Empirical Studies into Demand Based Reactor Sizing in Low-Cost Biogas Production for Domestic Utilization

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Abstract— A low-cost biogas reactor incorporating a hydro-pressurizing and gas dispensing unit which was able to deliver biogas at a rate of 6.25 x 10⁻³ m³/s and calculated pressure of 58.7N/m² was designed and fabricated for the purpose of this study. The substrate loading intervals for the reactor were varied at 6, 7, 8, 12, 13, 17 and 33 days interval to determine which of the intervals gave the optimum yield in gas production. The fabricated unit had the highest average daily biogas production level and optimum total yield to substrate ratio at substrate feed interval of 13 days. Results obtained from the study were used to propose a biogas reactor sizing guideline for the low-cost biogas reactor design for domestic use. The proposed guideline would help in adequate deployment and management of resources for waste conversion and renewable energy production in rural areas.

Keywords—Biogas, Cooking, Energy, Hydro-pressurization, Lighting, Low-cost

1. INTRODUCTION

E nergy generation and usage are very important in the day-to-day activities of homes. Sources of energy used in homes could be in the form of electricity, wind, solar, hydro, geothermal, fossil fuels, natural gas etc., these energy sources are used for activities such as space heating, cooling, cooking, lighting amongst others. In recent years there have been concerns that the by-products derived from the use of most of these energy sources used by man especially fossil fuels and its derivatives have led to the gradual but consistent depletion of the earth’s ozone layer thus leading to global warming and its attendant crisis. This has called for a copious proactive approach amongst which is encouragement of adoption and use of renewable energy sources.

Biogas which is generated from the biological breakdown of organic matter in an oxygen deficient or anaerobic environment provides renewable energy currently favoured as a source of fuel for heating, lighting, generation of electricity as well as other associated uses. Its production and use are generally regarded as sustainable practices that can ensure substantial greenhouse gas (GHG) savings. According to Papacz (2011) due to the abundance and availability of biomass, biogas production if properly harnessed could be so large that it could replace 12 to 20 % of the current natural gas consumption. According to Abimbola et al. (2015) in Nigeria, virtually all renewable energy sources available are in serviceable quantity if judiciously harnessed. Research has shown that the production of biogas is dependent on the activities of two main classes of microorganisms which are the thermophilic and mesophilic bacteria, the process goes through a triple staged, complex biochemical process of hydrolysis, acidogenesis and methanogenesis (Ugwoke and Ekpe 2011; Ofoefule et al., 2009). Studies have also revealed that the gas is a composed of methane (55-65%), carbon dioxide (30-45%), traces of hydrogen sulphide and fraction of water vapour (Boleman et al., 2011; Kapdi et al., 2008).

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Studies by various authors have shown that the anaerobic process of biogas production is most times affected by a combination of factors such as co-digestion (Boulamanti et al., 2013; Ogunwande, et al., 2013), temperature (Zhao 2011; Chae et al., 2008), pH and buffering capacity (Kim et al., 2003), mixing level (Gomez et al., 2006), reactor design (Ugwoke and Ekpe (2011); Nielsen et al., 2004); feedstocks (Ogunwande et al., 2015) etc. However, the relationship between loaded substrate volume and biogas yield as well as gas yield and reactor sizing for domestic use are still sketchy.

This study is therefore aimed at proposing a guideline for sizing biogas reactors for domestic use through analytical methods using relationships between substrate volume, loading intensity and gas yield.

2. MATERIALS AND METHODS

2.1 Fabrication of the Low Cost Hydro-Pressurized Biogas Production Unit

A hydro-pressurized biogas digester of volume 0.2 m³ was constructed in the Agricultural and Environmental unit’s test field at the Obafemi Awolowo University’s Institute of Agricultural Research and Training, Moor plantation Ibadan. The setup had four major components as shown in Fig. 1. These components include;

- a. The biogas digester
- b. The gas cleaning unit
- c. The gas metering unit
- d. The gas pressurizing unit

2.1.1 The Biogas Digester Unit

An 0.2 m³ digester was fabricated from plastic material. The digester and was fitted with 110 mm diameter inlet and outlet vents and a 25 mm diameter gas vents. The gas vents were then fitted with specially designed 6mm diameter gas nipples for easy manipulation of gas transport via rubber hose. The fabricated digester was installed at a tilt angle of 17° to facilitate the easy but optimum flow of slurry through the system. The outlet and inlet vents were fitted with ball valves to ensure anaerobic conditions and also help in building up of gas pressure for onward transmission to the metering unit.
2.1.2 Gas Cleaning Unit
The gas cleaning unit has the task of isolating impurities such as H₂S and CO₂ from the gas produced. A gas cleaning unit was fabricated as an air tight unit filled with iron filings for the removal of H₂S and calcium hydroxide in an aspirator configuration.

2.1.3 Gas Metering Unit
This unit served the purpose of measuring the volume of gas produced by displacement of water following Archimedes’ principle. The unit was also responsible for delivering the gas to the point of use. The gas metering unit consisted of a 0.2 m³ airtight chamber with three openings for gas inlet, outlet and pressurization. The gas inlet and outlet were located at the top of the gas metering chamber while the hydro-pressure port was located at the bottom of the chamber.

