International Journal of Multidisciplinary Department
Published by: International Journal & Research Global Publisher
ISSN: 3108-2718

Research Article

Design and Fabrication of a Domestic Biogas Plant for Cooking Purpose

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Article History:
Received: 25 May 2026 | **Accepted:** 02 June 2026 | **Published:** 09 June 2026
DOI: https://doi.org/10.5281/zenodo.20611659

*** Related declarations are provided in the final section of this article.*

Abstract

The increasing demand for clean, affordable, and sustainable energy has intensified the need for viable alternatives to conventional fossil fuels, particularly for domestic cooking applications in developing countries. This study focuses on the design and fabrication of a domestic biogas plant for cooking, utilizing biodegradable household waste and animal dung as feedstock for biogas production through anaerobic digestion. The system provides a sustainable solution to energy scarcity and improper waste disposal in rural and semi-urban communities. The biogas plant was designed using standard engineering principles, considering parameters such as gas yield, hydraulic retention time, substrate composition, temperature, and digester volume. Locally available materials were used in the construction of the system to ensure cost-effectiveness and ease of maintenance. Major components include the digester tank, gas holder, inlet and outlet pipes, and a biogas burner system for cooking applications. The result shows that methane-rich biogas was produced within 7–10 days after initial loading, indicating effective anaerobic digestion. The generated biogas was successfully utilized for cooking, demonstrating stable combustion and practical applicability for domestic use. The study highlights the potential of biogas technology in reducing dependence on traditional fuels such as firewood and kerosene, while promoting sustainable waste management. The developed system offers an efficient and affordable solution for household cooking energy, with potential for wider adoption in developing regions.

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Keywords: Biogas, Anaerobic digestion, Biodegradable Wastes, Co-digestion, Renewable energy, Cooking fuel

Introduction

Energy remains a fundamental enabler of socio-economic development, yet many households in developing countries, particularly in rural and semi-urban Nigeria, continue to experience persistent energy poverty. A large proportion of the population relies heavily on traditional biomass such as firewood and charcoal for cooking, which are inefficient, environmentally unsustainable, and associated with serious health risks due to indoor air pollution and respiratory diseases [1]. The rising cost and inconsistent supply of electricity and petroleum-based fuels have further intensified the need for alternative energy sources for domestic cooking [2, 3]. At the same time, Nigeria faces increasing challenges in waste management, with an estimated 32 million tons of solid waste generated annually, a significant portion of which is biodegradable [4]. In urban centers such as Lagos, Kaduna etc., large volumes of organic waste are produced from household and market activities, contributing to environmental pollution when improperly disposed [5, 6]. Additionally, agricultural and livestock activities generate substantial organic residues that can serve as feedstock for renewable energy production [1, 7]. Biogas technology, based on anaerobic digestion, offers a practical and sustainable solution for converting organic waste into useful energy for cooking. Through microbial processes, biodegradable materials such as food waste and animal dung are decomposed in the absence of oxygen to produce methane-rich biogas suitable for combustion [7, 8]. This process not only provides a renewable source of cooking fuel but also yields a nutrient-rich slurry that can be used as organic fertilizer [9]. The successful adoption of biogas systems in countries such as India, China, and Nepal demonstrate their effectiveness in replacing traditional cooking fuels and improving environmental conditions [8, 9]. Despite its significant potential, the adoption of biogas technology in Nigeria remains limited. Although awareness levels are relatively high, factors such as initial cost, safety concerns, and technical limitations hinder widespread implementation [10]. However, studies indicate that Nigeria has substantial capacity for biogas production from both animal waste and crop residues, which, if properly harnessed, can significantly contribute to domestic energy supply [1, 7, 11]. Therefore, the design and fabrication of a domestic biogas plant specifically for cooking applications provide a viable approach to addressing household energy challenges. By utilizing locally available materials and organic waste, such systems can offer a cost-effective,

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sustainable, and environmentally friendly alternative to conventional cooking fuels, while also contributing to improved waste management and public health.

MATERIALS AND METHOD.

Materials and Equipment.

