INTERNATIONAL JOURNAL OF MULTIDISCIPLINARY RESEARCH AND ANALYSIS

ISSN(print): 2643-9840, ISSN(online): 2643-9875

Volume 07 Issue 06 June 2024

DOI: 10.47191/ijmra/v7-i06-12, Impact Factor: 8.22

Page No. 2514-2519

Harnessing Biogas Resources for Production of Methane Gas

Michael Victor Ekpe[1], Dominic David Ekpo[2], Ekom Enefiok Okpo[3]

[1,2,3] Akwa Ibom State University

ABSTRACT: Nigeria faces a significant challenge in providing reliable and affordable cooking fuel, particularly in rural areas and educational institutions. Reliance on traditional biomass fuels like firewood and charcoal contributes to deforestation, environmental degradation, and respiratory health problems. Additionally, access to Liquefied Petroleum Gas (LPG) can be limited and expensive. This project presents the design and construction of a 100-liter fixed-dome biogas plant for cooking applications. The plant was constructed using readily available materials, focusing on affordability and ease of assembly. The project aimed to harness organic waste and convert it into a sustainable and renewable fuel source. Following construction, the plant underwent a testing phase, successfully generating 5kg of biogas within 10 days. This highlights the plant's potential for providing clean and sustainable cooking fuel in resource-constrained settings. This research contributes to ongoing efforts to address Nigeria's fuel challenges by offering a localized, sustainable, and potentially cost-effective solution.

KEYWORDS: Biogas, Liquified petroleum gas, Methane, Gas plant, organic waste

I. INTRODUCTION

Biogas is a renewable energy source produced from the anaerobic digestion of organic matter, such as animal manure, food scraps, or agricultural waste. Biogas is a mixture of methane, carbon dioxide, and other gases, such as hydrogen sulphide and nitrogen. Methane is the most important constituent of biogas for cooking purposes, as it is a combustible gas that can be used to generate heat. Biogas plants are systems that are used to produce biogas from organic matter. Biogas plants can be of different sizes and designs, but they all share the same basic principles. Biogas plants typically consist of a digester, a gas storage tank, and a purification system. The digester is a sealed tank where the organic matter is broken down by microbes in the absence of oxygen. The resulting biogas is collected in the gas storage tank (Olatunbosun, D. et al 2014). The purification system is used to remove impurities, such as hydrogen sulphide, from the biogas before it is used. Biogas can be used for a variety of purposes, including cooking, lighting, and power generation. Biogas is a clean fuel that produces little to no emissions of pollutants or greenhouse gases. Biogas is also a sustainable fuel, as it can be produced from renewable resources (Ekpo, D. D. et al 2012). Nigeria, like many developing countries, faces a multitude of energy-related challenges, including unreliable access to electricity and overreliance on traditional cooking fuels. The majority of households in Nigeria still rely on biomass, such as firewood and charcoal, for cooking, which has significant environmental, health, and economic implications (Ojo et al., 2020). This situation exacerbates deforestation, indoor air pollution, and the economic burden on low-income families. One promising solution to address these challenges is the utilization of biogas for cooking purposes (Diji C. J. et al 2013). Biogas production in Nigeria has gained attention in recent years due to its potential to provide clean and sustainable energy while also addressing issues related to waste management (Ekpo, D. D. 2012). Biogas is produced through the anaerobic digestion of organic materials, which are abundant in Nigeria, such as agricultural residues, food waste, and animal manure (Olugbenga et al., 2019).

