Design of Solid state digester for biogas production from banana wastes

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Abstract

Processing of banana results in a huge amount of waste generation, leaves, stems and peels etc. Indiscriminate disposal of these wastes when decomposed produces noxious gases such as hydrogen sulphide and ammonia, which pose serious environmental hazards. Thus turning them into biomass feedstock offers a better waste management option and also source of energy production. For the past 30 years, there has been only biogas plants which are developed for treating cow dung as feed material. In those plants only other organic wastes are used as feed material. As banana wastes contain high moisture, they can be treated by the way of solid state digestion. The paper describes the design of solid state digester of 1 m³ capacity of biogas production, exclusively for treating banana wastes by the method of solid state anaerobic digestion. The reactor was designed based on the hydraulic retention time and the total solid content of the banana feedstock in order to complete digest and produce biogas at a faster rate with optimum quantity and methane content. The digester was designed for a feed capacity of 30 kg with 30 days retention time with a gas holder volume of 1 m³. The diameter and height of the digester are 1.09 m and 2.1 m and for gas holder the diameter and height are 1.01 m and 0.9 m respectively. The developed digester was found to convert 90% of the solid content in feed to bioenergy.

Keywords: Anaerobic digestion, Banana wastes, Biogas, Energy, Solid state digester

1. Introduction

Biogas can be produced from any biodegradable feedstock that are suitable for anaerobic digestion. Generally the feedstock used for biogas production may be solid, slurries and both concentrated and dilute liquids [1]. Efforts are being taken in exploring alternate feedstock for biogas production [2]. Banana wastes can also be used as an alternate feedstock as they are a concentrated source of putrid organic waste, ideal for anaerobic digestion to produce a valuable energy source in form of biogas [3]. Debabandya Mohapatra et al. [4] reported on the pulp and peel composition of dessert bananas that the moisture content in the banana peel is about 83.5%. The other important parameters like starch, cellulose and total sugars are about 1.2%, 8.4% and 29% respectively. They also reported that bananas give the advantage of producing a very clean form of biogas, consisting of just methane and carbon dioxide as compared to the other waste streams such as human sewage, piggery or feedlot waste, with the added attraction of less noxious odors as well as different trace elements. This proved that banana wastes had energy content which can be potentially tapped for bioenergy recovery. Channeling these wastes into the production of biogas by anaerobic digestion is an effective way of waste management helping to mitigate environmental pollution.
Among the anaerobic biogas production technologies used for treating wastes, floating drum biogas plants offer more advantages like simple in construction, easily understood operation, constant gas pressure, volume of stored gas visible directly, etc [5]. Reports on floating drum biogas plants suggested that further modifications are needed to overcome some of its disadvantages for effective biogas production [6]. Keeping this in view, modifications were done and the design has been arrived for a solid state digester for enhancing the biogas production by exclusively treating banana wastes. The methodology adopted for the design of anaerobic solid state digester is detailed in this paper.

2. Materials and methods

The methodology adopted for the design of anaerobic solid state digester of biogas holding capacity of 1 m$^3$ is outlined. Floating drum biogas plants offer more advantages and biogas experts suggested that further modifications are needed to overcome some of its disadvantages for effective biogas production and treatment of wide variety of wastes with even less moisture content [7][8].

In view of enhancing the biogas production especially for treating solid wastes and preventing the foam formation inside the digester, few modifications were done to enable solid state digestion. A provision of wedge and stirring arrangements are incorporated to form a solid state digester. The wedge provision inside the outer drum holds the inner drum and acts as a solid-liquid-gas separator [9]. The stirring arrangements were made by attaching four number of T-angle rods from the base of inner drum. When the inner drum (gas holder) is rotated, in order to remove the scum formed in the upper layer of the feed material inside the digester, which is lacking in conventional floating drum biogas plants treating wastes so far [10].

On the basis of the daily feed rate and hydraulic retention time, the volume of the digester is obtained [11] using the formula,

$$V_d = Q_i \times HRT$$

where,

- $V_d$ = Digester volume in m$^3$
- $Q_i$ = Daily feed rate in kg/day
- HRT = Hydraulic Retention Time (days)

The design of gas holder, feed inlet, sludge outlet, sludge drain, wedge, stirring arrangements, sampling ports and gas outlet was arrived and kept according to the calculated design diameter and height of the digester.

3. Results and discussion

3.1. Design of digester

The solid state digester was designed for a daily feed of 30 kg which was fixed based on the availability of feed materials. The design was carried out based on the hydraulic retention time needed for the feed materials to digest completely and moisture content available in the feed.

Design daily feed = 30 kg
Total mass of slurry = feed + water (1:1) = 30 + 30 = 60 kg/day
Design HRT = 30 days
Volume of slurry/day = Total mass of slurry / Specific gravity
(Specific gravity of banana wastes is about 872 kg/m$^3$, [12])

Volume of slurry/day = 60 / 872 = 0.068 m$^3$
Total volume of the digester = 0.068 x 30 = 2.064 m$^3$

Thus the volume of the digester is approximately taken as 2 m$^3$. 

