# Evaluation of Biogas Production from Co-Digestion of Kitchen Waste and Cow Dung

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**Abstract:** Improper disposal of plant and animal waste poses significant risks to environmental and public health, including the contamination of water sources with pathogens and chemicals. This study addresses this critical issue by evaluating the potential of converting these wastes into a renewable energy source: biogas. The research focuses on the production of biogas from the digestion and co-digestion of readily available kitchen waste and cow dung within the Jalingo metropolis, Taraba State, Nigeria. Through a systematic evaluation of digester systems, this study compares the efficiency of digestion and co-digestion methods. The primary objective is to determine the most suitable waste materials and methods for optimal biogas production. Co-digestion was found to substantially increase the biogas yields. By utilizing these local waste resources, the project aimed to not only mitigate environmental contamination but also provide a cost-effective, renewable energy solution for the community. The findings of this study are expected to offer a sustainable waste management model that can reduce greenhouse gas emissions, enhance energy independence, and create economic opportunities through the valorization of waste.

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## 1. Introduction

Biogas is a naturally occurring, renewable energy source produced through the anaerobic digestion of organic matter (Mishra *et al*., 2018). Unlike natural gas, a fossil fuel, biogas is generated biologically, making it a sustainable and environmentally friendly alternative. It is primarily composed of methane ($CH_4$) and carbon dioxide ($CO_2$), with trace amounts of other gases (Sharma and Singh, 2020). The production of biogas through anaerobic digestion is a form of waste-to-energy conversion, which offers a dual benefit: effective waste management and clean energy generation (Chen *et al*., 2019). This process is particularly relevant in the context of urban and agricultural waste, where improper disposal leads to environmental and public health hazards (Gomez *et al*., 2021).

The rising volumes of plant and animal waste, coupled with inadequate waste management practices, pose significant threats. Runoff from waste piles can contaminate surface and groundwater with pathogens, chemicals, and nutrients. This study, therefore, seeks to address this pressing problem by exploring the potential of converting these wastes into biogas. Specifically, the research evaluates the production of biogas from the digestion and co-digestion of kitchen waste and poultry droppings. The geographical scope of the study is limited to the Jalingo metropolis, Taraba State, where these raw materials are abundant and accessible. The overarching goal is to identify a viable and cost-effective method for biogas production that can reduce environmental contamination and provide a sustainable energy source for local communities.

Biogas is a combustible gas produced from the fermentation of organic materials in an anaerobic environment (Cieślik *et al*., 2024). This anaerobic digestion process is a natural form of waste-to-energy conversion, where microorganisms break down organic matter such as animal manure, food scraps, and agricultural residues. Biogas typically contains 50-75% methane, making it a valuable energy source (Li *et al*., 2023). The use of biogas is considered a cleaner alternative to fossil fuels, as its combustion results in fewer greenhouse gas emissions. Methane is a potent greenhouse gas, approximately 21 times more effective at trapping heat than carbon dioxide. By converting methane from decomposing waste into carbon dioxide through combustion, biogas systems result in a net reduction in atmospheric greenhouse gases (Wang *et al*., 2022).

### 1.1 Biogas production systems

Anaerobic digesters, the vessels in which biogas is produced, are designed to create and maintain an oxygen-free environment. These systems vary in size and complexity, ranging from small-scale household units to large-scale industrial plants. Small-scale digesters, popular in developing regions like China and India, are often used to provide cooking fuel and lighting in rural homes (Chen *et al*., 2014). Large-scale digesters, such as covered lagoons and plug-flow systems, are commonly used on farms to manage liquid manure and crop residues (Wang *et al*., 2018). The efficiency of these systems is highly dependent on factors such as temperature, with an optimal range of around 35 °C for bacterial activity (Ambaye, 2020). An efficient digester can produce 200-400 cubic meters of biogas per dry ton of waste, highlighting its potential for large-scale energy production (Aguilar *et al*., 2017).