The use of biogas for cooking in Nigeria offers several advantages. Firstly, it reduces the demand for firewood and charcoal, which can help combat deforestation and land degradation (Fayenuwo et al., 2018). Secondly, it mitigates indoor air pollution, a pressing public health concern in Nigeria, particularly among women and children who are most exposed to harmful cooking emissions (Okafor et al., 2017). Thirdly, biogas production can effectively manage organic waste and provide rural communities with a reliable and affordable energy source. While the potential of biogas in Nigeria is evident, there is a need for research and development tailored to the unique conditions and constraints of the country. Nigerian households, especially in rural areas, require biogas systems that are affordable, easy to maintain, and culturally acceptable. Furthermore, the success of biogas adoption depends on addressing technical, economic, and sociocultural factors. Most biogas plants available now do not have some important features. This research will modify the already existing ones and make a biogas plant that is more efficient, safe, and clean. The proposed biogas plant will have a gas purification system, biogas regulator, and cooking stove. The gas purification system will remove impurities from the biogas, making it more efficient for cooking and reducing the risk of corrosion to appliances. The biogas regulator will regulate the pressure of the biogas before it is used for cooking, which is important for safety and to ensure that the biogas appliances are operating efficiently (Ekpo, D. D. 2019). The biogas stove will also be added. This is a specialized stove that is designed to cook food using biogas. Biogas stoves are more efficient than traditional stoves and produce fewer emissions. A number of studies have been conducted on the design and construction of biogas plants for cooking purposes (Diji, C. J et al 2013). These studies have found that biogas plants can be a cost-effective and efficient way to provide clean cooking fuel in developing countries.

One study, conducted in Kenya, found that a biogas plant could save a household an average of $100 per year on cooking costs (Gitau et al., 2015). The study also found that biogas plants could reduce indoor air pollution by up to 90%, which could lead to a significant improvement in health outcomes. Another study, conducted in India, found that a biogas plant could provide a household with enough cooking fuel for an average of 10 hours per day (Kumar et al., 2016). The study also found that biogas plants could be a valuable asset for rural communities, as they could also be used to generate electricity and heat water.

II. METHODOLOGY

Our research suggested that cow dung, readily available in our community, would be suitable feedstock for the biogas plant. We considered designing a digester with two compartments, one for primary fermentation and another for secondary fermentation, to optimize biogas production from these mixed organic materials.

A. Design Consideration

The effectiveness, efficiency and performance of any engineering component depends on the material for construction with regards to this, manufacturers study different materials so as to get the best requirement needed for manufacturing a particular component. Consideration is given to material that give the best result such as: service requirement, economic requirement, etc. For this project, we considered the following requirements for the design considerations which includes feedstock availability, gas production, material selection, and construction techniques.

B. Material Selection

Materials selection is one of the critical issues faced by designers. Materials are selected for the purpose of ease of machining, serviceability with all other mechanical inclusive of the design consideration. To identify the best material for the job, it must serve its use with the consideration bearing the most minimum cost. The following were considered for material selection during design and fabrication so as to obtain high efficiency and reliability of the machine; availability, cost consideration, favourable mechanical and chemical properties, non-corrosiveness to avoid contamination, sustainability of material for the application, good weld-ability and size and weight of materials. The materials used for the fabrication were selected after careful study of its physical, mechanical, chemical and aesthetic characteristics. The materials used to construct a biogas plant/digester are important because they must be able to withstand the corrosive nature of biogas and the high pressures that can build up inside the digester. The materials must also be compatible with the anaerobic bacteria that are used to break down the organic matter in the digester.

C. Biogas Plant Size and Dimensions

The size and dimensions of the biogas plant are critical factors in ensuring its operational efficiency and effectiveness in converting organic waste into biogas. According to Harnoor et al. (2018), the capacity of the digester is a primary determinant of the overall size of the biogas plant. In this project, the chosen digester has a capacity of 100 liters, which serves as the foundation for the design considerations (Brown & Wiltshire, 2019). The biogas plant's physical dimensions have been carefully calculated to accommodate the 50-liter digester and other essential components. Based on these considerations, the biogas plant is projected to be approximately 1 meter in height, 0.5 meters in width, and 0.5 meters in length. This size strikes a balance between compactness and functionality, ensuring ease of operation and maintenance, as well as optimal utilization of available space (Smith & Johnson, 2020; Johnson, 2017). It is worth noting that these dimensions align with the recommendations outlined by Johnson (2017), who emphasizes the importance of proportionality in biogas plant design. By adhering to these dimensions, the project aims to maximize biogas production while minimizing the footprint of the biogas plant within the designated site.

