OPTIMIZING GAS PRODUCTION THROUGH BIODIGESTER DESIGN OPTIONS IN A TROPICAL ENVIRONMENT

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ABSTRACT

The urgent need for alternative source of power brought the need for the design of the bio-digester to enable the generation of biogas for use. Different types of bio-digester and their construction have been elucidated and a better design had been decided as it concerns our region and climate. Different design concepts were discussed briefly and why the need for such designs, which will also include the methods of feeds and the method the biogas, was constructed. Various operating parameters was also discussed as it concerns the digester, which was included the digester dimension, the holder dimension and the temperature needed for adequate performance. For purposes of performance air test for digester was also included to ensure digester was fit for purpose. Basic consideration for bio-digester construction and design theories was also briefly discussed. A simple bio-digester can easily be designed and constructed by all household because it does not entail any special skill, if the said design and construction was adopted it will definitely go a long way in minimizing the complete dependent on Federal Power source which has always been epileptic and inconsistence. Hence, recommended the bio-digester design and construction using local materials for biogas production.

Keywords: Biogas production, design, continuous feed bio-digester plant, tropical environment

INTRODUCTION

The first sets of digester designed were single chambers. In this method, all biodegradable i.e. hydrolysis, methonogenesis all take place in one volume, this method is still constantly used (Igboro, 2014) However, present day design has gone ahead to create more biodegradable chambers taking into cognizance the fact that the biochemical pathogens of digestion occur in phases. Two stages are involved in the design which physically separates the bacteria population according to these stages. David and Cornwell (2019) reported that the environmental conditions in the single stage are kept at equilibrium and all the bacteria exist in the same volume. Also, they opined that the pH which is very important and always kept in neutral to ensure survival of the methanogens and acetogenes which thrive well in a pH lower than 7.5

LITERATURE REVIEW

It has be in literature that there different designs and shapes of digesters used for biogas production. Fixed dome digester also known as drumless digester was designed in China in the 1930’s. It is designed in underground brick masonry where the digester was comfortably built with concrete dome, with storage designed on top while the slurry is displaced into a compensation tank. In this design, it is important the location of the digester have 2- 4 hours of sunlight during winter to allow adequate digestion. Also the floating drum digester that was made up of cylindrical slope digester, with a floater that determines when production of biogas gas starts by sliding up and down depending on when the gas is produced and subsequently used. In other words, if the biogas is produced, the drums move up, if the gas is consumed, the gas holder sinks back as the gas is being used. By observing the level of the drum, one can assess the gas volume available. The main difference in the fixed dome Digester and the floating Digester is the movement (up and down) of the gas holder in floating digester. Furthermore, another digester designed was semi-buried digester, this digester is same with Dome digester in terms of principle of operations, though in this digester, part of it is completely buried underground. The digester, just like the floating digester can be designed with a metal plate and the buried part painted with oxide to avoid corrosion. Every other aspect of gas collection is same with Dome type of digester. The mode of collection of gas and subsequent discharge of slurry in this digester also falls within the single chamber digester design where all the biodegradable activities take place in a particular single chamber.

Further literature also reported that once in operation, the single chamber digesters are simpler to operate than the multi-stage digester where the substrate is transported to subsequent chamber where progressive stages of anaerobic digestion occur according to prescribed timing. In the multi-stage digester where tanks are also used for biodegradable, the first tank and second tank carry out hydrolysis, acetogenesis and methanogenesis respectively. The first tank is heated after thorough mixture to uniform temperature and continuous feed into the chamber. The residence time ranges from 9-14 days (David & Cornwell, 1998). It is important that the tank maintain a higher pH to enable adequate gas collection and storage. The multi-stage digesters have as much as eight tanks with all the tanks having and serving a specific purpose (David & Cornwell, 2019).

In light of previous findings, there is insufficiency of researches about the optimizing gas production through bio-digester design options in a tropical environment. The aim of this study was to optimize biogas production through design of continuous feed bio-digester plant in a tropical environment.

