

## Assessing the Biogas Generation Capacity of Organic Food Waste

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Article Info	ABSTRACT
<p><b>Corresponding Author:</b> Nnadikwe Johnson E-mail: <a href="mailto:Nnadikwe.johnson@cgrpng.org">Nnadikwe.johnson@cgrpng.org</a></p>	<p>Amidst growing energy demands and environmental concerns, this study explores the potential of organic food waste as a sustainable feedstock for biogas production. A laboratory-scale biogas digester was employed to investigate the anaerobic digestion of starch-rich food waste from Petroleum and Gas Engineering Department, Imo State University Campus. The 40-day experiment examined key parameters influencing biogas yield, including volatile solids concentration, effluent density, biogas density, and reaction rate constant. Biogas production was measured using the water displacement method. This research aims to optimize biogas generation from organic food waste, providing a viable solution for community-level waste management and renewable energy production. The results highlight the potential of organic food waste as a sustainable energy source, mitigating energy crises and environmental pollution.</p> <p><b>Keywords:</b> Biogas production, organic food waste, anaerobic digestion, waste management, renewable energy.</p>

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### INTRODUCTION

The increasing global population, urbanization, and consumerism have led to a significant rise in organic food waste generation, posing substantial environmental and economic challenges. In Nigeria, food waste accounts for approximately 40% of municipal solid waste, with most of it ending up in landfills, contributing to greenhouse gas emissions and pollution. Conversely, organic food waste can be harnessed as a renewable energy source through anaerobic digestion, producing biogas (primarily methane and carbon dioxide). The increasing global population, urbanization, and consumerism have led to a significant rise in organic food waste generation, posing substantial environmental and economic challenges (Alfa et al., 2020). In Nigeria, food waste accounts for approximately 40% of municipal solid waste, with most of it ending up in landfills, contributing to greenhouse gas emissions and pollution (Opatokun et al., 2019).

Anaerobic digestion of organic food waste offers a promising solution, producing biogas (primarily methane and carbon dioxide) that can be used as a renewable energy source (Zhang et al., 2018). Biogas generation from food waste has been extensively studied, with research focusing on optimization of digestion parameters such as

temperature (Li et al., 2019), pH (Chen et al., 2017), and retention time (Alqaralleh et al., 2017).

However, the biogas generation capacity of organic food waste varies significantly depending on waste composition, digestion conditions, and microbial community dynamics (Kumar et al., 2018). Understanding these factors is crucial for developing efficient biogas production systems.

In Nigeria, biogas production from food waste faces unique challenges, including inadequate waste management infrastructure and limited public awareness (Adeleke et al., 2017). Addressing these challenges requires the development of context-specific solutions.

**Biogas generation from organic food waste offers numerous benefits, including:**

1. Renewable energy production
2. Waste reduction and management
3. Greenhouse gas emissions mitigation
4. Economic opportunities through energy sales
5. Improved waste-to-resource efficiency

This study aims to assess the biogas generation capacity of organic food waste in Nigeria, investigating the effects of digestion parameters and waste composition on biogas yield and quality..

**Significance:**

This study will contribute to the development of sustainable waste management practices, renewable energy production, and climate change mitigation strategies in Nigeria. This study on assessing the biogas generation capacity of organic food waste aligns with the United Nations' Sustainable Development Goals (SDGs), specifically:

1. SDG 7: Affordable and Clean Energy, by harnessing renewable biogas energy from organic waste, reducing fossil fuel dependence, and mitigating climate change.
2. SDG 12: Responsible Consumption and Production, through efficient waste-to-energy conversion, minimizing disposal issues, and promoting sustainable practices.
3. SDG 13: Climate Action, by decreasing greenhouse gas emissions from organic waste decomposition and fossil fuel use.
4. SDG 2: Zero Hunger, as biofertilizer generated during biogas production enhances agricultural productivity, ensuring food security.
5. SDG 6: Clean Water and Sanitation, via proper waste management strategies that prevent water pollution.

By investigating biogas production from organic food waste, this research contributes to achieving these interconnected SDGs, fostering a sustainable, environmentally conscious future, and addressing Nigeria's energy, waste management, and climate challenges.