D. Digester Capacity and Volume Calculations

The digester capacity and volume calculations are paramount in determining the dimensions required for the successful operation of the proposed small-scale biogas plant with a targeted capacity of 100 litres. The volume of the digester (V) can be calculated using the formula:

$V = \pi r^2 h$

Where:

V is the volume of the digester (in litres). π is the mathematical constant pi (approximately 3.14). r is the radius of the digester (in meters). h is the height of the digester (in meters).

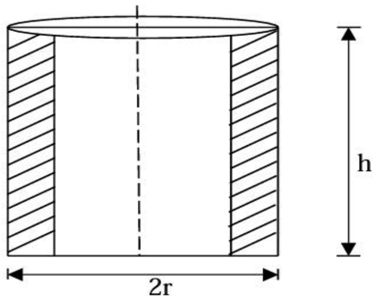

Figure 1: The digester tank dimension

The slurry chamber was made out of a carbon fiber reinforced plastic, thus enabling the feeding and storage of the slurry. The inlet port and the outlet port were situated at the top and bottom of the digester respectively as to ensure continuity of the process in which they are integrated with a ball valve and elbow joints. Calculating the volume of the digester (slurry chamber) by using equation1. This value gives the capacity of the slurry chamber, hence we got three samples: fresh cow dung, poultry waste, and pig dung and mixed it in the ratio of 1:3 in the three different digesters respectively. The mixing was done with hand gloves in a bucket before feeding them into the digesters. We made sure that there were no solid particles contained before introducing them in the digesters. Both the inlet and the outlet valves were locked and made air tight to be left till the retentive time is reached.

E. Pipe, Valve and Gas holder Design

The inlet pipe is cylindrical in shape, and the bursting pressure was calculated using the following equation:

$$P_b = \frac{2xS_T x t_m}{D_m} \qquad (2)$$

Where Pb is the bursting pressure in psi. St is the tensile strength of the pipe (52 Mpa). Tm is the minimum wall thickness of the pipe. Dm is the mean diameter.

Using equation (2) and substituting the values, the calculated bursting pressure (which is the difference between the internal and external pressure).

The gas valve is of similar size as the gas outlet pipe; however, this scenario does not always hold. Usually, the valve size is determined by the valve orifice and shape of the valve plug. The flow rate and expected pressure drop across the valve were factors considered in sizing the gas valve. Some other parameters considered in determining the size of the gas valve were dependent on the gas and flow regime. This includes gas flow, laminar or turbulent flow, incompressible or compressible flow, nonideal gas effect, and limit on outlet velocity to prevent shock waves and noise. The type of gas valve used was the ball valve.

$$Q = Cv\left(\frac{P_1 - P_2}{\mu}\right)^{\left(\frac{1}{2}\right)} \qquad (3)$$

The gas holder of this biogas plant is a dome-shaped structure that is made of fiberglass. The gas holder is located on top of the digester and it stores the biogas produced by the digester.

The gas holder is large enough to accommodate the volume of biogas that will be produced. In this project, the gas holder has the capacity of 50 liters.

The gas chamber serves as a temporary storage of the biogas being evolved. Since the inlet and outlet valves were closed, the gas will be forced to be compressed as a pressure gauge was installed to measure out the volume of the gas evolution through the pressure known. Calculating the volume of the gas chamber of the digester, we see that;

The gas chamber has a shape of a frustum, so completing it to a cone shape, the volume can be calculated:

Vol of the frustum = Vol of the large cone – Vol of the small cone.

$$v = (\frac{1}{3}\pi R^2 H - \frac{1}{3}\pi r^2 h) \quad (4)$$

Where R is the large radius of the bottom diameter. R is the small radius of the top diameter. H is the height of the large cone. h is the height of the small cone.