The materials and equipment used for the design and fabrication of the domestic biogas plant were selected based on durability, availability, cost-effectiveness, and suitability for low-pressure biogas applications. The primary component of the system is a 30 L High-Density Polyethylene (HDPE) digester tank, which serves as the chamber for anaerobic digestion. The digester was fitted with an inlet for slurry introduction, a gas outlet at the top section, and a slurry outlet at the bottom. The gas handling system consisted of PVC pipes and fittings, a flexible gas storage tube, reinforced rubber hose, and a brass control valve to regulate gas flow. A biogas burner fabricated from mild steel was used for cooking applications due to its high thermal resistance and ability to support efficient air–gas mixing during combustion. Supporting components included a metal frame for structural stability and sealing materials such as adhesives and hose clamps to ensure airtight connections throughout the system.

Method.

System Design and Description

The domestic biogas plant was designed as a small-scale, mobile system for household cooking applications. The system operates on the principle of anaerobic digestion, in which organic waste materials are decomposed by microorganisms in the absence of oxygen to produce methane-rich biogas. The major components of the system include the digester, gas outlet system, slurry outlet, gas storage unit, and biogas burner. Organic slurry introduced into the digester undergoes microbial degradation, resulting in biogas production. The generated gas accumulates in the storage unit and is conveyed through a piping system to the burner for combustion.

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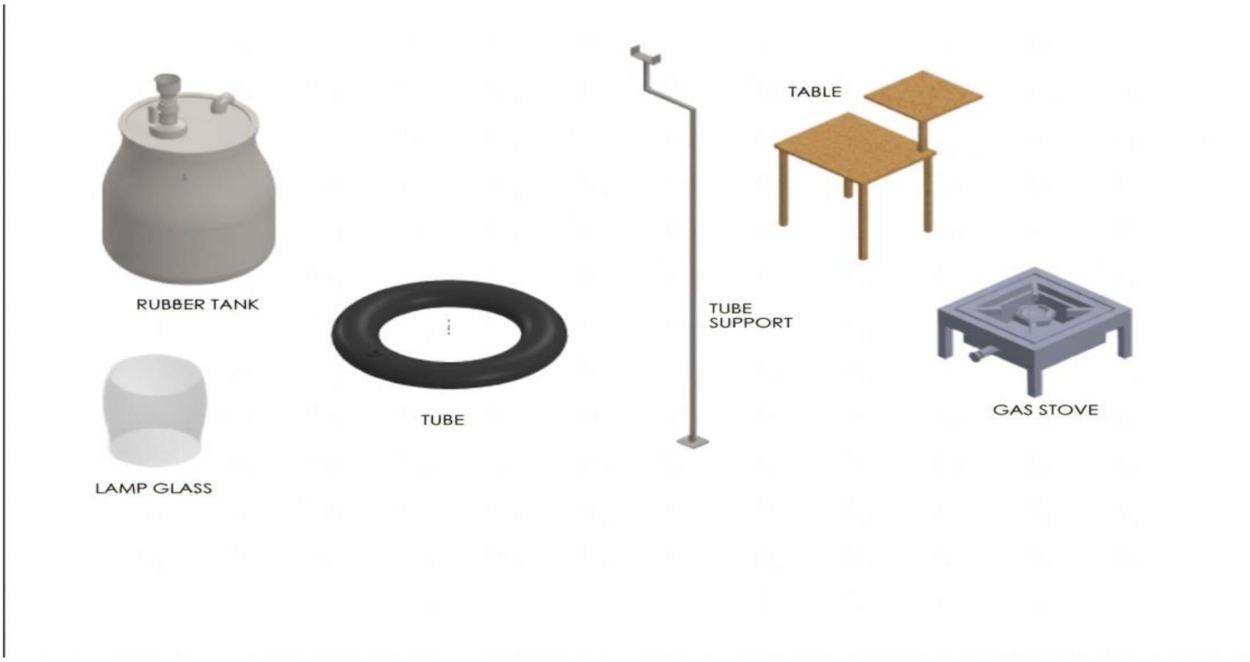

Figure 2.1: Components Of The Domestic Biogas Plant For Cooking.