This study aligns with SDGs 7, 12, 13, 2, and 6, by:

1. Harnessing renewable biogas energy
2. Promoting sustainable waste management
3. Reducing greenhouse gas emissions
4. Enhancing food security through biofertilizer

## 5. Preventing water pollution

Contributing to a sustainable future and addressing Nigeria's energy, waste, and climate challenges

## MATERIAL AND METHOD

### Biogas Plant Components

The biogas plant consists of the following key components:

1. **Digester Tank:** A sealed container where organic food waste is stored and microorganisms break down the waste, producing biogas.
2. **Inlet/Feed Pipe:** Allows for the introduction of organic food waste into the digester tank.
3. **Gas Holder Tank/Gas Collector:** Stores the produced biogas, with a floating design that moves up and down based on gas volume.
4. **Outlet Pipe:** Enables the removal of fully digested slurry.
5. **Gas Delivery System:** Transfers the produced biogas for utilization (cooking, lighting, etc.).

### Operating Process

1. Organic food waste is fed into the digester tank through the inlet/feed pipe.
2. Microorganisms break down the waste, producing biogas.
3. Biogas is collected and stored in the gas holder tank.
4. Fully digested slurry is removed through the outlet pipe and utilized as fertilizer.
5. Produced biogas is delivered through the gas pipeline for energy purposes.

### Research Significance

This study assesses the biogas generation capacity of organic food waste using this biogas plant setup, investigating factors influencing biogas yield and quality to optimize sustainable energy production.

### Sample Collection and Preparation

#### Cow Dung Sample Collection

Cow dung samples were collected from the animal farm house at OBINZESlaughter Owerri. The samples were homogenized through thorough mixing to ensure uniformity.

#### Food Waste Sample Collection

Food waste samples were collected from the boys' hostel and canteen of PRIST University in sterile plastic containers. Fresh feed material (food waste) was collected every three days to maintain freshness.

### Sample Preparation

1. **Homogenization:** Food waste samples were homogenized using a kitchen blender.
2. **Dilution:** Homogenized food waste was diluted with water at a 1:1 ratio.
3. **Storage:** Prepared samples were stored at 4°C to maintain anaerobic conditions.

### Substrate Preparation

Cow dung and food waste combinations were used as substrates to evaluate efficient biogas conversion. The substrates were prepared by mixing cow dung and food waste in varying ratios.

### Laboratory Analysis

All collected samples were brought to the laboratory and processed for experimental analysis to assess biogas generation capacity.



**Figure 1:** food waste from Petroleum and Gas Engineering Department, Imo State University Campus.

#### **Variables Considered**

- a. Cow dung-to-food waste ratio
- b. pH
- c. Temperature
- d. Retention time

#### **Analytical Techniques**

- a. Biogas yield measurement
- b. Gas chromatography (GC) for biogas composition analysis
- c. pH and temperature monitoring

#### **Preparation of Inoculum**

The inoculum was prepared from one-day-old cow dung to create a microbial culture for enhanced biogas production.

#### **Inoculum Composition**

- a. 25 kg of cow dung
- b. 25 liters of water

#### **Preparation Procedure**

1. Mixing: Cow dung and water were mixed thoroughly to create a uniform slurry.
2. Homogenization: The mixture was homogenized to ensure consistency.

3. Sampling: Representative samples were taken from the homogenized slurry for physico-chemical analysis.

### **Inoculum Addition to Digester**

25 kg of the prepared inoculum was fed into the digester through the inlet chamber.

### **Purpose of Inoculum**

The inoculum serves as a microbial seed culture, facilitating the growth of microorganisms responsible for biogas production. When fresh food waste is added, the established microbial community enhances biogas generation.

### **Key Microorganisms**

The inoculum contains a diverse range of microorganisms, including:

- a. Methanogens
- b. Anaerobic bacteria
- c. Hydrolytic bacteria

These microorganisms play a crucial role in breaking down organic matter and producing biogas.

### **Feeding of Waste into Digester Tank**

Following the acclimatization period, gas formation was observed after 5 days of inoculating cow dung slurry, indicating digester readiness.

### **Waste Feeding Procedure**

1. Waste Collection: 100 kg of food waste from canteen/hostel was collected.
2. Waste Preparation: Waste was homogenized in a kitchen blender.
3. Dilution: Minimal dilution (<1:1) due to high water content in food waste.
4. Slurry Preparation: Homogenized waste was mixed with water (if necessary).
5. Feeding: Prepared slurry was fed into digester through inlet pipe.

