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Development of A 0.044 m^3 Biodigester Integrated with A Purification Unit

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Abstract- This research presents development of batch type bio-digester of capacity 0.044 m^3 integrated with a purification unit. Plastic drum was used in the construction of the biodigester which was fitted with pressure gauge, digital thermometer and gas valve. The biogas was generated through co-digestion cow dung and foul dropping with retention period of thirty days. The biogas produced was purified using scrubbing technology which involves passing the raw biogas through a purification unit of 910ml capacity plastic filled with 450ml of water interconnected to 350ml capacity plastic filled with steel wool, and also a 350ml plastic filled with tiny pore silica gel as the drying agent. The generated biogas pressure and temperature were noted respectively. The performances of the biodigester were analysed. Careful analysis of the result shows that Biogas was produced with CO_2, SO_2 and H_2S content

Keywords: Biogas Production, Cow Dung, Poultry Waste, Co-Digestion, Purification Unit, Digester.

I INTRODUCTION

Biogas is generated when bacteria degrade biological material in the absence of oxygen in a process known as anaerobic digestion (AD) [1]. In general, the process of biogas formation includes hydrolysis, acidification and methanogenesis. Biogas is a source of renewable energy which is produced by biotechnology and can be used on a residential scale. Biogas is primarily a mixture of 50-60% methane (CH_4), 34-38% carbon dioxide ($C0_2$), 0-5% nitrogen (N_2), 6% water vapour ($H_2O_{(g)}$) and traces of hydrogen (H_2) and hydrogen sulphide (H_2S) [2]. It is a biofuel that is produced from natural decomposition of organic waste.

Anaerobic digestion is a waste conversion process. Energy is released during the pollution reduction process and slurry is less smelly, contains less pathogen and can be used as a plant fertilizer. Biogas is an eco-friendly energy resources compared to fossil fuel especially for domestic cooking application. A small biogas plant can meet a family cooking need. Larger size can meet the energy need of a small-scale industry while industrial plant size can supply gas for the generation of electricity.

Animal waste is in abundance all over the world. Fresh animal waste production in Nigeria per day is about 227,500,000kg and 1kg fresh animal waste produce about 0.03m^3 of gas per day [3]. It has been shown that Nigeria can theoretically produce 6.83 million cubic metres of Biogas everyday which in terms of energy is equivalent to 3.9 million litres of petroleum [3]. Bio digester can be built using locally available materials as Nigeria has all the needed materials to produce them [1]. The use of biogas for cooking in Nigeria will greatly improve livelihood of households especially in the rural area where larger percentage of our population resides.

Furthermore, its use for cooking can reduce the demand of fuel wood. Reduction in fuel wood demand will reduce the falling of trees and hence preserve our forest. In addition, the use of biogas will improve smoke and indoor air quality related matter like health. The potential of biogas as a prospective cooking fuel has not been exploited in the country. biogas is a renewable energy stored in organic materials such as plant matter and animal waste known as biomass. The variety of biomass fuel sources include agricultural residue, pulp/paper mill residue, urban wood waste, forest residue, energy crops, landfills and animal waste [3]. biogas feedstock includes cow dung, piggery waste, poultry droppings, water hyacinth, kitchen waste, human waste and waste from sugar refinery. These are in abundance in the country. Moreso, biogas is a cleaner burning fuel compare to fossil fuels. It is non-polluting and actually reduces greenhouse emission. Its methane content is between 50-60% content [2] and can be used in households for cooking [2]. Deploying biogas for cooking will go a long way on promoting the use of sustainable fuels. In addition, unlike other renewable energy sources, the process of production is natural not requiring energy for the generation processes. Hence, its uses will not only enhance clean cooking but also compliment the sources of energy in the country.

However, among the previously hinted biogas feedstocks, cow dung is one of the most abundant sources of feedstock for use in the digester. The challenge is that cow dung has high water content and only about 20-30% of the volatile compounds are converted to biogas by microbes [3]. Next to cow dung is chicken droppings, but it has high Nitrogen content, though very risk in biogas production, the retention time is longer than that of cow dung because microbes struggle to digest its nitrogen content. In order to improve its quality, it is mixed with carbon rich materials like cow dung. The mixture of cow dung and chicken dropping was adopted for the above stated reason to generate the biomethane.

II OBJECTIVES

The objectives are:

i. To develop a 0.044 m^3 bio-digester integrated with purification unit.
ii. To evaluate the performance of the bio-digester with purification.
iii. To analyse the biogas, produce.

III LITERATURE REVIEW

Awe conducted an experiment that provide a state-of-the-art review of biogas upgrading technology with focus on biotechnological methods for the removal of carbon dioxide, hydrogen sulfide, siloxanes, and halocarbons. The study evaluated product purity and impurity levels, methane recovery and losses, upgrading efficiency, and both investment and operating costs. Different techniques were employed to meet specific requirements depending on the intended application. The result shows that selection of appropriate technology depend on the specific biogas requirement, site specific, local circumstance and case sensitive.