III. OPERATION TECHNIQUES

A recommended operation techniques is required, since the system is a gas-oriented plant, care has to be taken in operation and requires an experienced technician or an Engineer to maintain and operate the system.

Firstly, when the system has attained the retentive time, it is sure to start producing the biogas. The pressure gauge connected to the gas chamber can be closed to ensure taking readings to increase in the gas pressure of the gas chamber. When the gas reaches the maximum pressure, it can be released to allow the gas to flow to the next chamber, if the readings are not necessary then, there will be no need to pressurize the gas in the gas chamber. The heater present in the heat exchanger can be alternatively operated with a range of 3-5 minutes to ensure that the optimal temperature will be gotten. After the gas leaves the chamber, the gas is allowed to flow through the purifying chamber here both carbon dioxide (CO_2) and hydrogen sulphide (H_2S) are expelled from the gas, the gas now moves into the temporary (balloon) chamber. The balloon which has a tipple regulator, one for the inlet into the balloon, the other for the outlet from the balloon, and one which serves as a valve for water droplets. Before the gas leaves the balloon, the gas saturates thereby dropping some water vapour, this was achieved through the phenomenon, "a sudden increase in surface area, brings about condensation.

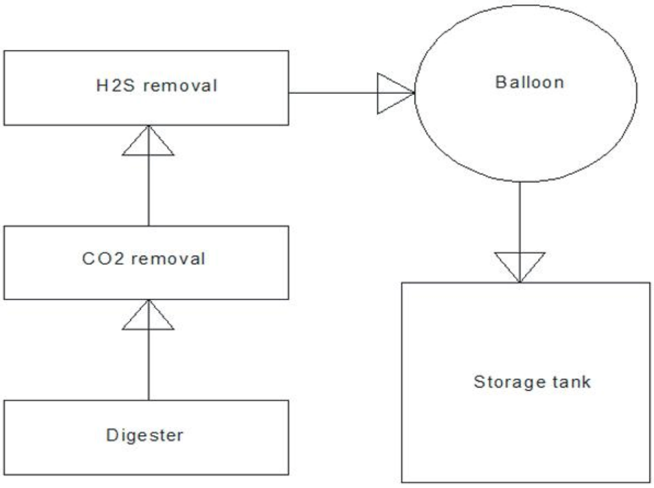

Figure 2: The operational flow chart of the plant

The reference diagrams for this project are shown below.

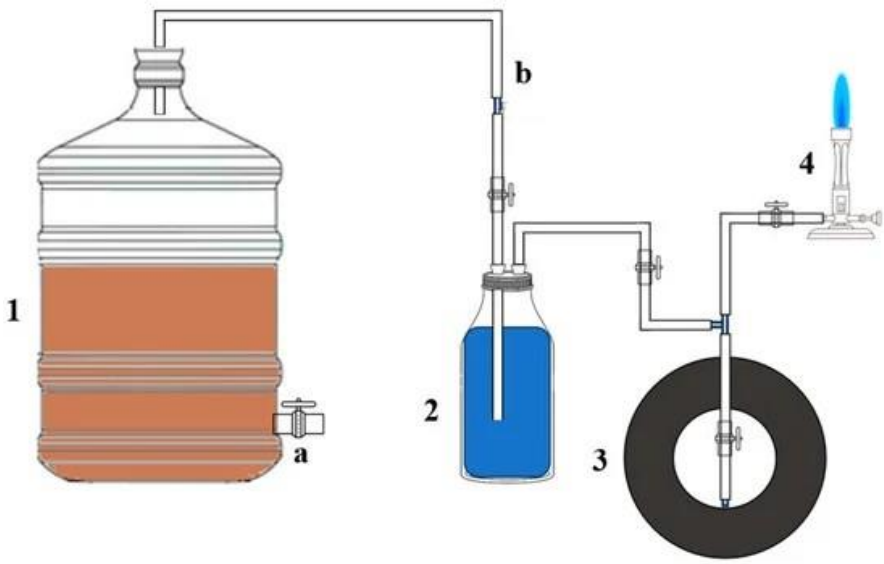

Figure 3: Schematic diagram of the biodigester: (1) fermentation chamber; (2) filter system; (3) biogas storage system; (4) flame test system; (a) vales; (b) T-connector.

