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Production of biogas using small-scale plug flow reactor and sizing calculation for biodegradable solid waste

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Abstract

Experiment was conducted on the fabricated biodigester of capacity 30 l. Slurry of cow manure in water was fed through the inlet until the digester is about 80% filled with slurry, and the slurry surface on both inlet and outlet did not leave holes by which the air can get into the digester. This was to ensure the anaerobic condition in the gas space inside the digester. After the first filling, both the inlet and outlet were covered and gas valve to the gas holder was opened. In the first 20 days, the gas holder expanded with produced gas. The first 20 days was the transient phase of the biogas production and it acted as a batch reactor. At the end of 20 days, the content of the gas holder was released as it did not burn due to the predomination of carbon dioxide. The next phase was started wherein the biodigester was fed periodically with slurry including kitchen and domestic waste from the M.S. Ramaiah Institute of Technology college canteen and hostels. After the digester was operational for several weeks (in reactor from which inoculation charge is obtained) and after the initial filling, the pH value had reached the stable value of 6.5 that remained constant during the period of sampling. The temperature was constant between 35 to 40 during the day and 25 to 30 during the night. Therefore, those two parameters were considered as the constants with respect to the model development. Based on our field data, those two parameters did not fluctuate significantly in Bangalore climate (where plug flow reactor is operated).

Keywords: Biogas; Plug flow reactor; Solid waste

Background

Unlike other renewable fuels such as biodiesel and bioethanol, biogas production is relatively simple and can operate under any conditions and is not monopolistic (Kalia et al. 1992; Kapadi et al. 2004). Dung is a potential substrate for biogas production, seen only as a floor polish and fertilizer in the garden for hundreds of years. Biogas for rural energy is sustainable, affordable, and has no negative effect on people's health or the environment, if handled properly (Khandelwal & Mahdi 1986; Kumar & Jain 1988). Complicated construction, difficult operation of the systems, high investment, and maintenance costs have pushed farmers to adopt cheaper and simpler anaerobic systems (Mittal 1996).

There are currently more than 30 million household digesters in China, followed by India with 3.8 million, 0.2 million in Nepal, and 60,000 in Bangladesh (MNES Report

2001; Nirmala & Gaur 1997). China has increased its investments in biogas infrastructure very rapidly. By 2020, 80 million households in China are expected to have biogas digesters serving 300 million people. India is implementing one of the world's largest renewable-energy programs with different scales of technologies. One of the strategies is to promote biogas plants. India began the project half a century ago, and was further supported by the National Project on Biogas Development in 1982 (Singh & Anil 1988).

The disadvantage with the fixed dome and floating drum models is that once installed they are difficult to move. Hence, portable models built over the ground called tubular or plug flow digesters were developed (Srivastava et al. 1994; Vijay 1989). Plug flow digesters have a constant volume, but produce biogas at a variable pressure. The size of such digesters varies from 2.4 to 7.5 m³. Plug flow digesters consist of a narrow and long tank with an average length to width ratio of 5:1. The inlet and outlet of the

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digester are located at opposite ends, kept above ground, while the remaining parts of the digester is buried in the ground in an inclined position (Vijay et al. 2004; Viresh & Javare Gowda 2002). As the fresh substrate is added from the inlet, the digestate flows toward the outlet at the other end of the tank. The inclined position makes it possible to separate acidogenesis and methanogenes in longitudinal fashion, thus producing a two-phase system. In order to avoid temperature fluctuations during the night and maintain the process temperature, a gable or shed roof is placed on top of the digester to cover it, which acts as an insulation both during day and night (Viresh Kumargoud and Venkatachalapathy 2003; Kumargoud & Tulsidas 2005; Vyas & Grewal 1983) small scale digestors can be fed with any kind of shredded biodegradable waste unlike cowdung in traditional digestors (Wyman 1994). The small-scale plug flow reactor designed for the production of biogas is shown in Figures 1 and 2. Figure 1 shows fabricated model, whereas Figure 2 shows the design model.