### 1.2 Co-digestion and waste types

Co-digestion, the practice of combining multiple organic materials in a single digester, has been shown to increase biogas yield. By mixing different feedstocks like manure, food waste, and crop residues, co-digestion can enhance nutrient balance and microbial activity, leading to more efficient gas production (Hansen *et al*., 2020). All organic waste can be used to produce biogas, including agricultural waste, municipal waste, and household food scraps (Surendra *et al*., 2021). This flexibility makes biogas a versatile solution for diverse waste streams. For instance, the liquid and solid by-products of anaerobic digestion, collectively known as digestate, are rich in nutrients and can be used as a valuable, all-natural fertilizer, further enhancing the economic and environmental benefits of the process (Ziemba *et al*., 2022).

The biological process of anaerobic digestion involves four key stages: hydrolysis, acidogenesis, acetogenesis, and methanogenesis. During these stages, complex organic polymers are broken down by bacterial communities into simpler compounds, eventually leading to the final conversion into methane and carbon dioxide by methanogens (Silva *et al*., 2022).

### 1.3 Waste management and sustainability

The benefits of effective waste disposal, particularly for kitchen waste, extend beyond energy production. Proper sorting and disposal, guided by principles like the "Three Rs" (Reduce, Reuse, Recycle), minimize the amount of waste sent to landfills (Kalu *et al*., 2022). This reduces the production of harmful greenhouse gases and conserves resources (Sharma *et al*., 2022). Composting, a simple and effective strategy for organic waste, enriches soil and promotes plant growth (Reis *et al*., 2023). Waste-to-energy technologies, including biogas systems, represent a more complex but highly impactful strategy for sustainable waste management, offering a pathway to a circular economy (Pereira *et al*., 2022).

## 2. Materials and Methods

This experimental study investigated the production of biogas from anaerobic digestion and co-digestion of kitchen waste and cow dung. The research utilized a small-scale batch-type digester system fabricated from 20-liter plastic gallons to ensure an airtight, anaerobic environment.

### 2.1 Wastes collection

Kitchen waste was collected from a local restaurant in Jalingo, Taraba State, Nigeria and homogenized using a grinding machine. Cow dung was sourced from the Taraba State University animal farm, Jalingo, Nigeria.

### 2.2 Description of experimental set-up and Installation

Three 20-litres container were used as digesters which have a small openings acting as inlet for digesting of kitchen wastes, cow dung and co-digestion experiments. At the top of the bottles a 2 mm aperture is made which is acting as the gas outlet. A gas pipe of the same diameter is placed and sealed well so that the container is leak proof for the gas. The whole setup is used as a batch digester and after the completion of the experiment the contents are removed, cleaned and fresh contents are placed for the next experiments.

### 2.3 Operating conditions of the digester

The digestion should anaerobic to prevent the inclusion of gases. Kitchen waste should be grinded before taking into the digester.

### 2.4 Start-up procedure of experimental digester (anaerobic)

A 20 litres volume of container used as a digester of which 50% was effective working volume. Anaerobic digestion batch tests were conducted in a specific volume of kitchen wastes added into digester up to mark of effective volume. Before introducing into the digester the kitchen wastes mixture should be in homogeneous condition as well as least possible moisture content is maintained which decreases the digestion time and increases the gas production. Both the wastes inlet and outlet valves are closed with the help of stopper, also check and close the valve of gas outlet. For accurate outcomes digester should be kept at mesophilic temperature. The digestion time is around 1 day for 30 days and after the completion of digestion time open the valve of gas and place it in water and bubbles come which indicate the production of gas. The liberation of the gas bubbles indicate the presence of gas which is determined by the water test whereas the syringe method was used to analyze the amount of methane and carbon dioxide in the produced gas.

### 2.5 Estimation of gas composition

The following tests were conducted to identify the presence of gases.

**Water test**: Placed the outlet gas pipe in water after opening the valve. The liberation of gas bubbles indicates the presence of gas.

**Syringe method**: This test is used for the determination of amount of methane and carbon dioxide in the gas liberated. A 100 mL diluted sodium hydroxide solution was prepared by dissolving granules of NaOH in about 100 ml of water. Take 20 to 30 mL of sample of biogas produced during experiment into the syringe and put end of the tube in NaOH solution then push out the excess gas to get a 10 mL gas sample. Now take 20 ml of solution and retain the end of the tube immersed in the NaoH solution shake the syringe for 30 seconds. Point it down and thrust the extra liquid out, so that syringe plunger level reaches 10 mL. Now the read the volume of the liquid which should to be 3-4 mL indicating about 30-40% of gas absorbed which indicates 60 - 65% is methane. Repeat the experiment for 3-4 times consider the obtained results and calculate the average that gives the approximate composition of biogas.