The production of biogas occurs through a series of biochemical processes, namely hydrolysis, acidogenesis, acetogenesis, and methanogenesis. Among these stages, methanogenesis is the most critical, as it leads to the formation of methane, which is the primary combustible component responsible for cooking applications. Methane formation occurs mainly through two biochemical pathways: hydrogenotrophic and acetoclastic methanogenesis. These reactions are represented as follows:

$CO2$ + $4H2$ → $CH4$ + $2H2O$ (i)

Carbon dioxide Hydrogen → Methane Water

$CH3COOH$ → $CH4$ + $CO2$ (ii)

Acetic acid → Methane Carbon dioxide

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These reactions explain the progressive increase in methane concentration observed during the digestion process and justify the suitability of the produced biogas for efficient and stable combustion in domestic cooking applications.

Design Considerations

The design of the biogas plant was guided by several engineering and operational factors to ensure efficiency and practicality. A 30 L HDPE drum was selected as the digester due to its corrosion resistance, lightweight nature, and ability to maintain anaerobic conditions. A feedstock-to-water ratio of 1:1 was adopted to ensure proper slurry formation and effective digestion. Flexible gas storage and delivery components were used to accommodate low-pressure gas flow, while mild steel was selected for the burner due to its thermal resistance and durability. All system joints were carefully sealed to prevent gas leakage, and the overall design emphasized affordability, ease of fabrication, and adaptability to local conditions.

Fabrication and Assembly Procedure

The fabrication of the biogas plant was carried out in a systematic sequence to ensure structural integrity and gas tightness. The support frame was constructed using metal angle bars, which were cut, welded, and coated with anti-corrosion paint. Openings for the inlet, outlet, and gas delivery system were created on the digester, and appropriate pipe fittings were installed and sealed. All joints were reinforced using sealants to ensure airtight connections. The system components were then assembled by mounting the digester onto the support frame, connecting the inlet and outlet pipes, and installing the gas delivery system. A control valve was incorporated to regulate gas flow to the burner. Leak testing was conducted using pressurized water to identify and correct any faults before operation.

Feedstock Preparation

The feedstock used for biogas production consisted primarily of cow dung, supplemented with kitchen waste in a ratio of 3:1. Cow dung was selected due to its high content of methanogenic microorganisms and favourable carbon-to-nitrogen ratio, which enhances anaerobic digestion. Kitchen waste, including food remnants and vegetable scraps, was added to increase the biodegradable organic content. The materials were mixed thoroughly with water in a 1:1 ratio to produce a homogeneous slurry suitable for digestion. This combination represents a co-digestion approach, where cow dung acts as a microbial inoculum while kitchen waste improves gas yield.

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Operational Procedure

The prepared slurry was introduced into the digester through the inlet until the required level was reached. The system was then sealed to maintain anaerobic conditions. The digestion process was allowed to proceed over a specified retention period, during which microbial activity resulted in biogas production. Gas accumulation was monitored through pressure build-up in the system. After sufficient gas generation, the produced biogas was directed to the burner through a control valve and ignited for cooking. The quality of combustion was assessed based on flame characteristics such as colour and stability.

RESULTS AND DISCUSSION.

Results.

Two experiments were carried out namely: biodegradable or kitchen waste (Occasion 1) and Hybrid waste, which was a mixture of cow dung and kitchen waste in a ration of 3:1 (Occasion 2). That is, Occasion 1 was done using a feedstock of only kitchen wastes, while Occasion 2 was done using a feedstock of cow dung in excess and kitchen waste in a small quantity (3:1). The results of the study are presented below:

Table 3.1: Biogas Production and Composition for Occasion 1

Week	Average Temperature (°C)	Slurry Ph	Weekly Biogas Volume (L)	Cumulative Biogas Volume (L)	Methane Content (%)
1	27.5	6.2	1.5	1.5	50
2	28.8	6.6	3.8	5.3	55
3	30.2	7	5.5	10.8	58
4	30.8	7.2	4.2	15	60