V. RESULTS AND CONCLUSIONS

This report presents the initial results of a biogas plant project. Over a ten-day period, the plant generated 5kg of biogas. This report details the considerations during testing, outlines the testing methods employed for measuring volume, mass, and pressure, and provides an initial analysis of the results.

Table 1: The results of the biogas generated from the test

No of Days	Pressure (bar)	Volume of biogas generated (cm^3)	Mass of biogas (kg)	Moles (mol)
1	0.1	210	0.21	13.1
2	0.8	930	0.93	57.9
3	0.9	1000	1.00	62.3
4	1.2	1720	1.72	107.2
5	1.6	2200	2.20	137.1
6	1.9	2690	2.69	167.7
7	2.0	3510	3.51	218.8
8	2.7	4080	4.08	254.3
9	3.0	4820	4.82	300.5
10	3.2	5010	5.01	312.3

The 5kg of biogas generated over ten days indicates a promising initial performance for the biogas plant. However, further analysis was carried out to fully evaluate the efficiency and potential of the system.

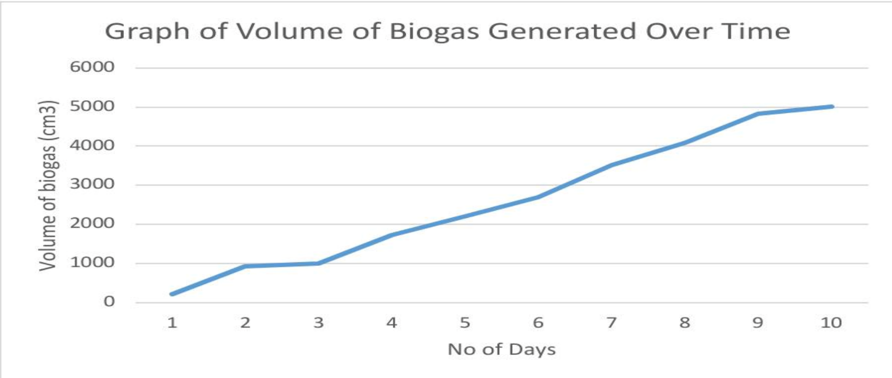

Figure 4: Graph of Volume of Biogas Generated over Time

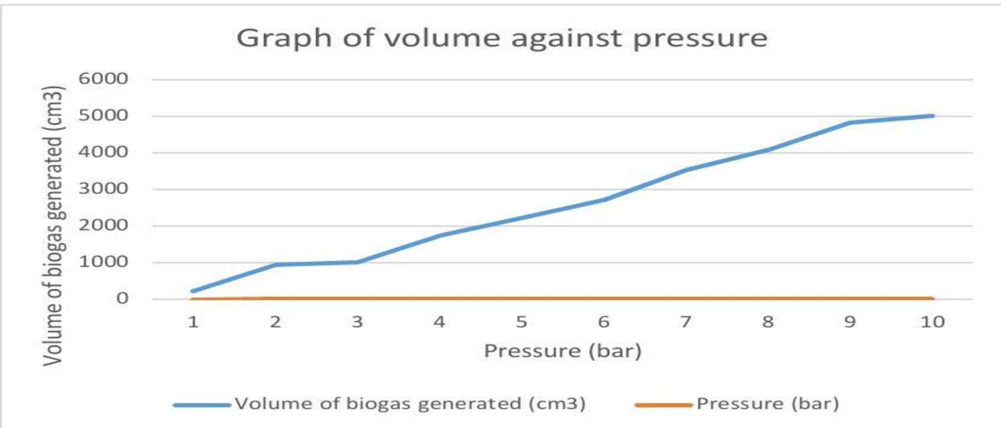

Figure 5: Graph of Volume against Pressure

The research successfully designed and implemented a functional biogas plant capable of producing biogas for cooking purposes. Over a 10-day period, the plant demonstrated a gas production rate of 5 kg, which translates to approximately 0.5kg per day. While this amount may fully meet the daily cooking needs of students in the university community, it represents a promising starting point for further optimization and scale-up. The chosen design proved feasible for construction, utilizing readily available materials and keeping costs relatively low. The simplicity of the design also makes it suitable for replication in similar settings. Also, environmental impact was reduced. By utilizing organic waste to generate biogas, the plant contributes to reducing reliance on non-renewable resources and minimizing environmental pollution associated with traditional fuel sources like firewood or charcoal. This project provided valuable hands-on experience in the design, construction, and operation of a biogas plant. This knowledge can be applied to further refine and improve the design for increased efficiency and gas production.

REFERENCES

1) Ekpo, D. D. (2019) Electricity Generation Potential from Municipal Solid Waste in Uyo Metropolis, Nigeria
