DESIGN, FABRICATION AND TESTING OF A BIOGAS DIGESTER USING RICE HUSK AS A FEEDSTOCK

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ABSTRACT
Rice husk, an abundant agricultural waste, offers a promising feedstock for biogas production. The necessity for alternative energy sources, particularly in regions like Nigeria with limited access to traditional fuels, has become imperative. The utilization of biogas from organic waste materials presents a sustainable solution to mitigate environmental degradation caused by deforestation and desert encroachment. This study aims to design and construct a biogas production system from rice husk, offering a viable energy alternative for rural communities. This study investigates the production of biogas from rice husk and its performance in a dual stove for cooking applications. The experiment was conducted over a 42-day period, with various samples (35g, 50g, 65g, 80g) monitored for temperature, pressure, and gas production. The results show that the biogas produced is suitable for burning and efficient cooking. The dual stove performance evaluation demonstrated that biogas cooks food faster than kerosene for boiling fish (4-minute difference), boiling meat (4-minute difference), and cooking rice (8-minute difference). The study concludes that biogas production from rice husk is a viable and sustainable energy solution, with the potential to contribute to reduced greenhouse gas emissions and decreased reliance on fossil fuels. Recommendations include optimizing digester conditions, monitoring pressure, reducing carbon dioxide content, scaling up production, and exploring different feedstock materials and retention times. The findings highlight the importance of developing comprehensive biogas utilization plans for effective storage, distribution, and utilization of the generated biogas.

Keywords: Biogas, Rice Husk, Sustainable Energy, Cooking Fuel, Digester, Methane Content, Dual Stove.

1. INTRODUCTION
Climate change is one of the most pressing issues of our time, with far-reaching consequences for our planet and its inhabitants. It is characterized by rising temperatures, melting ice caps, and altered ecosystems, leading to extreme weather events, sea-level rise, and devastating impacts on biodiversity and human societies (Atemoagbo, *et al.,* 2023). Hence there is need for alternative source of energy to reduce greenhouse gas emission. Rice husk, a byproduct of rice production, holds immense potential as a renewable energy source due to its abundance and environmental benefits. The utilization of rice husk for biogas production offers a sustainable solution to reduce greenhouse gas emissions, minimize organic waste generation, and decrease reliance on fossil fuels. This renewable energy source, when processed into biogas, can be utilized as a clean fuel for various applications, including powering vehicles and generating electricity. By exploring the potential of rice husk as a substrate for biogas production, we can contribute to a greener and more sustainable future by tapping into this readily

available agricultural waste to meet energy needs while promoting environmental conservation and energy independence. Rice husk can be effectively converted into biogas through anaerobic digestion. The biogas production process involves hydrolysis, acid formation, and methane generation, with various substrates like agricultural and industrial waste proving suitable feedstock for biogas production. The characteristics of biogas, its uses in cooking, lighting, and agricultural activities, underscore its versatility and potential as a renewable energy source.

About one third of the world's population have little or no access to modern energy services. Majority of these people are living in poverty (Bank, 2021). The acute symptoms of this poverty, as well as its chronic causes, are critically linked in many ways to today's patterns of energy production and use (Ezekoye*, et al.,* 2014). Pre-treatment of biomass for the removal of lignin is an appropriate approach for the maximum usage of digestible contents present in it for its conversion to biogas (Sharma, *et al.,* 2014). The results obtained from anaerobic co-digestion of pre-treated rice husks inoculated with ostrich dung were most effective than those of untreated rice husks. In addition, the combined pre-treatments for rice husks showed better results than solo pre-treatment in biogas and methane production. The combined hydrothermal and ultrasonic pre-treatment showed better productivity of biogas and methane than ultrasonic and hydrothermal pre-treatments separately. Also, the combined alkaline and ultrasonic pre-treatment showed better productivity of biogas and methane than alkaline and ultrasonic pre-treatments separately. Best performance in biogas and methane increase for solo pre-treatments was for alkaline pre-treatment with 3% NaOH by 60.85 and 77.89 %, respectively as compared with untreated rice husks. The combined alkaline and ultrasonic pre-treatment were preferably recommended for biogas and methane enhancement, it caused an increase by 78.65 and 101.62 %, respectively, as compared to untreated rice husks (Jassim & Amal , 2021). Among the biomaterials, melon husk was the densest in terms of total solid content followed by rice husk while cow dung has the lowest. Melon husk and rice husk can be seen to have close values of total solids. There was variation in the volatile solids content of the three biomaterials; while cow dung and melon husk have values close to each other, rice husk recorded lower value (Ibrahim, *et al.,* 2021). Rice husk presents a significant opportunity for sustainable energy production through biogas generation. As the world grapples with the challenges of climate change, energy security, and environmental degradation, innovative solutions that harness renewable energy sources are crucial. Biogas production from rice husk offers a promising alternative to fossil fuels, with the potential to reduce greenhouse gas emissions, mitigate waste management issues, and provide energy access to rural communities. This topic explores the potential of rice husk biogas for sustainable energy production, including its benefits, production processes, and potential applications, with a focus on promoting a cleaner, more sustainable energy future.