METHODOLOGY

Biodigesters are designed based on the way the feeds are introduced into the digester, the feed can be introduced horizontally where the inlet digester and outlet are on same path, other methods of feed is where the feed is introduced from the bottom, while the outlet is on top. This method is not so common because of the logistic of introduction of the said feed. Finally, the vertical introduction of feeds which is most common and more ideal. The feeds are predominantly gravity driven, forcing materials to generally drop down into the biodigester for biodegradation. This method is ideal and very easy to operate

Design Concept of Anaerobic Plant

There are three main models of anaerobic digester plant that have been developed overtime by developing countries (Karki et al, 2015). These are fixed dome plant, Deebandhu and floating drum plant.

Sequence of Biogas Generation

In the design of biodigester, there are some considerations that need to be put in order to achieve adequate Biogas production. These are:

- Biodigester must be spherical in shape to allow easy mixing of the slurry.
- Biodigester must be air-tight, the process of generation of the sand Biogas is Anaerobic.

- Feeds must be thoroughly stirred before introduction into biodigester.
- Since the Biogas (methane gas) is lighter than air, it must be collected through upward receiving; any plans to run the hose carrying the gas downward will lead to the Biogas not being adequately collected.

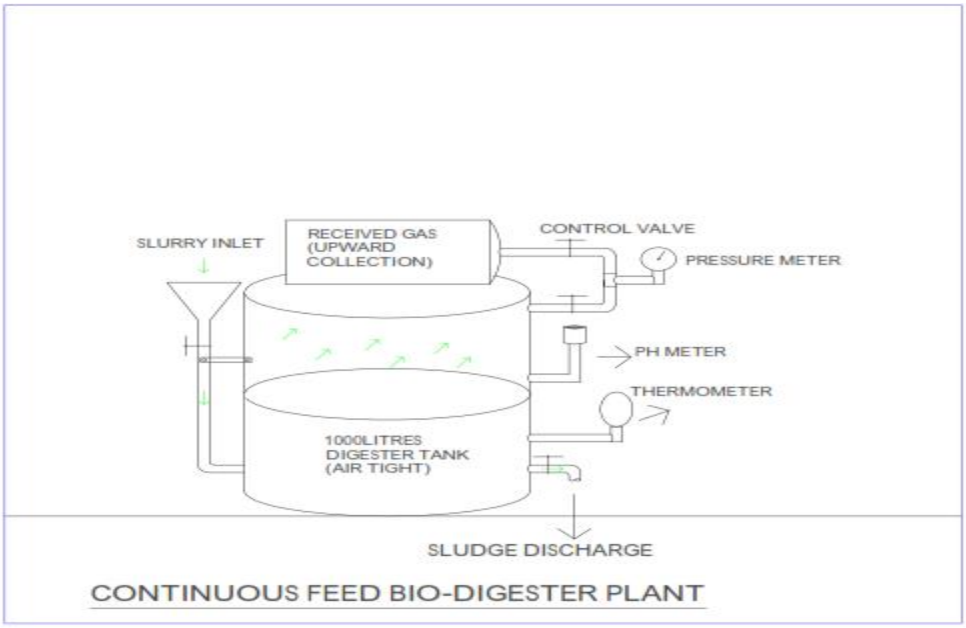

Figure 1: Continuous Feed Bio-Digester Plant

In the design of the bio-digester, likely hazard associated with it, like fire explosion was considered. Methane is made up of about 0 - 80% of biogas and it forms explosive mixture in air with lower explosion limit being 5%. Naked flame should be kept away at least 10 meters from the vicinity of the digester and electrical equipment must be explosive proof being used or brought near the digester. Disease is expected to emanate during the process of biodegradation. Care should be taken when introducing feedstock; hand should be thoroughly washed after making contact with digester.