Methods

Production process of biogas

A plug flow reactor mainly consists of four parts: digester (bottom part), dome (top part), inlet pipe, and gas balloon. The volume of the plant is 1 m³ and is made of fiberglass. The plant working is as follows:

The slurry which is a mixture of cow dung and water in the ratio 1:10 is fed into the digester through the inlet pipe. The inlet pipe is at an angle of 45° so that the waste is inserted into the slurry and mixed properly.

In other biogas plants, much of the digested biomass feed stock is held under the metallic holder, and this phenomenon often reduced the gas storage levels significantly. So a PFR is designed in such a way that the solid biomass feedstock moves horizontally.



Figure 1 Fabricated model.

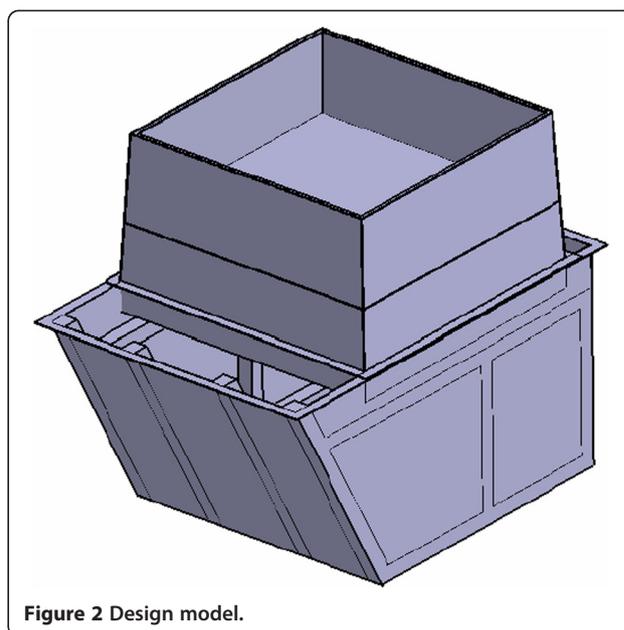


Figure 2 Design model.

Once sufficient biogas is generated, the slurry is taken out completely and a new batch of waste is introduced. Hence the wastes are fed in batches or plugs and hence the name. Such plug flow digesters for floating biomass feedstock have length to width ratio 2:1.

So, as the waste is fed, it floats on top of water in the digester. This floating tendency enables efficient biogas generation.

When the digester is partially filled with the slurry, the introduction of slurry is stopped and the plant is left unused for about 15 to 30 days which is the retention period for biogas generation.

During this period, anaerobic bacteria present in the slurry decompose or ferments the biomass in the presence of water.

When cattle feed or any organic waste is mixed with water, its liquefaction occurs and acids are produced. The methanogen bacteria then act on the acids and convert them into methane and carbon dioxide.

The top part (dome) is inserted 10 cm into the water in the bottom part so that pressure equivalent to 10 cm of water is built up for the gas to be generated. Also, the gas cannot escape out and it starts moving upwards and collects in the dome.

In the top part, a partition is provided 300 mm from the top where the balloon is placed. This is the part

Table 1 Percent of types of solids present in the feed stock

Type of feed stock	Total solids TS (%)	Volatile solids VS (% of TS)
Cow dung	8.5	80
Domestic waste	10	80

Table 2 Biogas yield respective to feed stock

Type of feed stock	Amount of slurry	Biogas yield (m ³)
Cow dung	20 kg	0.18
Domestic waste	10 kg	0.17

where the biogas gets collected. The balloon is made from polythene and has a capacity of 270 l.

A T-joint is provided in the top part which connects the two sides of the partition through a gas pipe.

One opening of the T joint is connected to the valve which is below the partition, through a gas pipe. The other opening is connected to another valve whose outlet is left open for connecting to external appliance through which the gas can be tapped out.

As the gas gets collected below the partition, the valve is opened through which biogas fills up the balloon, whereas the valve connected to external appliance is closed.