The conclusion from the study of Ofoefule *et al.* (2011) shown that when rice husks are pre-treated, flammable biogas can be produced to serve both community and rural energy needs. The combined rice husk had the best onset of gas flammability and cumulative gas yield due to the synergy that existed between the combined wastes. This is expected to provide a lee-way for local rice millers to utilize these wastes which are generally left to rot. It will also bring about an integrated system with reduced cost of operation and consequent increased earnings while providing better aesthetics and healthier environment.

Rice husk, with its high lignocellulosic content, presents a valuable substrate for biogas production. Despite its abundance, the full-scale utilization of rice husk for biogas production remains underexplored, particularly in some regions like Nigeria (Matin & Hady , 2018). Efforts to optimize biogas production from rice husk involve addressing challenges such as lignin content inhibition through co-digestion and pre-treatment methods. Research on utilizing rice husk for biogas production is ongoing, focusing on enhancing biogas yields and overcoming existing obstacles. By tapping into the potential of rice husk as a biogas substrate, it can contribute to a more sustainable energy future while reducing dependence on fossil fuels and mitigating greenhouse gas emissions. The aim of this innovative project was threefold: (i) to design, construct, and fabricate a cutting-edge digester that harnesses the power of rice husk to produce biogas for heating purposes; (ii) to develop a state-of-the-art gas storage cylinder that safely stores the produced gas; (iii) and to develop a revolutionary dual stove that utilizes the biogas for efficient and eco-friendly cooking. By achieving these aims, we sought to breathe new life into sustainable energy solutions, reduce our carbon footprint, and empower communities with access to clean and reliable energy.

2. MATERIAL AND METHODS

2.1 Materials

2.1.1 Materials used for the study

The materials used for this research included a biogas digester, a dual stone that utilizes both gas and kerosene, and various steel materials for construction, such as plates, pipes, and rods. Additionally, welding equipment and consumables, measuring and marking tools like tape measures and markers, and cutting tools including saws and grinders were employed. Assembly components like bolts, nuts, and gaskets were also used, along with a gas storage cylinder. Furthermore, calculations and design software, such as Auto-card and Excel, were utilized to optimize biogas production and storage efficiency.

2.1.2 Design consideration for digester

The following was taken into consideration during the design of the digester (i) The volume of gas needed (ii) The design was made compatible with the type of inputs that would be used (iii) To ensure that the digester was air-tight, the welding was done properly (iv) Locally available materials were used to minimize costs because one of the objectives of this research is to provide an alternative energy source for rural dwellers. (v) The digester was designed such that it requires low skill since it is fabricated for rural dwellers. (vii) The digester was designed such that the maintenance required is very easy and not complex.

2.1.3 Components of the digester

The anaerobic digester contains the following parts

a) The stirrer, made from mild steel, is utilized to mix the digestate during anaerobic digestion, aiding in accelerating the fermentation process.
b) Digestion chamber: This is the part where the digestion process takes place. It is made of mild steel.
c) Inlet opening: this is the part where the digesting material is fed into the digester cylinder.
d) Stirrer handle: this is the part that aids the easy rotation of the stirrer. It is made of a mild steel sheet.
e) Digester cover: this is used to cover the digester cylinder properly to prevent the inflow of air since it is anaerobic process.