Design Procedure

In the design of the bio-digester, there are some processes that need to be considered or put in place to get maximum functionality of the bio-digester, they include:

- Removal of the non-biodegradable materials.
- The feed stock are expected to be uniform i.e. thorough stirring of the feed stock is very important.
- The bio-digester must be air-tight to give room for proper anaerobic digestion (Monnet, 2013)

Design Consideration

In the design consideration of the Biogas Plant some certain parameters need to be considered;

Operating volume

cow dung that has be thoroughly mixed Ahmadu, (2017)

The operating volume of the digester which will referred to as (V_o) is ascertain by the retention time (RT) and the daily substrate input quantity (S_d) and is given as;

$$V_o = S_d \times RT(M^3 = M^3/day \times Number\ of\ day) \quad (1)$$

The retention can be defined as the period of time the substrate is allowed to retention in Bio-digester before the generation of biogas, though the retention time can be determines by the chosen digester temperature and the amount of the biomass resources available.

A simple design plant should not exceed 30 days for its retention time even though the type of substrate also has a role to play in the retention time as presented in equation (2).

$$Substrate\ input, S_d = Biomass(B) + Water(W)(M^3/day) \qquad (2)$$

In most agricultural plant, mixing ratio of dung to water varies between 1:1, 2:1 or even 3:1 to achieve better mixture

Total volume

The total volume of the digester (V_T) should be greater than the operating volume, this will allow for adequate for fermentation and subsequent biogas production. The operating must not exceed 80% of the total volume of the Digester, this can be represented in equation (3) as:

$$V_T = V_o/0.8 \qquad (3)$$

Digester dimension

The ratio of the dimension can be ascertain depending on the shape adopted to use for biodigester, it is ideal to us a cylindrical shape digester to allow for easy stirring and mixing of the slurry. For a cylindrical framework digester the formula is represented in equation (4):

$$V_T = \pi r_d^2 d h_d \qquad (4)$$

Where V_T = Total volume of Digester
r_d = radius of digester
h_d = height of digester

Digester temperature

We have two types of temperature required in the Bio-digester, the thermophilic temperature and the mesophilic temperature. Most digester is designed to operate in mesophilic temperature which falls within the range of (20 – 40^{0}C).

This temperature can mostly be attained from the natural heat coming from the sun through and absorptive surface from the sun ray during the day and a designed insulating material that will help to retain the temperature in the bio-digester to manageable level at night where the external heat from the sun no more exist. A thermometer was used to determine the temperature of the digester.

Gas Holder Design

Gas holder volume (Vg)

The gas holder that holds all the gas generated in the bio-digester to suit the expected to be generated and the size of the bio-digester.
The gas holder should be design to consider the following:
The expected maximum consumption rate (gc_{max})
Maximum consumption (tc_{max}), $V_g = V_{gl}$
To hold the gas produce during the longest production period

$$(tz), V_g = V_{g2} \qquad (5)$$

Gas holder dimension

Having determined the volume of the cylindrical bio-digester, its dimension was determined using equation (6);

$$V_g = \pi r_g^2 h_g \tag{6}$$

Vg =Volume of gas holder
r_g = radius of gas holder
h_g = height of gas holder

Force on the gas holder (Fg)

The force on the gas holder was determined using equation (7) as

$$F_g = P_g \times A_g \tag{7}$$

P_g = Pressure in gas holder
A_g = Cross sectional area of gas holder.

Gas Pipe Diameter

The gas pipe diameter is chosen after considering the level of flow of the generated biogas the distance of flow is also considered. Since the pressure rating of the produce biogas is usually very low, the pipe to be use does not necessarily have to be thick.

RESULTS

Bio-digester was designed and subsequently used to generate biogas. Data was collected for a period of thirty Nine (39) days; various Parameters were installed in the Bio-digester to determine appropriate readings that will enhance adequate Biogas Production.

