas yield and enhanced energy sustainability.

This research is highly significant due to its contributions to environmental sustainability and energy independence. This study directly aims to promote renewable energy generation by exploring efficient methods, while simultaneously addressing a critical need for improved waste management. By converting waste materials into a useful resource, the project inherently reduces greenhouse emission and environmental pollution, offering a cleaner alternative to conventional energy sources and waste disposal practices.

The aim of the work is to evaluate the energy potential of different animal dungs for energy generation. Then compare the biogas yield from different animal dungs and determine methane content and energy value of the biogas produced. Assess the retention time and digestion efficiency of each dung type then identify the most efficient animal dung for energy generation.

The research will only focus on evaluating biogas production potential and energy conversion efficiency of selected animal dungs specifically focusing on cow, pig, goat and poultry. The study was a laboratory-scale digestion experiment. Therefore, investigation focused on determining the biogas potential and energy conversion efficiency from a limited sample variety of animal dungs. Consequently, the study's findings are constrained by its small scale, which limits the direct scalability of the experiment. Further limitations include inherent variability of biogas potential due to the animal breed, diet and health, environmental conditions and measurement and equipment constraints. Biogas' potential may vary with breed, diet, and health of animals.

Fresh animal dung (cow, sheep/goat, pig, poultry droppings), a sealed container or digester (plastic container with a lid), tubing or a gas collection system and a graduated cylinder (gas measuring device) were used as material for the study.

3. METHODOLOGY

The animal dung was collected from different animal farms. Each sample of the animal dung was sorted to remove inorganic substance from it. One kilogram of each sample was mixed with one liter of water to create a slurry with a 1:1 Ratio. The mixture was poured into the sealed container (Digester). The digester was sealed airtight to create anaerobic condition. The temperature range of about 30-40 ºC of the digester was maintained to favor the growth of the methane producing bacteria.

3.1 ANAEROBIC DIGESTION

The mixture was allowed to digest anaerobically inside the sealed container.

Biogas production started after about 5 days of digestion process. Day 1 – 5 microbes' adaptation, little gas is produced, Day 5 – 30 active digestion and methane production. After 30 days gas yields decrease as organic matter is depleted.

Figure 1 and Equation 1 shows collections and measurements of biogas produced. A tubing connected to the digester is used to capture the biogas released. The volume of the biogas released daily was measured with a graduated cylinder scale. Ideal gas law is also applied to standardized volume measurement depending on temperature and pressure.

$$V_{STD} = V \times \frac{P}{P_{STD}} \times \frac{T_{STD}}{T} \quad (1)$$

Fig. 1: Collections and measurement of biogas produced

Methane yield from a substrate elemental composition can be calculated theoretically using a formula derived from Buswell equation, which relates to substrate and chemical formula to methane and CO_2 production. The substrate typically has an elemental formula as shown below:

$$C_aH_bO_cN_d$$

The methane yields M_y in l/kg of volatile solids can be calculated using equation two below.

$$M_y = \frac{4a + b - 2c - 3d}{12a + b + 16c + 14d} \quad (2)$$

To convert Methane volume to moles, mass and Energy, the constant values used are temperature 0^0C, pressure 1atm and molar volume 22.414 l/mol = 0.022414m3/mol, lower heating value (LHV) of methane approximately = 50MJ/kg

No of moles of CH_4;

$$n = \frac{V_{CH4}}{0.022414} mol \quad (3)$$

From mole to mass; mass (kg) = n ×molar mass of CH_4

$$mass\ (kg) = n \times 0.01604$$

From mass to energy (MJ);

$$energy\ (MJ) = mass\ (kg) \times 55MJ/kg$$

4. Results Analysis

Table 1: Biogas produced in m3/kg of the animal dungs

Animal type	Biogas yield in m³/kg
Cow dung	0.070
Sheep and goat	0.040
Pig dung	0.045
Poultry droppings	0.055

Fig. 2: Biogas produced in m3/kg of the animal dungs

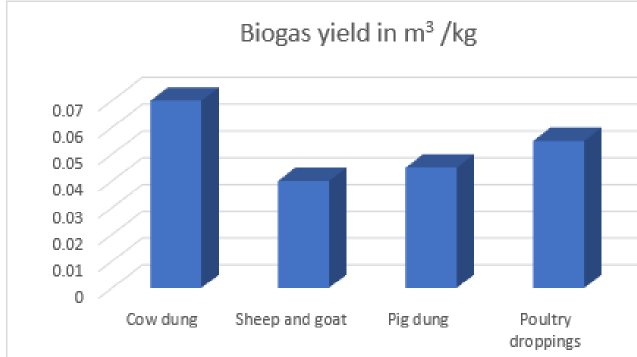

Table 2: Methane (CH4) yield in m3/kg of the animal dungs

Animal type	Biogas yield in m³/kg	Methane (CH4) yield in m³/kg
Cow dung	0.070	0.042
Sheep and goat	0.040	0.024
Pig dung	0.045	0.027
Poultry droppings	0.055	0.033