2.1.4 Gas Pressurizing Unit
The gas pressurizing unit was responsible for supplying a pressure differential in the gas metering unit as a result of difference in the head of fluid between the gas metering and pressurizing units. The unit had a head of 3,000 mm above the metering unit. This was capable of producing a calculated pressure of 58.7 N/m² in the gas metering unit. The obtained pressure was altered by either increasing or decreasing the head of the unit. The unit was also able to deliver gas at a rate of 6.25 \times 10^{-5} m³/s.

2.2 Digester Loading Rate and Interval
The outlet, inlet and gas ports were open before the digester was loaded with slurry derived from cattle dung at a mix ratio of 0.48 (water : cattle dung) through the digester inlet until there was an overflow at the outlet. The outlet was then locked while loading continued until all the air pockets in the digester was expelled through the gas port. The inlet was then closed and gas production monitored from the water outlet port of the gas metering unit. The slurry loading intervals were varied at 6, 7, 8, 12, 13, 17 and 33 days interval to determine which of the intervals gave the optimum yield in gas production. Readings of peak gas production for these loading intervals as well as the average daily gas production over each loading were also obtained. Gas to substrate ratio (G:S) which is an indication of suitability of substrate material for biogas production was also obtained using equation 1.

\[
Y_{G:S} = \frac{\text{Total Volume of Gas Production}}{\text{Mass of Substrate Loaded}}
\]  

(1)

3. RESULTS AND DISCUSSION
3.1 Variation in Gas Production with Loading Interval
The results obtained from the setup showed that the total gas volume (TGV) produced within the respective loading durations was observed to have dropped between the 6 to 7 days loading interval as shown in Fig. 2, this may have been due to instability in the rate of methanogenic bacteria growth (Nopharatana et al., 2007) resulting from environmental shock. It was then observed that the TGV production was constant as the loading interval increased from 7 and 8 days this also may have been due to the effect of increase in retention time. After this the TGV was observed to have risen with increase in loading interval this corresponding increase in gas production with interval may have been attributable to increased stabilization of digester environment leading to more efficient conversion by the biogas forming bacteria. This observed increase peaked at 17 days loading interval when it began to decline, this decline may have been due to depletion of nutrient and production of toxic compounds associated with digestion of cow dung as (Aragaw et al., 2013) within the reactor thus leading to reduced microbial activity this decline was also observed by Ezekoye et al. (2011).

The average daily gas production (AGP) is the average value of all production volumes recorded within each loading interval. The AGP was also observed to follow the same trend as that for TGV except for the fact that the average values peaked at 13 days loading interval. After the 13-day interval loading, the value began to decline as shown in fig. 3. This shows that the difference between production peak and minimal during the 17-day recharge interval must have must have been substantial thus leading to a lower average value than
what was observed during the 13-day recharge interval. From this it can be deduced that the although the 17-day recharge offered a higher TGV that the AGV, the 13-day interval was more reliable since the deviation between mean production values were not as much as what was observed in the 17-day interval recharge cycle.

3.3 Reactor Sizing

The reactor sizing for the low cost biogas system was done based on estimated cooking time using a single burner gas cooker and a single unit of biogas powered lamp. This demand volume was then compared with the total gas production level of the reactor to obtain a trend used in the estimation of reactor sizes. The estimated requirement per day (m³/day) for cooking ($E_{GDC}$) was calculated using equation 2.0 while the estimate for lighting ($E_{GDL}$) was obtained from equation 3.0.

$$E_{GDC} = 2.44t$$  \hspace{1cm} (2.0)

$$E_{GDL} = 2.44t \times 0.5$$  \hspace{1cm} (3.0)

The reactor size ($RS_{DBC}$) was then estimated with the aid of equation 4.0.

$$RS_{DBC} = E_{GDC} + 0.77 + [0.39(t - 2)]$$  \hspace{1cm} (4.0)

Where $t$ is the gas supply duration (hrs)

Results as shown in Table 1 revealed that for a family requiring a 3 hrs daily cooking time using a single burner cooking unit the proposed reactor size should not be less than 8.5 m³ which would have to be recharged daily with cow dung of about 8 kg after the first 13 days of loading in order to ensure that there is constant gas production in the unit.

4. CONCLUSION

The study was able to design and fabricate a low-cost biogas reactor incorporating a hydro-pressurizing unit. Parameters derived through empirical data collected from the fabricated biogas production unit had the highest average daily biogas production level and optimum total yield to substrate ratio at substrate feed interval of 13 days. This implies that for optimum production topping of substrate level in the reactor should not exceed the 13-day duration. The study was also able to propose a biogas reactor sizing guideline for the low-cost biogas reactor design for domestic use. The proposed guideline would help in adequate deployment and management of resources for waste conversion and renewable energy production in rural areas.

ACKNOWLEDGEMENTS

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Table 1: Proposed guidelines for reactor sizing

<table>
<thead>
<tr>
<th>Cooking time per day (hr)</th>
<th>Lighting time per day (hr)</th>
<th>Estimated requirement per day (m³/day)</th>
<th><strong>Calorific value (MJ)</strong></th>
<th>Proposed Reactor size (m³)</th>
<th>Slurry mix ratio</th>
<th>Daily recharge weight (Kg)</th>
<th>*Periodic recharge weight (Kg)</th>
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<td>2</td>
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<td>4.88</td>
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</tr>
</tbody>
</table>

*13 day recharge interval **1m³ of Biogas = 36 MJ

REFERENCES