Table 1: Biogas Data collection Over Period of Time

DAYS	TEMPERATURE	PRESSURE (PSI)	Ph	BIOGAS (Litres)	Biogas (M^3)	Biogas (Standard)
15th June 2019	5^0C	0.000	2.5	Nil	Nil	Nil
19th June	25^0C	0.0012	7.0	3.3 Litres	0.0033	3.3×10^{-3}
20th June	35^0C	0.0010	7.2	3.0 Litres	0.0030	3.0×10^{-3}
21th June	36^0C	0.0010	7.3	3.1 Litres	0.0031	3.1×10^{-3}
30st June	28^0C	0.0010	7.3	2.8 Litres	0.0028	2.8×10^{-3}
1th July	38^0C	0.0010	7.5	4.0 Litres	0.0040	4.0×10^{-3}
2nd July	38^0C	0.0010	7.5	3.2 Litres	0.0032	3.2×10^{-3}
3rd July	40^0C	0.0013	7.5	4.4 Litres	0.0044	4.4×10^{-3}
4th July	40^0C	0.0014	7.5	4.8 Litres	0.0048	4.8×10^{-3}
5th July	30^0C	0.0010	7.5	3.8 Litres	0.0038	3.8×10^{-3}
6th July	37^0C	0.0015	7.5	4.3 Litres	0.0043	4.3×10^{-3}
7th July	25^0C	0.0010	7.5	2.5 Litres	0.0025	2.5×10^{-3}
8th July	20^0C	0.0010	7.5	2.5 Litres	0.0020	2.0×10^{-3}
9th July	20^0C	0.0010	7.0	2.5 Litres	0.0025	2.5×10^{-3}
10th July	34^0C	0.0010	7.0	3.8Litres	0.0038	3.8×10^{-3}
11th July	37^0C	0.0010	7.0	4.5Litres	0.0045	4.5×10^{-3}
12th July	37^0C	0.0010	7.0	4.4Litres	0.0044	4.4×10^{-3}
13th July	35^0C	0.0010	7.0	4.6Litres	0.0046	4.6×10^{-3}

14th July	**30^{0}C**	**0.0010**	**7.0**	**4.7Litres**	**0.0047**	**4.7 x10^{-3}**
15th July	**25^{0}C**	**0.0010**	**7.0**	**4.3Litres**	**0.0043**	**4.3 x10^{-3}**
16th July	**20^{0}C**	**0.0010**	**7.0**	**4.4 Litres**	**0.0044**	**4.4 x10^{-3}**
17th July	**28^{0}C**	**0.0010**	**7.0**	**4.5Litres**	**0.0045**	**4.5 x10^{-3}**
18th July	**29^{0}C**	**0.0010**	**7.0**	**4.0Litres**	**0.0040**	**4.0 x10^{-3}**
19th July	**35^{0}C**	**0.0010**	**7.0**	**3.8Litres**	**0.0038**	**3.8 x10^{-3}**
20th July	**37^{0}C**	**0.0010**	**7.0**	**4.0Litres**	**0.0040**	**4.0 x10^{-3}**
21st July	**29^{0}C**	**0.0010**	**7.0**	**4.1Litres**	**0.0041**	**4.1 x10^{-3}**
22nd July	**35^{0}C**	**0.0010**	**7.2**	**4.0Litres**	**0.0040**	**4.0 x10^{-3}**
23rd July	**29^{0}C**	**0.0010**	**7.1**	**3.8Litres**	**0.0038**	**3.8 x10^{-3}**
24th July	**24^{0}C**	**0.0010**	**7.0**	**2.9Litres**	**0.0029**	**2.9 x10^{-3}**
25th July	**40^{0}C**	**0.0010**	**7.0**	**3.7Litres**	**0.0037**	**3.7 x10^{-3}**
26th July	**32^{0}C**	**0.0010**	**7.0**	**3.4Litres**	**0.0034**	**3.4 x10^{-3}**
27th July	**41^{0}C**	**0.0010**	**7.2**	**3.8Litres**	**0.0038**	**3.8 x10^{-3}**
28th July	**38^{0}C**	**0.0010**	**7.1**	**3.0Litres**	**0.0030**	**3.0 x10^{-3}**
29th July	**38^{0}C**	**0.0010**	**7.2**	**3.8Litres**	**0.0038**	**3.8 x10^{-3}**
30th July	**32^{0}C**	**0.0010**	**7.0**	**3.1Litres**	**0.0031**	**3.1 x10^{-3}**
31st July	**30^{0}C**	**0.0010**	**7.0**	**2.9 Litres**	**0.0029**	**2.9 x10^{-3}**