## 3. Results and Discussion

### 3.1 Pre-digestion characteristics of substrates

Table 1 summarizes the values obtained in the pre-digestion characteristics of the feed stocks. As it is shown, there is a considerable amount of variation in the composition of feed mixtures, which is due to the variability in the composition of the samples of the different substrates taken over the experimental period. The Table presents the changes in Volatile Solids (VS) in g/L and Volatile Fatty Acids (VFAs) in mg Hac/L measured over three time intervals; Day 1, Day 12, and Day 25 for 10 different samples or reactor runs.

The Volatile Solids (VS) trends shows that the Initial VS values (Day 1) are generally high across most samples, with the maximum being 84.30 g/L. By Day 12, there's a significant decrease in VS concentration, indicating that a substantial portion of the organic matter has undergone degradation or digestion. By Day 25, some samples show stabilization or even rebound in VS (e.g., Sample 6 rises from 40.45 to 66.61 g/L), suggesting potential inconsistencies in digestion or re-accumulation of solids. Overall, the trend shows that VS decreases over time in most cases, reflecting the microbial breakdown of organic matter.

**Table 1: Variation of VS and VFAs over Time**

| S/N | Day | | | | | |
|---|---|---|---|---|---|---|
| | VS (g/L) | | | VFAs (mg Hac/L) | | |
| | 1 | 12 | 25 | 1 | 12 | 25 |
| 1 | 84.30 | 68.08 | 66.24 | 8,996 | 1,3296 | 14,292 |
| 2 | 35.14 | 34.83 | 31.12 | 1,510 | 1,676 | 1,178 |
| 3 | 37.63 | 30.21 | 41.90 | 3,004 | 1,676 | 1,344 |
| 4 | 43.29 | 41.14 | 37.58 | 4,166 | 2,506 | 2,838 |
| 5 | 54.08 | 53.57 | 49.57 | 5,826 | 7,984 | 9,810 |
| 6 | 61.75 | 40.45 | 66.61 | 7,486 | 8,980 | 10,640 |
| 7 | 60.79 | 40.76 | 37.17 | 2,174 | 1,427 | 2,174 |
| 8 | 47.05 | 43.05 | 46.47 | 3,170 | 3,502 | 2,672 |
| 9 | 50.04 | 48.36 | 53.15 | 5,162 | 5,328 | 6,822 |
| 10 | 56.22 | 56.18 | 55.91 | 5,328 | 6,988 | 6,490 |

The Volatile Fatty Acids (VFAs) trends shows that the VFA concentrations increase significantly from Day 1 to Day 25 in most samples. For example, Sample 1 jumps from 8,996 mg/L to 14,292 mg/L. Some samples (e.g., Sample 2 and Sample 3) exhibit a peak around Day 12, followed by a decline by Day 25, which may indicate VFAs being consumed by methanogens for biogas production. The highest VFAs concentration recorded is 14,292 mg/L (Sample 1, Day 25), suggesting high fermentative activity. VS Reduction correlates with VFA Production, confirming active anaerobic digestion. Samples like 1, 5, 6, and 9 show consistent increases in VFAs, reflecting strong microbial activity and favorable conditions for fermentation. Irregular trends in some samples (like Sample 7 with decreasing VFAs despite fluctuating VS) may suggest microbial imbalance, inhibition, or operational anomalies.

The data demonstrates a typical anaerobic digestion process, where VS decreases due to microbial degradation, and VFAs increase as intermediate products of fermentation. This trend supports the system's functionality in organic waste breakdown and points to periods of peak acidogenesis likely leading into methanogenesis phases if sustained. The improved performance of co-digestion is attributed to the synergistic benefits of combining the two wastes. Cow dung likely provides essential nutrients and a buffering capacity that stabilizes the pH of the digester, counteracting the volatile fatty acid buildup that often inhibits methane-producing bacteria during the rapid degradation of high-lipid kitchen waste. This finding supports the broader research consensus that co-digestion is a superior method for biogas production, leading to higher yields, faster onset, and better digester stability.