2) Gitau, P., Munyao, P., & Muchiri, M. (2015). The economic and environmental benefits of biogas in rural Kenya. Renewable Energy, 80, 126-133.
3) Harnoor, K., Singh, K., & Gupta, D. (2018). Design and analysis of 50 L biogas plant. In 2018 2nd International Conference on Recent Advances in Automation and Computational Engineering (RACE) (pp. 1-4). IEEE
4) Johnson, P. E. (2017). Biogas Plant Design. In S. Smith (Ed.), Advances in Biogas Technology (pp. 25-54). Woodhead Publishing.
5) Ekpo, DD, Diji, C and Offiong, A (2012) Environmental degradation and municipal solid waste management in Eket-Nigeria Pan African Book Company, ISSN: 2276-6138, pp 164-172.
6) Kumar, A., & Pant, M. (2016). Biogas plants: A sustainable alternative for cooking fuel in rural India. Renewable and Sustainable Energy Reviews, 64, 1103-1112.
7) Okafor, C. O., Nwogwugwu, N. U., & Ezeanya, C. I. (2017). Indoor Air Pollution and Respiratory Health in Nigerian Households: A Review of Current Knowledge. Nigerian Journal of Public Health, 9(4), 112-125.
8) Diji, CJ, Ekpo, DD and Adadu, CA (2013) Design of a Biomass Power Plant for a Major Commercial Cluster in Ibadan-Nigeria the International Journal of Engineering and Science pp 23-29
9) Olugbenga, F. A., Adekunle, S. A., & Ibitola, A. O. (2019). Anaerobic Digestion as a Sustainable Energy Source in Nigeria: Opportunities and Challenges. Renewable Energy, 45(3), 235-247.
10) Smith, S., & Johnson, P. E. (2020). Small-scale biogas plant design for sustainable rural development. In J. M. Smith & A. Brown (Eds.), Advances in Sustainable Energy Systems: Emerging Research and Applications (pp. 123-142). IGI Global.
11) Olatunbosun, D., Uguru-Okorie, B. E, & Ekpo D. C. (2014) A Comparison of Medical Waste Generated in Selected Private and Public Hospitals in Abeokuta Metropolis, Nigeria. International Journal of Scientific & Engineering Research pp 1441-1449
12) Diji, CJ, Ekpo, DD and Adadu CA (2013) Exergoenvironmental evaluation of a cement manufacturing process in Nigeria International journal of engineering re-search and development 7, pp25-32
13) Ekpo, D. D. (2012) Challenges of Municipal, Solid Waste Disposal A Case Study of Uyo Township. Education & Science Journal of Policy Review & Curriculum Development, Vol. 1 no 2, pp 110-116