Analysis of Biogas Table

Table 1 showed the various data collected over thirty Nine (39) days' time frame , the table showed that the highest level of biogas was collected during the period when the temperature was at the range of 40^{0}C - 44^{0}C. The bulk of gas was also generated from the 18th and lasted for almost seven days (11th July – 18th July) after the slurry was introduced into the Bio-digester as against 25th day as generally recorded by various researchers, it is also important to note that the biogas Production exceeded the 40 days' time frame for collection.

The P^H was stable for almost the entire duration of the research, a constant readings of 7.0 -7.5 was recorded although the period, which conforms to statistics given by other researchers. It is also important to note that the pressure rating was very low in spite of various temperature changes and the days recorded for anaerobic digestion period, which invariably means temperature and the number of days for digestion didn't affect the pressure that was recorded. 0.0010 psi was recorded for better period of the entire research.

DISCUSSION

Design Suggestion For A Tropical Environment

Biogas can be constructed using very affordable material that be can be locally sourced. We can use plastic tank of any size depending on the expected biogas to be generated. The gas holder can be a very light material that will indicate the presence of the biogas once it has been collected.
Plastic one inch pipe can be used for carrying the gas from the Bio-digester to the gas holder for the purpose of this review work, Plastic ball valves where installed to regulate the rate of flow of the biogas to enable intermittent readings to be taken at different time of the day.
It is important to note that for an industrial bio-digester construction bricks can be used with gas holder constructed separately from bio-digester with a connecting link.

Since the bio-digester is a continuous process where the slurry is discharge after 40 or 50 days depending on the time when all the biogas has been collected, there is a need for a discharge point where all the slurry will be collected and use for farm manure, this discharged point is usually at the bottom of the bio-digester.

There is also a loading point of the feed material which most times are at the top of the bio-digester to allow gravity receiving process.

Air Test

The bio-digester is an anaerobic digestion process so it expected be air tight to achieve the desired process. To achieve this air test need to be carried out to ensure there is no leakage in any part of the digester and the gas holder when the process starts.

This can be achieved by introducing air into the digester when it is properly sealed that is all the connecting outlet valves are properly closed, soapy water can be poured all over the digester and the gas holder looking for bubbles to show likely leakage. After ascertaining that there is no leakage we can introduce our substrate in the bio-digester.

Basic Consideration for Digester Construction

Specific factors to be considered in the design of a bio-digester:

- Should be simple in terms of operation and construction.
- Repair and maintenance cost should be minimal.
- Construction should be made using 90 % of local materials.
- Should be durable, easy to operate and cost effective.
- Should be efficient i.e. the gas production should be optimum per unit volume of a biogas plant for given type and quantity of input.

CONCLUSIONS

Need for bio-digester and hence the design has become imperative because of the urgent need for alternative means of power. Biogas has succeeded in meeting the thermal energy needs of so many countries, especially in China, India and Belgium over 1million bio-digesters have been built and fully used. Design of bio-digester follows a simple concept as shown in the various design in this review paper. Different households can design the sand bio-digester in their various homes to give them the necessary power source they need for daily activities, the maintenance and sustenance are very simple. The continuous dependence on hydro and gas turbine means of power must stop, since it is not meeting up with our needs, and it is epileptic. Bio-digester can act as alternative source of power in various homes, this is the time to make that move, considering the fact that the bio-digester can be design and constructed easily no special skill is required.

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