2
Assuming the diameter to height ratio as 0.5 and based on the volume of the digester the following dimensions have been arrived.

\[
\begin{align*}
\text{Diameter of the digester} &= 1.09 \text{ m} \\
\text{Height of the digester} &= 2.19 \text{ m}
\end{align*}
\]

3.1.1. Feed inlet
The feed inlet was provided at a slope of 30°. The feed inlet consisted of 0.1 m diameter pipe and was positioned at a height of 0.38 m from the bottom of the digester. The total length of the feed inlet is 2.5 m.

3.1.2. Sludge outlet
A 0.07 m diameter sludge outlet was provided to collect the sludge coming out of the digester. The outlet pipe was positioned on one side of the outer wall of the digester adjacent to feed inlet in such a way to collect the sludge at one point and it was 0.07 m below from the top level of the digester.

3.1.3. Sludge drain
The sludge drain was positioned at the bottom of the digester. A port with a diameter of 0.1 m was provided for draining the sludge after certain period of plant operation.

3.1.4. Gas holder
The gas holder was made of 12 gauge M.S. sheet and it was placed in the reactor in such a way that a clearance of 7 cm was provided all around the gas holder so that it moves freely on the guide frame provided in the reactor. It was coated with fiber reinforced plastic (FRP) of 2 mm thickness, which prevents the drum from being corroded [13]. The gas holder was designed as conical towards at the top and the gas outlet was connected to a wet gas flow meter for gas production measurement.

3.1.5. Wedge
Wedge provision was made in the outer drum at a height of 0.95 m from the bottom of the digester. It acts as a holder of the inner drum i.e. the gas holder and also as a solid-liquid-gas separator. The width and height of the wedge was 0.1 m and 0.17 m respectively.

3.1.6. Stirring arrangements
Stirring arrangements are provided with four T-angle rods of length 1.5 m which is attached to the guide frame of the gas holder. This arrangement helps in prevention of foam formation inside the digester when the drum is rotated [10].

3.1.7. Sampling ports
Three sampling ports of 0.05 m diameter were provided in the outer wall of the digester with equal spacing of 0.58 m.

3.1.8. Gas outlet
The biogas produced in the plant was collected in the gas holder. The gas outlet was connected to a wet gas flow meter to measure the daily biogas production.

3.2. Design dimensions
The primary dimensions of the solid state digester were as follows:

\[
\begin{align*}
\text{Diameter of the digester} &= 1.09 \text{ m} \\
\text{Total height of the digester} &= 2.19 \text{ m} \\
\text{Diameter of the gas holder} &= 0.95 \text{ m} \\
\text{Height of the gas holder} &= 0.78 \text{ m}
\end{align*}
\]
The designed digester with dimensions were shown in figure 1.

**Figure 1.** Design of solid state digester of biogas capacity 1m$^3$ (All dimensions are in meters)

The designed solid state digester was fabricated in the workshop at the department of Bioenergy, Tamil Nadu Agricultural University, Coimbatore. The gas holder was coated with fiber reinforced plastic (FRP) on the inner portion inorder to avoid the corrosion of gasholder due to the presence of Hydrogen sulphide in the biogas and enhance the biogas and methane recovery from banana wastes [14]. Similar study [15] was reported on a new cartridge design anaerobic digester to treat lignocellulosic wastes like corn stover as the feedstock was operated in three conditions: three cartridges rotated every week in the digester; four cartridges rotated every week in the digester and four cartridges rotated every 9-10 days in the digester. Stable biogas production was observed in all three conditions and the average yield of methane was 7.57, 7.11, and 6.9 l/day/kg-VS for respective conditions, which was comparable to other digester designs. Another similar novel system on solid state seriel anaerobic digestion (AD) of aquatic biomass was designed to enhance the methane recovery [16], which resulted in a better volumetric methane recovery of 42% in serial AD against single-stage AD which is a challenge in anaerobic digestion of aquatic biomass. The two-stage serial wet- and solid-state AD (SS-AD) system quickly digests the labile cytoplasm fraction in the first wet AD
reactor in a short retention time while slowly digesting the lignocellulosic fraction in the later SS-AD with long retention time.

**Figure 2.** Fabrication of digester and gas holder

**Figure 3.** Developed solid state digester with wet gas flow meter
The biogas produced in the digester was measured by using wet gas flow meter attached to it in order to measure the daily biogas production. Figure 2 and 3 show the fabrication of digester and gas holder and the developed solid state digester with gas measuring setup respectively.

4. Conclusion
Solid state digester of biogas capacity 1 m$^3$ was designed based on 30 days Hydraulic Retention Time. The total height of the solid state digester was 2.18 m with diameter of 1.09 m and digester volume of 2 m$^3$. The height of gas holder was 0.78 m with diameter of 0.95 m and gas holding volume of 1 m$^3$. It was fabricated and installed in the Renewable energy park of Bioenergy workshop, TNAU, Coimbatore. In the developed digester, the biogas production was found to vary in the range of 4.89 to 5.67 m$^3$ over weeks. The specific gas production of banana wastes over weeks varied in the range of 0.023 to 0.027 m$^3$/kg of fresh feed.

5. References

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