The dual stove was designed and fabricated using locally sourced materials, including metal sheets and pipes. Two separate burning chambers were created, allowing for simultaneous cooking with biogas and kerosene. A heat exchanger was integrated to optimize heat transfer and efficiency. The stove was designed with safety features, including a flame failure device and heat-resistant handles. The fabrication process involved local artisans and materials, promoting community engagement and sustainability. The design and fabrication of the digester and dual stove were tailored to meet the specific needs of the community, ensuring a practical and effective solution for biogas production and utilization as shown in Figure 1 (a) and (b).

Figure 1 (a) and (b): The fabricated digester and the dual stove

2.2 Methods

2.2.1 Digester capacity

The key factors considered in this research when estimating the digester capacity were retention time, daily feedstock volume and total solids and volatile Solid used.

Retention time (RT): The time the feedstock remains in the digester was 42 days at 40 to 42^0C. Feedstock volume (DFV): The amount of feedstock added to the digester was 52 Tonnes which was required to produce high quantity of biogas. Total solids (TS) and volatile solids (VS): The TS and VS content of the feedstock determine the organic loading rate and biogas yield. The digester volume (DV) was calculated using Equation (1).

$$DFV \times RT \quad (1)$$

2.2.2 Gas storage cylinder

A mild steel gas storage cylinder, 0.263 meters in height, was designed and fabricated to store the biogas produced by the digester.

2.2.3 Components of gas storage capacity

The biogas system's components work together in harmony, ensuring a seamless process from generation to utilization. The pressure gauge, attached to a low-pressure butane regulator, carefully monitors the pressure of the gas stored in the gas storage cylinder, providing a crucial safety check. The gas storage cylinder, the heart of the system, safely stores the precious biogas generated from the digestate/slurry. A sturdy supporting rod securely attaches the gas cylinder to the digestate, ensuring optimal positioning for efficient gas flow. The inlet chute provides a smooth passage for gas to flow from the digestate into the gas cylinder, while the outlet chute directs the biogas to the dual stove, where it's utilized for cooking, bringing warmth and nourishment to those who need it.

2.3 Dual Stove Design

A dual stove which burns both biogas and kerosene was designed, constructed and tested in this study to compare and evaluate the economic importance of using biogas technology over fossil fuel. The following were taken into consideration during the design of the stove. (i) The cost of materials for the design (ii) The size of the stove was made moderate for ease mobility (iii) The principle of operation of the stove was also considered (iii) The design was made to ensure that there is a tight lock of the gas line when kerosene is in use for safety purpose. (iv) The stove is designed such that each of its components can be detached for the purpose of maintenance.

2.3.1 Components of the dual stove

The component of the dual stove includes:

1. Kerosene chamber: this is where kerosene is stored for cooking.
2. Gas burner: this is the unit that produces the flame from the gas.
3. Wick pipe: This pipe had a hole through which the kerosene wick was passed.
4. Kerosene/Gas regulator: this is used to regulate the heat
5. Gas Inlet: this is the pipe where the gas hose is connected from the biodigester to the stove.
6. Kerosene Burner: this unit produces flames from the kerosene.
7. Kerosene inlet: this is the unit where kerosene is fed into kerosene chamber.

2.4 Digester Test Run/Experiment

After the digester was fabricated, the digester was tested to ensure that it was air-tight by introducing air into the digester through the gas outlet using a vulcanizing machine. With the gas outlet closed, the pressure gauge was at 6 bars and the digester was left for 5 days did and the pressure gauge did not drop, which shows that there was no leakage and the digester was airtight. Other material/instruments used for the purpose of the experiment includes the following; A glass digester, measuring cylinder (1000ml), a weighing balance (Model BH 600) with a capacity of 600 g and a resolution of 0.01g, digital pH meter (HANNA Model PH – 211), a thermometer (range – 10^0C – 100^0C, accuracy ± 0.1, sodium Chloride (NaCl), tap water, corks and connecting tubes. Bio-Digester, Measuring Cylinder, Thermometer, Cor and connecting tube.

