Design and Construction of Food Waste Biogas Plant for Hostel Mess

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Abstract— The extraction of energy from the biomass wastes by its anaerobic degradation with the help of various technologies adopted and will be leading to the use of renewable energy systems effectively and efficiently. In this contest one of the best methods to extract the energy from the biological wastes which includes, Kitchen wastes, Agricultural wastes; Animal wastes etc…are the installation and generation of biogas plant. The biogas released acts as an environmentally sustainable energy source. In our Institute we have two hostels and all are having their own individual mess. The each hostel having about 350 students where daily about 30 kg of kitchen waste is obtained which can be utilized for better purposes. This work is to create an organic processing facility to generate biogas which will be more cost effective, eco-friendly, reduce landfill waste, generate a quality renewable fuel and reduce carbon dioxide and methane emissions. Overall by constructing the biogas reactors in campus at the backyard of our hostels will be beneficial. Kitchen (food waste) was collected from boys hostel mess as feedstock for reactor which works as anaerobic digester system to produce biogas energy. Biogas can be used as energy source for cooking and also for numerous purposes. But any possible application requires knowledge and information about design and construction of digester to generate biogas. This work also deals with the pilot study of kitchen waste generation and fuel saving by using biogas plant in engineering college hostels of Karnataka state.

Key words: Biogas, Kitchen waste, Methane production, anaerobic digestion

I. INTRODUCTION

As the biomass extraction technologies are the basically renewable one and which decreases the dependence on the fossil fuels ones the proper technology is adopted for extraction of the energy efficiently and economically. The typical biogas is having the highest composition of Methane (50-70%) and remaining Carbon dioxide (30-50%), also small traces of some other gases, having the calorific value ranging from 21-24MJ/m^3 [1]. The main advantage of this process is that the product can be used as a cooking, vehicle fuel or for co-generation of electricity and heat, and also leads to reductions in greenhouse gas emissions. The potential can be translated to an aggregated estimated capacity of approximately 48383 million m^3 of biogas generation annually [2].The installation of biogas plant in the developing countries like India and China are started in 1970s.Currently there are 4 and 22 million biogas plants are installed in India and China respectively. The installation is not only the problem with respective to biogas generation but also its maintenance concerns increased attention towards the efficient working of biogas plants as about 50% of installed plants stops working due to lack of maintenance in many countries. There remains potential for domestic plants to utilize currently underexploited biogas substrates such as kitchen waste, weeds and crop residues.

Kitchen waste is an easily biodegradable organic matter with high moisture, carbohydrate, lipid, and protein compositions. The major limitation of anaerobic digestion of kitchen waste alone is the rapid accumulation of volatile fatty acids (VFAs) followed by a pH drop in the reactor, which inhibits methanogenic bacteria [3]. Co-digestion of Taihu algae with varying the carbon percentage, can balance the fermentation process. By the optimal mixing of co digestion of Taihu algae and kitchen waste are used to improve the yield of biogas generated. Considerable increase in the biogas can be obtained by adjusting C/N ratio of 15:1 yields to maximum biogas yield up to 2003.7Ml and which id 33.3% higher than Taihu alone. Increasing the concentration of Kitchen waste in mixed substrate will increases the concentration of VFA. Thus co- digestion mode promotes the enzymes activity more and increasing the yield of fermentation process **[**4**].** The suitability of using synthetic kitchen waste (KW) and fat, oil, and grease (FOG) as co substrates in the anaerobic digestion of waste activated sludge (WAS) was investigated using two series of biochemical methane potential (BMP) tests. The range of substrate to inoculums (S/I) ratio is found to be for the FOG (0.25–0.75) and KW (0.80–1.26) as single substrates in the first experiment. The optimized test concluded that the FOG and KW positively affects the methane production and in turn will affect the yield of biogas production thus ideal ratio is found to be 1.20 and 0.46 respectively. Co-substrate effectively decreases the Lag-phase of a co-digestion [5]. Every year natural biodegradation of the natural biodegradation of organic matter under anaerobic conditions is estimated to release 590–800million tons of methane into the atmosphere [6]. This large quantity of biogas generation will differentiate the anthropogenic anaerobic bacteria which recovers the energy within the biogas plant. Now days it is not only a task of obtaining highest efficiency of degradation of organic substrates but also providing the organic fertilizers [7,8].The kitchen waste contain high-nitrogen components, and thus the generation of high concentration of ammonia nitrogen is inevitable [9]. Agricultural residues, co-digestion is considered more cost effective than pretreatments. Addition of nitrogen-rich substrates such as animal manure could balance the combustion of carbon-rich biomass (e.g., rice straw) and further increase the biogas yield and volumetric biogas production rate [10]. The small scale kitchen waste biogas plants [11] and (ARTI) Appropriate Rural Technology Institute type biogas plants has been already developed and using for the energy [12]. But the 4 m^3 capacity dome type biogas plant for the kitchen waste is rarely used.

II. METHODOLOGY

Biogas is produced by bacteria through the bio-degradation of organic material under anaerobic conditions. Natural generation of biogas is an important part of bio-geochemical carbon cycle. It can be used both in rural and urban areas.