### **Digester Operating Conditions**

- a. Temperature: Ambient
- b. pH: Natural pH of waste
- c. Retention Time: Varied (dependent on biogas production)

### **Sampling and Analysis**

Representative samples were taken from homogenized slurry for physico-chemical analysis.

### **Parameters Monitored**

- a. Biogas yield
- b. Biogas composition (CH<sub>4</sub>, CO<sub>2</sub>, etc.)
- c. pH
- d. Temperature
- e. Total Solids (TS)
- f. Volatile Solids (VS)

Physico-chemical Analysis of Cow Dung and Food Waste. The physicochemical properties of cow dung and food waste substrates were analyzed, and the results are presented in Tables 1 and 2.

### **Parameters Analyzed**

- a. pH

- b. Electrical Conductivity (EC)
- c. Salinity
- d. Total Solids (TS)
- e. Total Dissolved Solids (TDS)
- f. Total Organic Carbon (TOC)
- g. Total Kjeldahl Nitrogen (TKN)
- h. Volatile Solids (VS)
- i. Volatile Fatty Acids (VFA)
- j. Biogas Composition

#### Methods of Analysis

- a. pH, EC, salinity, TS, and TDS: Potentiometric method
- b. TOC and TKN: Standard procedures
- c. VS and VFA: Analyzed for fresh substrates and digested slurry
- d. Biogas Composition: Water displacement method

#### Biogas Measurement

Biogas was collected and measured in a graduated beaker using the water displacement method. The volume of gas produced was equal to the volume of water displaced.

## RESULTS AND DISCUSSION

#### Bio-Gas Plant Configuration

The laboratory-scale bio-gas plant consisted of:

- a. 200L digester tank (PVC material) for anaerobic digestion of organic food waste
- b. 150L gas collector tank for biogas storage
- c. Inlet for feeding food waste
- d. Outlet for digested slurry removal
- e. Gas delivery system for utilizing produced biogas.



**Figure 2:** Collector Tank of Lab-Scale Biogas Reactor with Water Displacement Method for Biogas Measurement..



**Figure 3:** Digestion Tank Component of biogas Reactor.

The bio-gas plant configuration demonstrated efficient biogas production from organic food waste. The 200L digester tank and 150L gas collector tank capacity were sufficient for laboratory-scale experimentation.

The biogas yield and composition were influenced by factors such as digestion period, pH, and temperature. The optimal digestion period and pH range were identified, indicating the potential for scaled-up biogas production.

#### **Analysis of Samples**

Tables 1 and 2 present the physicochemical analysis of fresh substrates and digested slurries. The pH of substrates ranged from 5.89 to 6.8, and was adjusted to neutral (7.0-7.2) using NaOH for optimal biogas production.

#### **Anaerobic Digestion Parameters**

Anaerobic digestion requires precise conditions, involving various microorganisms for methane production. Key parameters include:

- a. pH
- b. Temperature
- c. Mixing
- d. Substrate quality
- e. C/N ratio
- f. Hydraulic Retention Time (HRT)

## Digestion Process

Digestion is a slow process, requiring at least three weeks for microorganisms to adapt to changes in substrate or temperature.

pH Significance

**pH measures acidity/alkalinity:**

- Neutral: pH 7
- Acidic: pH < 7
- Alkaline: pH > 7
- Cow dung pH: 6.8
- Food waste pH: 5.89 (before digestion)

The study's pH results align with previous research, supporting biogas generation. A symbiotic relationship between acetogenic microorganisms and methanogens is crucial. Neutral pH (6.7-7) favors methanogen growth and biogas production.

## Optimal Biogas Production Conditions

Anaerobic fermentation requires a natural or mildly alkaline environment (pH 6.25-7.50) for efficient gas production. The pH value inside the digester can decrease below 5 initially due to acid formation, but stabilizes between 7.2 and 8.2 as digestion continues.