Nallamoth design biogas purification system to remove carbon dioxide, hydrogen sulfide, and water vapor from raw biogas using a three-stage scrubbing process. The system includes a scrubbing column, gas storage unit, a refrigerant compressor, moisture removal column, storage cylinder, and pressure gauge. H2S was removed using steel wool, CO2 with water as an absorbent, and water vapor with silica gel. The unit were interconnected with plastic hose, and biogas was compressed to 5bar over 12-14 minutes.

From the experiment, it was concluded that purified biogas has a higher methane concentration than the raw biogas indicating effective removal of impurities through the scrubbing system.

Zhao carried out research aimed to evaluate different techniques for biogas purification the following methods were examined. Water scrubbing, a physical absorption process where H2S and CO2 are selectively dissolved in water due to their higher solubility compared to methane. It operates under pressure and requires minimal chemicals. Pressure swing adsorption (PSA), uses adsorptive materials like zeolite and activated carbon as molecular sieves. Target gases are adsorbed at high pressure, allowing methane to be recovered at higher purity. Membrane separation, employs high pressure membranes to selectively separate H_2S and CO_2 from methane. typically configured in three stages, it can achieve methane purity up to 96%. Biofiltration, uses biological process to remove H_2S. it is cost effective and environmentally friendly with low chemical usage. Cryogenic separation, separates CO_2, H_2S, and other contaminants by liquefying them at distinct temperature and pressure. This method can achieve methane purity up to 99%, but requires turbine, heat exchanger, and compressors, resulting in high energy consumption. In conclusion, while cryogenic and

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membrane methods achieve the highest methane purity, water scrubbing, PSA, and biofiltration offer low cost, less energy intensive alternative depending on the required purity and scale.

Kosna carried out experiment aimed to develop a portable biogas purification and storage system. The design includes two compressors, two heat exchangers, a liquid gas separator, and a storage tank, with a total weight of 12kg.the system was capable of purifying 15kg of biogas per hour and storing 4kg of bio methane. Conclusively, the cryogenic method met the requirements for a portable purification system and eliminated the need for regeneration since no scrubbing process was involved. The main drawback was its high energy consumption.

III. MATERIALS AND METHODS

A. Materials

The following materials were used to develop the bio-digester and the purification unit
See table 1.

Table 1: Materials used

S/N	Items	Size
1	Plastic drum	44L
2	Gas hose	⦰12.7x4570 mm
3	Metal clip	⦰15 mm
4	Gas valve	⦰10.2 mm
5	Thermometer	
6	Steel wool	
7	Silicon seal	310 ml
8	Silicon	500 g
9	Teflon	19x0.2x1500 mm
10	a. Cow dung, b. Chicken droppings	
11	Silica gel	
12	Araldite glue	250 g
13	Plastics rubber	

B. Tools and Equipment

The following tabulated equipment and tool was used in the development of the bio digester and purification unit. As shown in

Table 2.

S/N	Equipment	Country of Manufacture	Description
1	Digital thermometer	China	-50^{o}C to +300^{o}TP3001
2	Tape rule	China	5m
3	Pressure gauge	Holland	100KPa
4	Steel rule	England	

IV RESULTS AND DISCUSSION

1 Performance Evaluation of the Developed Biodigester

The developed batch biodigester with an effective working volume of 0.044 m³ operated successfully throughout the 30-day hydraulic retention period under mesophilic conditions. The system was charged with a slurry consisting of 6 kg of cow dung, 1 kg of poultry droppings, and 15 L of water, resulting in stable anaerobic digestion and continuous biogas production. Approximately 22 L of biogas was generated, with an overall digester efficiency of 78%, while the measured methane production closely agreed with the theoretical estimate, confirming effective conversion of biodegradable organic matter into combustible gas. The observed efficiency demonstrates that the selected feedstock composition and operating conditions were suitable for household-scale biogas production. Although the efficiency was slightly lower than the theoretical maximum due to factors such as temperature fluctuations and substrate characteristics, the developed biodigester performed satisfactorily under experimental conditions. The successful operation of the system further demonstrates that compact biodigesters fabricated from inexpensive, locally available materials can provide a practical and sustainable renewable energy solution for decentralized household applications.

2 Temperature and Pressure Characteristics During Anaerobic Digestion

The variation of pressure with temperature reflected the different stages of anaerobic digestion. During the first week, no measurable gas pressure was observed,

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indicating the microbial adaptation phase before active methane production commenced. In the second week, gas pressure increased to approximately 9 kN m^{-2} at temperatures between 31 and 33°C, confirming the establishment of active methanogenic bacteria and the onset of significant biogas production. The maximum pressure of approximately 18 kN m^{-2} was recorded during the third week, after which pressure gradually decreased and stabilized as biodegradable organic matter became depleted. The highest biogas yield was achieved at approximately 36°C, demonstrating that mesophilic operating conditions favour efficient methane production. These observations are consistent with the typical behaviour of batch anaerobic digestion systems and confirm that temperature remains one of the most influential factors governing microbial activity and gas generation.