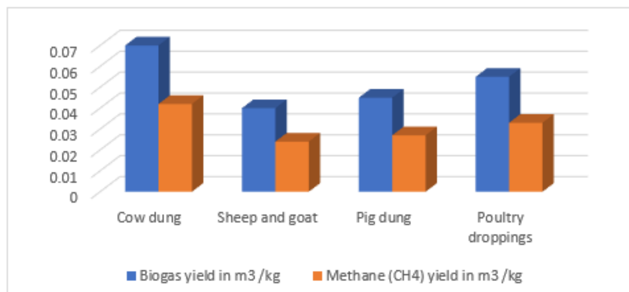

Fig. 3: Methane (CH4) yield in m3/kg of the animal dungs

Table 3: Energy produced from the animal dung in MJ/kg

Animal type	Energy produced in MJ/kg
Cow dung	2.310
Sheep and goat	1.300
Pig dung	1.485
Poultry droppings	1.815

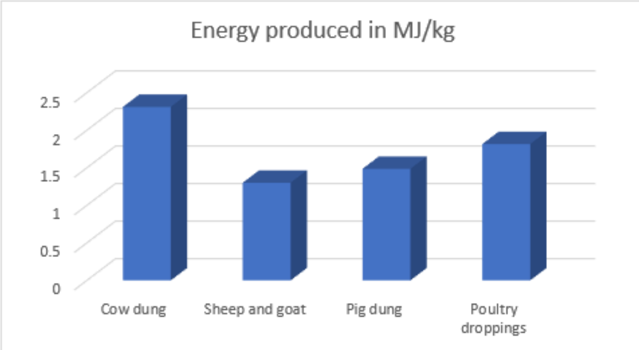

Fig. 4: Energy produced from the animal dung in MJ/kg

Table 4: Estimated total animal dungs deposited per year in Nigeria

Animal	Population (count used)	Manure per head (kg/year)	Total manure (kg/year)	Share of total percentage	Sources
Cow	54,810,000	10,950	600,169,500,000	96.60	NBS summary /2023 livestock figures
Poultry	258,500,000	32.85	8,491,725,000	1.37	National poultry estimate
Pig	9,200,000	396	3,643,200,000	0.59	National estimate/ sample census summary
Sheep	64, 330, 138	1.38	8,960,340,000	1.44	NBS summary/ 2023 livestock summary

Table 5: Typical calorific values of common fuels

Fuel type	Calorific value (KJ/kg)
Cow dungs	12,000
Firewood	18,000
Coal	35,000
Biogas	23,000
Methane	55,500
Petrol	47000

(Source: Rajbut, R.K, 2016 Engineering thermodynamics. Laxmi publications)

5. RESULTS INTERPRETATION

Cow dung produced the highest volume of biogas per kilogram (0.0706m3/kg) of substrate. This indicates high biodegradability and a balanced nutrient composition, particularly a favorable Carbon-to-Nitrogen (C/N) ratio, which supports microbial activity during anaerobic digestion. The result suggests cow dung is the most efficient feedstock for energy generation among the tested sample.

Poultry droppings with $0.055m^3/kg$ slightly having lower gas than cow dung but still demonstrated good energy potential. The lower yield could be due to high nitrogen content, leading to ammonia inhibition which can suppress methane genetic bacteria if not well balanced. However, poultry manure remains a strong alternative feed, especially when co-digested with carbon-rich materials.

Pig dung generated a moderate amount of biogas (0.045m3/kg). This suggests medium biodegradability, possibly due to higher fat content or fibrous residues that show down microbial degradation. Pig dung could benefit from pre-treatment or co-digestion to enhance gas output.

The lowest yield is sheep and goat dung (0.040m3/kg). This indicates low digestion of the materials. The fibrous nature and dry texture of sheep and goat dung limit microbial access to organic matters, reducing methane (CH4) production. Grinding or mixing with more easily degradable substrate could improve its performance.

From table 4.0, based on the estimated values of cow dung deposited per year, the total energy that can be generated from the cow dung is calculated to be 992,135,289,631MJ/kg which is equivalent to 31,460W of power that can be generated from cow dung.

6. CONCLUSION AND RECOMMENDATIONS

Cow dung is the most efficient substrate for biogas generation under the given experimental conditions. Sheep and goat dung are the least efficient and may require improvement strategies. The results demonstrate that the type of animal dung significantly affects the biogas yield and energy conversion efficiency. For optimal performance, combining animal dung (co-digestion) or improving processing parameters (temperature, PH, retention time) could enhance overall energy output.

It is recommended that in-depth research be conducted on the use of animal waste as a sustainable alternative to fossil fuels. Given the increasing depletion of fossil fuel reserves, exploring animal waste as a renewable energy source presents a viable solution to the global energy challenges. Comprehensive studies should be carried out to evaluate the efficiency, feasibility, and environmental impact of converting animal waste into bioenergy.

The government should formulate and implement policies on effective waste management that prioritizes the collection, processing and utilization of animal dungs for sustainable energy production.

Further research should focus on analyzing various animal dung to determine their comparative energy potentials. This will assist in identifying the most suitable species or combinations for large-scale energy generation.

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