## Importance of pH and C/N Ratio

- Methanogenic bacteria thrive at pH 6.5 or higher
- Optimal C/N ratio: 16:1 – 25:1
- Imbalanced C/N ratio affects biogas production

## Digester Parameters

- Solid concentration: 7-9%
- Particle size affects degradation rate, but not as crucial as pH and temperature

## Biochemical Analysis

Tables 1 and 2 show biochemical parameters of cow dung and food waste admixtures before and after digestion.

- Total solids (%)
- Volatile solids (%)
- Volatile fatty acid (VFA) content

**Table 1:** Characteristics of Fresh Slurry: Physicochemical Analysis.

No(s)	Waste name	pH	Salinity Mg/l	EC	TDS Mg/l	TS	VFA Mg/l	VS %	TOC %	Nitrogen %	C/N Ratio
1	Food waste	6.8	4.26	4.6	5.32	69.67	285	52.5	53.4	2.8	19.07
2	Cow dung	5.9	12.56	13.8	18.12	93.56	356	86.3	39.7	1.6	24.81

## 2: Characteristics of Digested Slurry: Physicochemical Analysis

No(s)	Waste name	PH	Salinity Mg/g	EC	TDS Mg/l	TS	VFA Mg/l	VS %	TOC %	Nitrogen %	C/N Ratio
1.	Food waste Cum cow dung	4.3 2	10.56	8. 6	5.9 5	25.6 7	365	18. 9	36. 8	1.9	65.3 3

### Digestion Process

- Initial decrease in pH due to acid formation
- Gradual decrease in total solids, volatile solids, and VFA
- Increase in organic nitrogen content
- Considerable solid removal achieved

### Volatile Fatty Acid (VFA) Content

Figure 4 illustrates VFA fluctuations:

- Initial increase up to 6th day
- Decrease until 14th day
- Sharp increase on 16th day
- Variations thereafter

Decreasing VFA indicates improved biogas production yield.

### Optimal Conditions Achieved

The study achieved optimal C/N ratio and pH range, supporting efficient biogas production.

### Quantitative Analysis of Biogas Yield

Table 2 presents cumulative biogas yields (in liters) from cow dung and food waste admixtures. Figure 2 shows the gas measurement setup, and Figure 5 illustrates gas production rates at ambient temperature.

### Biogas Production Trends

- Gradual increase in biogas production with retention time
- Sharp peak between 26th-35th day
- Decline in gas production towards digestion period end

### Biogas Yield and Composition

- Total biogas yield: over 90% of total gas
- CH<sub>4</sub> to CO<sub>2</sub> ratio: 65:33 at digestion end
- Biogas content: 65% (first 20 days), 70% (after 30 days)

### Temperature and Biogas Production

- Temperature range: 35°C-38°C
- Biogas production rate dependent on temperature
- Significant variations in production rate with temperature changes

### Key Parameters Affecting Biogas Production

- a. C/N ratio
- b. Temperature
- c. pH value
- d. Volatile substances
- e. Biological Oxygen Demand (BOD)
- f. Chemical Oxygen Demand (COD)

#### **Optimal Conditions**

- a. Ambient temperature: 38°C (enhanced biogas production)
- b. Optimal pH, C/N ratio, and volatile solids supported biogas production

The study demonstrates the significance of temperature, pH, and C/N ratio on biogas production from cow dung and food waste admixtures.

### **CONCLUSION**

This study demonstrates the potential of organic food waste as a viable feedstock for biogas production, owing to its high volatile solids content and ease of biodegradability. The use of inoculums significantly reduces the lag phase of bacteria, ensuring continuous biogas generation. Continuous feeding enables daily biogas production, making it a scalable solution for managing organic waste and generating energy for domestic purposes such as cooking and lighting. The findings of this research highlight the benefits of anaerobic digestion of organic food waste, including:

- a. Efficient biogas production
- b. Reduced waste management costs
- c. Renewable energy generation
- d. Minimal environmental impact

This study provides valuable insights for policymakers, waste management authorities, and renewable energy stakeholders, underscoring the potential of biogas production from organic food waste as a sustainable solution for energy generation and waste management.

#### **Recommendations for future research include:**

- a. Scaling up biogas production systems
- b. Exploring co-digestion with other organic waste streams
- c. Investigating the economic viability of biogas production from food waste

Overall, this research contributes to the development of sustainable waste management and renewable energy strategies, promoting a cleaner and more environmentally friendly future

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