2.5 Sample Collection

Rice husks were collected in large quantities from a rice mill in Orele, Auchi, Edo state. Approximately 150 kg of husk was collected for the purpose of this study. The rice husk obtained was ground into a fine powder using an attrition mill, with a particle size range of 0.5-2 mm, suitable for optimal biogas production

2.6 Preparation of Feedstock

In this experiment, the feedstock, rice husks, underwent a transformation, being precision-cut to a uniform 600 µm particle size, and then pulverized into a fine powder using a sieve with 600 µm mesh. This meticulous process was crucial to unlock the full potential of the feedstock, increasing the surface area for microbial activities to thrive, and setting the stage for optimal biogas production.

2.7 Apparatus Set – Up

All apparatus were properly washed with soap solution and allowed to dry by standing over night in the test room. The weighing balance was used to determine the mass of powdered rice husk that made up the total solid for particular fermentation slurry. The digester was operated at ambient temperatures. A thermometer was used to determine the daily temperature. The average temperature was calculated and assumed to be the operating temperature. A digital pH meter was used to determine the pH of the fermentation slurry (sample) on the first and last days of the experiment.

In the experiment, four (4) glass digesters were used initially to perform the experiment for a period of 42 days in order to obtain variables of gases generated from each glass digester. This was done so as to save the time of replicating the experiment when only one digester is used. The powdered rice husks were measured using a weighing balance into grammes of 35 g, 50 g, 65 g and 80 g and were poured into the glass digester mixed with 1000ml of water and sodium chloride solution using a stirrer to form slurry in ration of 1:1. Thereafter the constructed digester was used to perform the same experiment in large quantity. The digestion was allowed to run for the period stated above with constant agitation during which the volume of gases produced daily were recorded, then after the slurry in the digester was discharged, sieved and allowed to dry. The valve (gas outlet) was carefully opened. A lit matches was placed closed to the valve to test for biogas production.

2.8 Parameters of Biogas Production and their selected Operating Conditions

The experiment was carried out under room temperature that varied between 25 and 30.5^0 C, which represents mesophilic condition. pH values of 7.29 which is within the pH range for biogas production.

2.9 Water Content

The water content for each sample was determined using the recommendation for better biogas production as stated by Elijah *et al.* (2009), that is, a total solid (TS) of 8 % in the fermentation slurry. This was the basis for the determination of the amount of water to be added for any given mass of total solid. Hence the proportion of total solid to water was the same in all fermentation slurry samples.

2.10 Fermentation Slurry

Preparation of fermentation slurry was by the addition and vigorous mixing of total solid with an equivalent amount of water needed for maximum yield. This mixture was the sample contained in the digester.

3. RESULTS AND DISCUSSION

The gas produced throughout the 42 days by each glass digester is shown in Table 1.

3.1 Gas Production by the Digester

This table displays various data points for different samples (35ml, 50g, 65g, 80g) over a period of 42 days, including temperature readings and pressure measurements Table 1. The gas produced moved the pressure gauge on the day 9 to 0.02 bar, after which the pressure gauge did not move any further throughout the next 8 days. When discharging the slurry, it was observed that the fermentation rice husk settled at the bottom and the water solution at the top without the rice husk being caked.

After the gas has been produced in the digester, the valve (gas outlet) was carefully opened. A lit match was placed close to the valve. The biogas produced from the digester did burn. This shows that the methane content was above 60 % in the digester. This is a better result when compare to the research done by Hashfi and Hadiyanto (2017).

With a 42-day RT and 180 L/day feedstock, the digester volume was
DV = 180 L/day × 42 days = 7,560 L = 7.56 m^3

The total digester volume is typically 75-80% slurry volume and 20-25% gas storage volume.
The biogas production can then be estimated from the VS content and typical biogas yields for that feedstock. For vegetable waste, a yield of 0.67 m3/kg VS is common.