3 Biogas Production Performance

The quantity of biogas produced confirms that co-digestion of cow dung and poultry droppings provides a favourable substrate for anaerobic digestion. Poultry droppings supplied nitrogen-rich organic matter, while cow dung contributed an active microbial population and buffering capacity that stabilized the digestion process. The gradual increase in gas production after the initial adaptation period indicates that the selected substrate mixture provided suitable conditions for sustained microbial activity and methane generation. The production of approximately 22 L of biogas together with a digester efficiency of 78% demonstrates the satisfactory performance of the developed system under laboratory conditions. These results indicate that the compact biodigester can effectively convert organic waste into renewable energy using simple construction materials, making it suitable for household-scale applications in developing countries where affordable renewable energy technologies are required.

4 Performance of the Integrated Biogas Purification Unit

The integrated purification unit successfully improved the quality of the generated biogas through sequential removal of carbon dioxide, hydrogen sulphide, and moisture using water, steel wool, and silica gel, respectively. Gas composition analysis showed that methane concentration increased from 74.82% in the raw biogas to approximately 79.00% after purification, representing an increase of 4.18 percentage points and confirming the effectiveness of the purification process. The observed methane enrichment resulted from the combined action of the three purification stages. Water preferentially absorbed carbon dioxide, steel wool chemically removed hydrogen sulphide through the formation of iron sulphides, and silica gel adsorbed residual moisture from the gas stream. Although the methane concentration remained lower than that achieved by advanced commercial upgrading technologies, the developed purification unit provides a low-cost and practical alternative for improving biogas quality in small-scale household energy systems.

5 Comparative Assessment with Previous Studies

The performance of the developed biodigester compares favourably with previous studies on small-scale anaerobic digestion and low-cost biogas purification. While advanced purification methods such as membrane separation and pressure swing adsorption can achieve methane purities exceeding 90%, they require sophisticated equipment and considerably higher capital investment. In contrast, the present study demonstrated that appreciable methane enrichment could be achieved using inexpensive purification materials readily available in local markets. The integration of the biodigester and purification unit into a single compact system distinguishes this work from many previous investigations that considered biogas production and upgrading separately. Consequently, the developed technology offers a technically feasible and economically sustainable solution for decentralized renewable energy production, particularly in rural and peri-urban communities where affordability, simplicity, and ease of maintenance are essential considerations.

6 Engineering Significance

The principal contribution of this study lies in the successful integration of a compact biodigester with a low-cost purification unit into a single operational system capable of generating and upgrading biogas for household use. The experimental results demonstrate that efficient anaerobic digestion and measurable methane enrichment can be achieved using locally available materials without relying on expensive commercial purification technologies. Beyond renewable energy production, the developed system provides additional environmental and socio-economic benefits through improved organic waste management, reduced greenhouse gas emissions, and decreased dependence on conventional cooking fuels. These findings demonstrate the potential of the developed biodigester purification system as an affordable and sustainable engineering solution for decentralized household energy applications in developing countries.

V CONCLUSION AND RECOMMENDATIONS

A Conclusion

This study successfully developed and experimentally evaluated a low-cost 0.044 m^3 integrated biodigester–biogas purification system for household renewable energy applications using locally available materials. The biodigester operated efficiently under mesophilic conditions over a 30-day hydraulic retention period, demonstrating stable anaerobic digestion and an overall digester efficiency of 78%. The system generated approximately 22 L of biogas, while progressive increases in internal pressure and favourable operating temperatures confirmed sustained microbial activity throughout the digestion process. These findings demonstrate that co-digestion of cow dung and poultry droppings provides an effective substrate for small-scale biogas production and supports the development of affordable decentralized renewable energy systems.

The integrated purification unit, comprising water, steel wool, and silica gel, effectively improved the quality of the produced biogas by increasing the methane concentration from 74.82% to 79.00%, thereby enhancing its calorific value and combustion characteristics. The sequential removal of carbon dioxide, hydrogen sulphide, and moisture demonstrates that low-cost purification techniques can provide practical alternatives to expensive commercial upgrading technologies. Overall, the developed biodigester purification system offers a technically feasible, economically viable, and environmentally sustainable solution for household energy production, improved organic waste management, and reduction of dependence on conventional fossil fuels in developing countries.

B Recommendations

Based on the findings of this study, the following recommendations have been made:

i. Future studies should investigate different feedstock combinations and mixing ratios to optimize methane yield and improve overall biodigester performance.
ii. The developed purification unit should be evaluated using alternative low-cost adsorbent materials such as activated carbon, natural zeolite, and biochar to compare their effectiveness in removing carbon dioxide, hydrogen sulphide, and moisture.
iii. Long-term performance studies should be conducted to assess the durability, regeneration, and replacement intervals of the purification media under continuous operating conditions.
iv. Pilot-scale and community-scale versions of the integrated biodigester should be developed and tested to evaluate their technical, economic, and environmental performance under real household operating conditions.
v. Future research should incorporate automated monitoring systems, optimization of hydraulic retention time, and techno-economic analysis to facilitate large-scale commercialization and wider adoption of the developed technology.

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