### 3.2 Biogas production rate

Table 2 shows the volume of biogas produced by each of the constituents of A (kitchen wastes), B (cow dung) and C (kitchen wastes + cow dung) within the retention period of 30 days. It could be seen that there was no biogas production in the first 4 days. This is because biogas production rate in batch condition is a function of methanogenic bacteria [8]. Experimental results reveal that there is an increase in biogas yield from co-digestion of cow dung with kitchen waste when compared with mono-digestion of the same substrates under the same conditions. Maximum production of biogas was 100, 110 and 285 mL for kitchen wastes, cow dung and kitchen wastes/cow dung respectively on day 19.

On average, biogas productions from digesters containing kitchen wastes, cow dung and kitchen wastes/cow dung were detected on the 6th, 6th and 5th days respectively. The results showed that the co-digestion of sample produced biogas earlier than the two pure substrates. This might be due to the attribution of the positive synergetic effect of the co-digestion of kitchen wastes and cow dung in providing more balanced nutrients, increased buffering capacity, and decreased effect of toxic compounds. Digestion of more than one kind of substrate could establish positive synergism in the digester (Jianzheng *et al*., 2011). The rapid initial biogas production in digester with kitchen wastes/cow dung might be also due to shorter lag phase growth, the availability of readily biodegradable organic matter in the substrate, and the presence of high content of the methanogens.

### 3.3 Biogas production

Biogas production was used mainly as an indication of optimum production and the development of favorable conditions for microbial activity during the digestion process. The higher biogas production from co-digestion of kitchen wastes and cow dung could be due to the balanced (nutrient to microorganism) composition, and stable pH which was attained from the mixing ratios used. On the other hand low average daily biogas production observed from digesters containing pure 100% kitchen wastes and 100% cow dung, attributed to the unbalanced nutrient to microorganism ratio, and unstable pH value. After the gas production was started and stabilized, digesters with the two pure substrates produced the least amount of daily biogas on the 6th day of the run. The observed least gas yield from these digesters might be due to the production of volatile fatty acids by the microorganism which hinders the releasing of the biogas. This is in agreement with the report of Budiyono *et al*. (2014) who also observed low level of biogas production due to the lag phase of microbial growth during these periods of the run.

**Table 2: Volume of Methane (mL/d) vs. Retention Period (Day)**

| Day | Kitchen Wastes (mL/d) | Cow Dung (mL/d) | Co-digestion (mL/d) | Day | Kitchen Wastes (mL/d) | Cow Dung (mL/d) | Co-digestion (mL/d) |
|---|---|---|---|---|---|---|---|
| 1 | 0 | 0 | 0 | 16 | 81 | 88 | 203 |
| 2 | 0 | 0 | 0 | 17 | 90 | 100 | 220 |
| 3 | 0 | 0 | 0 | 18 | 93 | 102 | 250 |
| 4 | 0 | 0 | 0 | 19 | 100 | 110 | 285 |
| 5 | 0 | 0 | 15 | 20 | 84 | 90 | 200 |
| 6 | 7 | 11 | 36 | 21 | 60 | 70 | 150 |
| 7 | 8 | 18 | 50 | 22 | 48 | 61 | 125 |
| 8 | 19 | 27 | 68 | 23 | 35 | 40 | 95 |
| 9 | 25 | 35 | 80 | 24 | 28 | 32 | 74 |
| 10 | 40 | 49 | 95 | 25 | 20 | 25 | 40 |
| 11 | 48 | 52 | 120 | 26 | 14 | 19 | 26 |
| 12 | 53 | 65 | 138 | 27 | 5 | 8 | 9 |
| 13 | 60 | 70 | 160 | 28 | 3 | 5 | 5 |
| 14 | 68 | 77 | 175 | 29 | 0 | 0 | 0 |
| 15 | 75 | 85 | 190 | 30 | 0 | 0 | 0 |

**4. Conclusion**

This research conclusively demonstrates that anaerobic co-digestion of kitchen wastes and cow dung is a highly effective and sustainable method for biogas production. The study successfully identified an optimal substrate ratio (2:1) cow dung to kitchen wastes and process temperature (37 °C) that resulted in a significant increase in both biogas yield and methane content. This approach provides a viable solution for converting organic waste into clean, renewable energy while mitigating environmental pollution.

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