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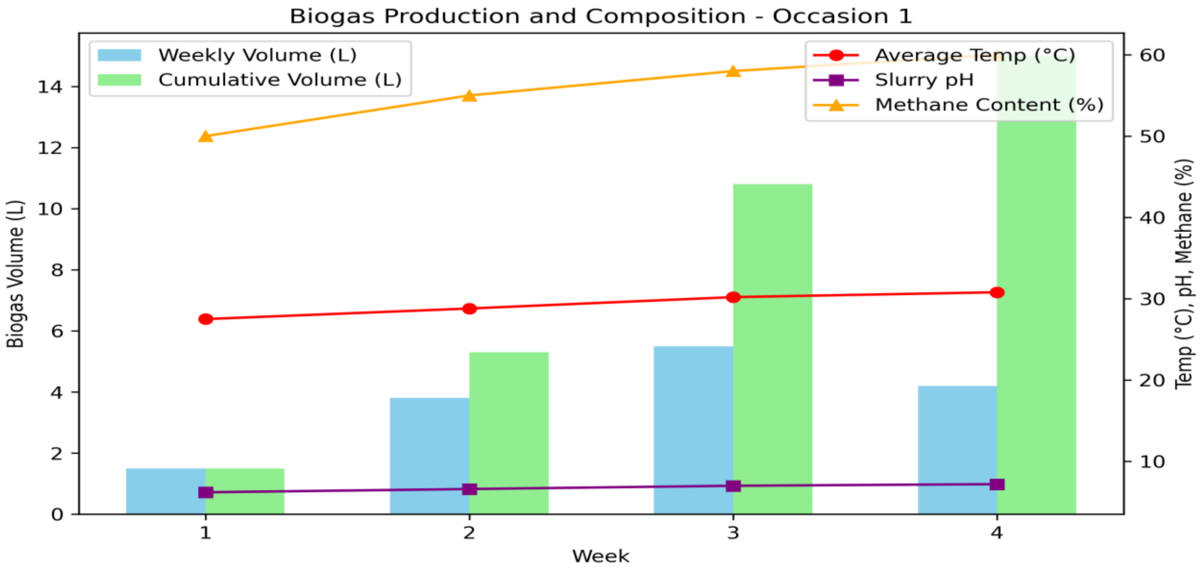

Figure 3.1: Biogas production with respect to composition of all parameters for Occasion

Week	Average Temperature (°C)	Slurry Ph	Weekly Biogas Volume (L)	Cumulative Biogas Volume (L)	Methane Content (%)
1	28	6.1	2	2	52
2	29.5	6.7	4.8	6.8	57
3	31	7.1	6.5	13.3	61
4	31.5	7.3	5	18.3	63

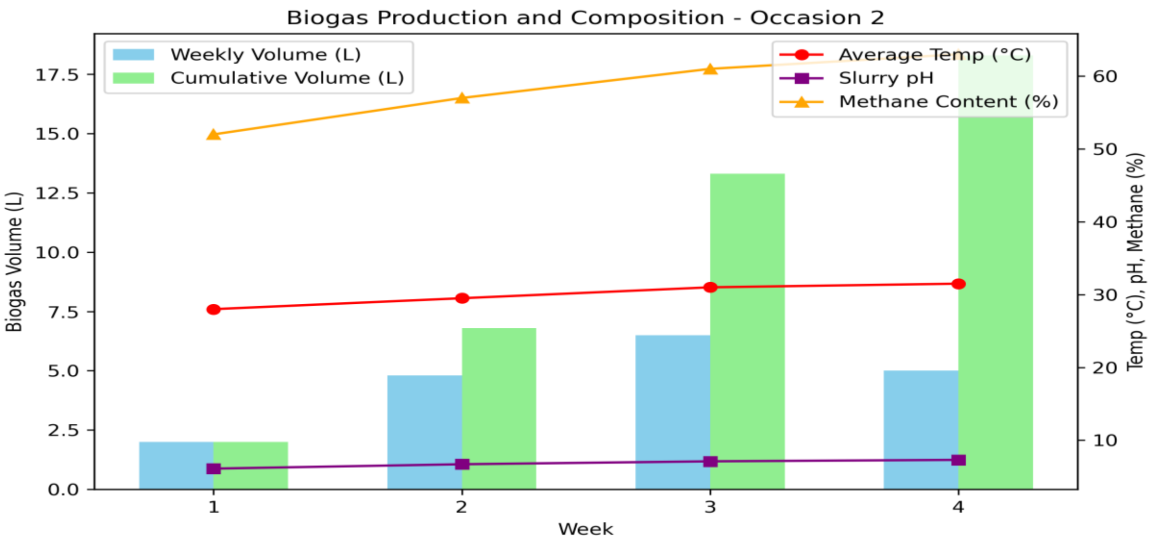

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Figure 3.2: Biogas production with respect to composition of all parameters for Occasion

Discussion.