Table 1. Biogas production of rice husk per day

Day	Sample 35ml ml	Sample B 50g (ml)	Sample C 65g (ml)	Sample D 80g (ml)	Temperature reading (^{0}c)	Pressure ml (mmHg)
0	0	0	0	0	0	615.1
1	110	45	110	-	25	615.1
2	450	170	340	-	25	615.1
3	50	15	85	-	25	615.1
4	80	10	85	-	25	607.6
5	95	15	20	-	25	615.1
6	5	15	20	-	27.3	615.1
7	-	5	5	12.5	27.3	615.1
8	5	12.5	-	12.5	28	615.1
9	-	7.5	-	5	30	615.1
10	-	-	-	-	28	615.1
11	-	5	15	5	30.5	615.1
12	5	-	5	-	29.5	617.3
13	10	5	15	5	30.1	615.1
14	10	-	5	55	28.4	617.3
15	-	-	10	50	30.5	618.8
16	5	5	-	35	28	618.8
17	5	13.5	10	5	28.4	618.8
18	10	15	-	30	27.5	618.8
19	10	90	5	5	28.1	618.8
20	10	5	5	-	28.2	618.8
21	-	-	25	-	28.7	618.8
22	5	-	-	-	28.7	618.8
23	-	-	-	-	28	615.1
24	-	5	15	5	30.5	615.1
25	5	-	5	-	29.5	617.3
26	10	5	15	5	30.1	615.1
27	10	-	5	55	28.4	617.3
28	-	-	10	50	30.5	618.8
29	5	5	-	35	28	618.8
30	5	13.5	10	5	28.4	618.8
31	10	15	-	30	27.5	618.8
32	-	-	-	-	28	615.1
33	-	5	15	5	30.5	615.1
34	5	-	5	-	29.5	617.3
35	10	5	15	5	30.1	615.1
36	10	-	5	55	28.4	617.3
37	-	-	10	50	30.5	618.8
38	5	5	-	35	28	618.8
39	5	13.5	10	5	28.4	618.8
40	10	15	-	30	27.5	618.8
41	5	-	5	-	29.5	617.3
42	10	5	15	5	30.1	615.1

3.2 Performance Evaluation for the Dual stove

On completing the dual stove, the stove was tested using a purchased Kerosene and the Gas Generated from the Biogas.

Table 2. Analysis of food heated

Food Items	Boil Fish	Boil Meat	Rice
Time of Gas obtained from the Digester	5 mins	8 mins	20 mins
Time of Kerosene	9 mins	12 mins	28 mins

From Table 2, Biogas from the digester cooks food faster than kerosene for all three food items; Boil Fish: Biogas takes 5 minutes, while kerosene takes 9 minutes (a 4-minute difference), Boil Meat: Biogas takes 8 minutes, while kerosene takes 12 minutes (a 4-minute difference), Rice: Biogas takes 20 minutes, while kerosene takes 28 minutes (an 8-minute difference).

4. CONCLUSION AND RECOMMENDATION

4.1 Conclusion

In conclusion, this study has successfully demonstrated the viability of rice husk as a feedstock for biogas production, offering a sustainable energy alternative for rural communities. The experiment, conducted over a 42-day period, yielded significant results, including biogas production suitable for burning and efficient cooking, as well as dual stove performance advantages, with biogas cooking food 4-8 minutes faster than kerosene for various applications. These findings highlight the potential of rice husk biogas production to contribute to reduced greenhouse gas emissions and decreased reliance on fossil fuels, making it a crucial component of sustainable energy solutions, particularly in regions like Nigeria with limited access to traditional fuels.

Furthermore, the study identifies opportunities for optimization, including digester conditions, pressure monitoring, carbon dioxide content reduction, scaling up production, and exploring different feedstock materials and retention times. To fully harness the potential of biogas production from rice husk, comprehensive utilization plans are necessary, ensuring effective storage, distribution, and utilization of the generated biogas. With further development and implementation, rice husk biogas production can play a vital role in mitigating environmental degradation and promoting sustainable energy solutions for rural communities.

4.2 Recommendation

To further enhance the viability and sustainability of biogas production from rice husk, the following recommendation is/are made:

a. Optimization of digester conditions through response surface methodology to maximize biogas yield and quality;
b. Real-time pressure monitoring and control systems to ensure safe and efficient operation;
c. Implementation of carbon dioxide scrubbing technologies to reduce CH_4 losses and enhance biogas quality;
d. Scale-up of biogas production systems to accommodate larger feedstock quantities and meet increasing energy demands; and
e. Exploration of diverse feedstock materials and retention times to diversify biogas production and reduce dependency on singular feedstocks.

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