A sheet with 5 to 8 kg of weight is placed on top of the balloon so that enough gas pressure is built up and to ensure smooth gas flow without any leakage.

Simultaneously, the gas can also be tapped out through the joint and can be used for cooking purposes. During this, the valve connected to external appliance is opened and the other valve is closed.

An overflow pipe is provided in the bottom part to detect any leakage.

Once sufficient gas is generated, the slurry is taken out and fresh batch of waste is introduced into the plant.

The slurry can then be used as manure for the plants.

Results and discussion

After the digester was operational for several weeks after the initial filling, the pH value had reached the stable value of 6.5 that remained constant during the period of sampling. pH of 7 is neutral, less than 7 is acidic, and more than 7 is alkaline.

Ideal pH value is 6.5 to 7.5. Anaerobic digestion requires a neutral environment (pH around 7) for optimum

functioning. In the Bangalore environment (where plug flow reactor is operated), this will be maintained throughout the year as the variation in temperature is very less throughout the year. During the starting of the biogas plant, the slurry from other working biogas plants is added to the plant for inoculation, to obtain the desired PH value. The stable pH is obtained in this operating cycle of the working biogas.

The temperature was constant between 35 to 40 during the day and 25 to 30 during the night. Therefore, those two parameters were considered as the constants with respect to the model development. Based on our field data, those two parameters did not fluctuate significantly in Bangalore climate (Tables 1 and 2) (Figures 3 and 4).

Calculations

Calculation (cow dung)

Step-I: finding the amount of total solid (TS) in the slurry

$$TS = 8.5\% \text{ of slurry} = 0.085 \times 20 \text{ kg} = 1.7 \text{ kg}$$

Step-II: finding the amount of volatile solid (VS) in the slurry

$$VS = 0.8TS = 1.36 \text{ kg}$$

Step III: finding the biogas yield in terms of per kg of VS
The total amount of degradable material present in the VS is about 50% only.

$$\text{Thus, the VS used} = 0.5 \times 1.36 = 0.68 \text{ kg}$$

Now, 20 kg of slurry gives 0.18 m³ of biogas; alternately, 0.68 kg of VS gives 0.18 m³ of biogas. Therefore, 1 kg of VS will give 0.18/0.68 = 0.264 m³ of biogas.

Thus, the biogas yield is 0.264 m³/kg VS from Cow dung slurry.

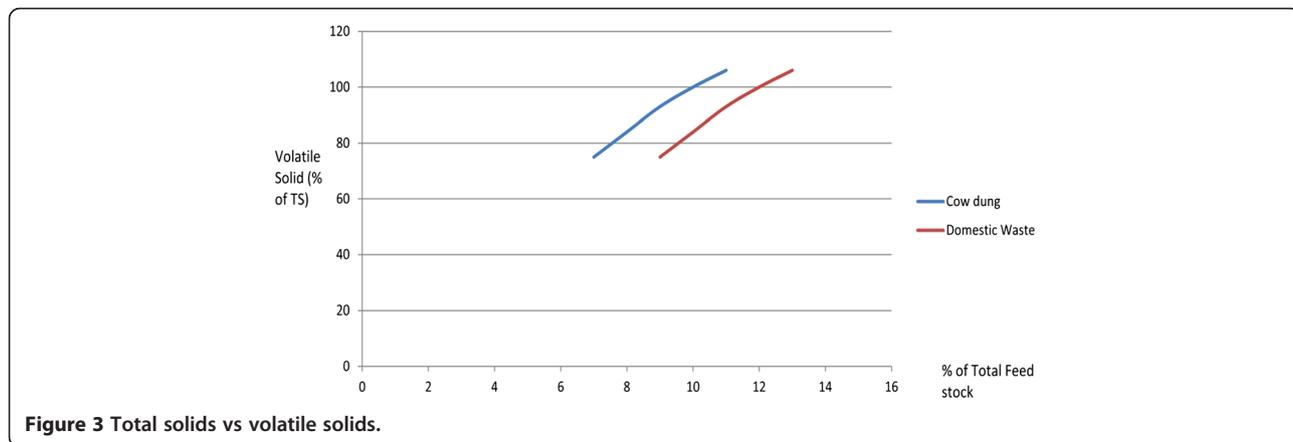


Figure 3 Total solids vs volatile solids.