The experimental results reveal clear trends in biogas production under two feedstock conditions, highlighting the influence of substrate composition on anaerobic digestion performance.

For occasion 1, consisting of kitchen waste only, the cumulative biogas yield reached 15.0 L over 28 days, with peak weekly production occurring in Week 3. The slower and relatively lower gas generation can be attributed to the limited microbial inoculum and lower buffer capacity in kitchen waste, which reduced the rate of anaerobic breakdown of organic matter. In contrast, occasion 2, dominated by cow dung with a smaller proportion of kitchen waste, achieved a cumulative yield of 18.3 L between 7 – 14 days, indicating enhanced gas production. The cow dung provided a rich source of methanogenic bacteria and balanced carbon-to-nitrogen ratio, which accelerated hydrolysis and methanogenesis, leading to higher and more stable biogas output. In both batches, methane content increased progressively over the retention period, reflecting the maturation of anaerobic digestion. Batch A reached 60 % methane by Week 4, whereas Batch B achieved 63 %. The slightly higher methane concentration in Batch B demonstrates the role of cow dung in promoting more complete substrate conversion and enhancing biogas quality.

The observed pH trends (6.2 – 7.3 for Batch A and 6.1 – 7.4 for Batch B) remained within the optimal range for methanogenesis (6 – 7.5), indicating that the system maintained suitable conditions for microbial activity. The inclusion of cow dung in Batch B contributed to higher buffering capacity, reducing fluctuations in pH and supporting more consistent microbial metabolism. Similarly, the gradual increase in slurry temperature over time, peaking around 31 – 32 °C, favored microbial activity in both batches, with the higher temperatures in Batch B facilitating faster degradation and gas production.

Peak biogas production in both batches occurred around Week 3, followed by a slight reduction in Week 4, consistent with the depletion of readily degradable organic matter. This pattern aligns with the expected dynamics of batch digestion, where gas generation is initially low during microbial adaptation, rises during active methanogenesis, and stabilizes as the substrate is consumed. The hydraulic retention time of 28 days was sufficient to achieve substantial digestion and methane production for both feedstocks.

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The comparison between single feedstock (kitchen waste) and co-digestion (cow dung and kitchen waste) clearly demonstrates the benefits of co-digestion. Cow dung acted as a microbial inoculum and stabilizer, enhancing the breakdown of kitchen waste, increasing biogas yield, and improving methane content. These findings are consistent with previous studies highlighting that co-digestion improves system performance by providing balanced nutrients, buffering capacity, and microbial synergy [12, 13].

The results indicate that for domestic biogas plants, incorporating cow dung as the primary substrate ensures efficient biogas production and stable operation, while kitchen waste can be added as a supplementary feedstock to improve biodegradability without compromising system stability. The observed trends in gas volume, methane content, pH, and temperature confirm that the fabricated plant can operate effectively under mesophilic batch conditions and is suitable for household cooking application.

Overall, substrate composition critically affects biogas yield, methane content, and operational stability. The co-digestion approach maximizes methane generation while maintaining safe and stable digester conditions. These observations validate the design and operational strategy adopted for the mobile domestic biogas plant and provide guidance for optimal feedstock management in household-scale applications.

CONCLUSION

This study successfully demonstrated the design and fabrication of a domestic biogas plant for cooking applications using locally available materials. The system effectively converted organic waste into methane-rich biogas through anaerobic digestion, confirming its suitability as an alternative household energy source. The results showed that while kitchen waste alone was capable of producing biogas, the inclusion of cow dung in higher proportion significantly improved gas yield, methane concentration, and overall system stability. The enhanced performance observed in the co-digestion process is attributed to the presence of active methanogenic microorganisms and improved substrate balance provided by cow dung. Biogas production followed a typical batch digestion pattern, with peak gas generation occurring around the third week and stabilization towards the end of the retention period. The methane content increased progressively in both cases, resulting in a combustible gas that supported stable and efficient cooking. Overall, the developed biogas plant proved to be a practical, cost-effective, and environmentally sustainable solution for domestic cooking energy. The findings highlight the

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importance of feedstock composition and proper system design in optimizing biogas production and ensuring reliable performance in household applications.

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