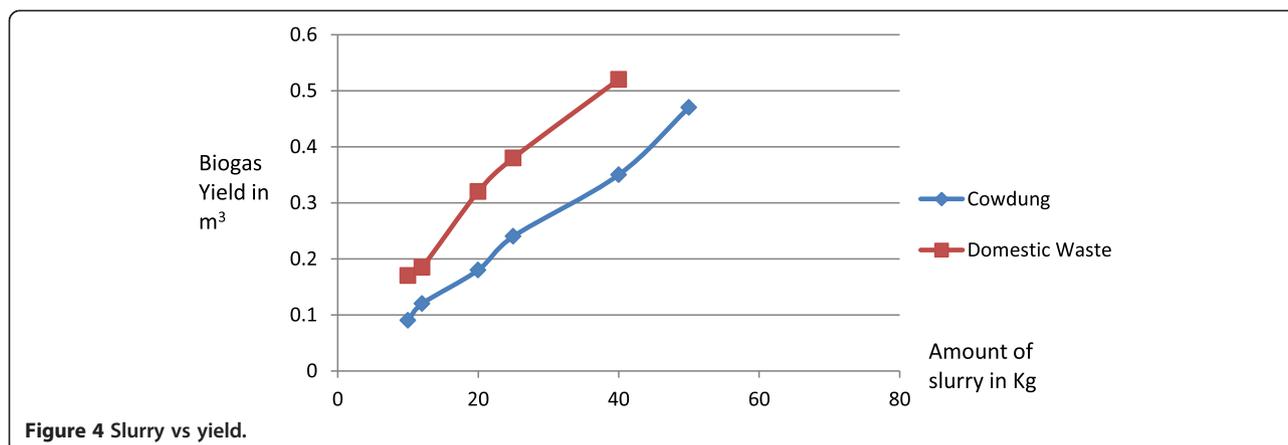


Figure 4 Slurry vs yield.

Calculation (domestic waste)

Step-I: finding the amount of TS

$$TS = 10\% \text{ of slurry} = 0.1 \times 10 \text{ kg} = 1 \text{ kg}$$

Step-II: finding the VS

$$VS = 0.8 \times TS = 0.8 \times 1 = 0.8 \text{ kg}$$

Step III: finding the biogas yield in terms of per kg of VS

The total amount of degradable material present in the VS is about 50% only.

$$\text{Thus, the VS used} = 0.5 \times 0.8 = 0.4 \text{ kg}$$

Now, 10 kg of slurry gives 0.17 m^3 of biogas; alternately, 0.4 kg of VS gives 0.17 m^3 of biogas.

Therefore, 1 kg of VS will give $0.017/0.4 = 0.425 \text{ m}^3$ of biogas.

Thus, the biogas yield is $0.425 \text{ m}^3/\text{kg}$ VS from domestic waste slurry.

Conclusions

The study proposes a better and efficient design of biogas plant which is suitable for using in houses and canteen. The biogas plant has been planned for easy usage since the maintenance of the plant is low.

The PFR biogas plant thus designed has some good features like,

1. The plant can be used in compact spaces and also transportation is easy.
2. It is easy to use and maintain since there are very less moving parts.
3. The slurry in this plant need not be stirred regularly.
4. The biogas is produced regularly in this plant.
5. Since the plant is made of fiberglass, the corrosion does not take place and this increases the life of the plant.

6. The biogas produced by this plant is enough to cook three meals daily for a family six.

Competing interests

JR: Production Engg., Renewable energy, solid waste management, biogasification. SVP: Biomass energy, Biogas slurry, biodiesel and engine characterization and simulation.

Authors' contributions

JR: Designed and fabricated the PFR digester and carried out studies on them SVP: Gave the guidelines in development of the system and helped in analysis of the results.

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