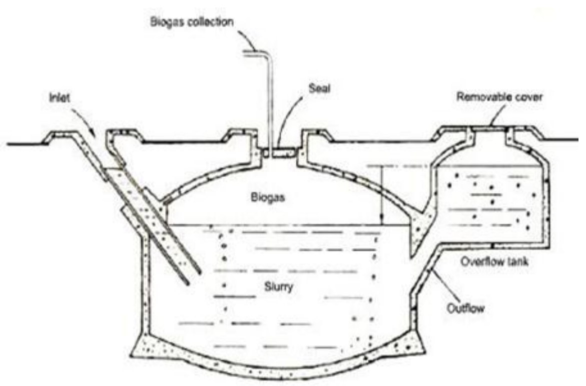

Fig. 1: Model of dome type biogas digester

The feedstock is collected from the hostel mess and transported to plant. The required quantity of feedstock and water is mixed in the inlet tank and the slurry is discharged to the digester vessel for digestion. The gas produced through methanogenesis bacteria in the digester is collected in the dome. The digested slurry flows to the outlet tank through the manhole. The slurry then flows through the overflow opening in the outlet tank to the compost pit. The gas is supplied from the dome to the point of application through a turret and pipeline. When a biogas plant is underfed the gas production will be low; in this case, the pressure of the gas might not be sufficient to fully displace the slurry in the outlet chamber. It is important to design the plant keeping hydrostatic pressure higher at the inlet tank than the outlet tank. The hydrostatic pressure from slurry in the inlet and outlet tanks will pressurize the biogas accumulated in the dome. If too much material is fed into the digester and the volume of gas is consumed, the slurry may enter the gas pipe and to the appliance.

A. A Typical Biogas System Consists Of The Following Components:

1) Manure collection: As we are constructing the biogas plant for kitchen waste, the waste food collecting in the hostel mess is stored and transported to the site for feeding
2) Anaerobic digester: The digester in form of dome is the anaerobic digester or reactor. This is constructed by following the guidelines and using the design dimensions
3) Effluent storage: After the digestion the slurry coming out of the digester is the rich fertilizer, this is stored in the compost pit provided at the outlet of the digester. Later that can be transported to the fields
4) Gas handling: The generated biogas is stored in the dome and at the top, the biogas trap hole is provided. From the trap hole the flexible pipe line is connected up to the kitchen, where it is connected to the biogas stove for cooking food.
5) Gas use: The biogas is having the different applications such as domestic cooking, lighting and for internal combustion engines.

III. DESIGN AND CONSTRUCTION OF BIOGAS PLANT

A. Design Calculations:

1) Gas production rate G: One kg of kitchen waste (undiluted) if digested well, yields about 0.24m^3 of gas. The gas production rate G for the available waste thus given as

$$G = 0.24W \qquad (1.1)$$

Where W = 30 kg/day

2) Active slurry volume Vs: The active slurry volume in the digester is directly related to the HRT chosen and is given by

$$V_s = HRT\,\frac{2W}{1000} \qquad (1.2)$$

Taking *HRT* = 50days

3) Calculation of H and D: There is no strict rule for the relative values of H and D, but usually a D/H ratio 2.0 is used in practice. Knowing the active slurry volume from above calculation, H can be calculated from equations.

$$\frac{\pi}{4} \times D^2 H = V_s \quad \text{Herein } D = 2H \qquad (1.3)$$

4) Slurry displacement inside digester d: The selection of a suitable value of d depends upon gas usage pattern. If the total cooking time is about 3 hours, the variable gas storage volume V_{sd} is obtained from equation

$$\frac{3}{24} G + V_{sd} = 0.5G \qquad (1.4)$$

This after simplification leads to

$$V_{sd} = 0.375G \cong 0.4G \qquad (1.5)$$

d is then obtained as

$$\frac{\pi}{4} D^2\, d = V_{sd} = 0.4G \qquad (1.6)$$

$$D = \frac{H}{2.5} \times 0.4 \qquad (1.7)$$

5) Slurry displacement in the inlet and outlet tanks h: The maximum pressure attained by the gas is equal to the pressure of the water (slurry) column above the lowest slurry level in the inlet/outlet tanks. The pressure usually selected to be 0.85 m water gauge as a safe limit for brick.

i.e., $h + d = 0.85 \qquad (1.8)$

6) Length l and breadth b of the inlet and outlet tanks: Usually a rectangular shape with $l = 1.5b$ is selected. If the inlet and outlet cross sectional areas are selected to be identical we get.

$$2 \times l \times b \times h = V_{sd} = 0.4 \qquad (1.9)$$

Substituting $l = 1.5b$

$$b = \left(\frac{0.2G}{1.5h}\right)^{\frac{1}{2}} \qquad (2.0)$$

7) Calculation of the dome height d_h: The volume of the sphere (dome) is given by

$$V_d = \frac{\pi}{6} d_h [3(\tfrac{D}{2})^2 + {d_h}^2] \qquad (2.1)$$

The total volume of the gas space, as mentioned earlier is taken as equal to G. As the slurry or gas volume V_{sd} is already fixed as 0.4G, the remaining gas space volume, which is the volume of some, will be equal to (G-0.4G)

$$0.6G == \frac{\pi}{6} d_h [3(\tfrac{D}{2})^2 + {d_h}^2] \qquad (2.2)$$

d_h can be obtained by solving the above equation

8) Radius of dome r: The radius is obtained by the equation

$$r = \frac{(\frac{D}{2})^2 + d^2{}_h}{2d_h} \qquad (2.3)$$

9) Calculation for H^1 for curved bottom digester: For digester with curved bottom, the bottom portion is identical to the dome. H^1 is then obtained from the equation

$$G\frac{\pi}{4}D^2H^1 + 0.6G \quad (2.4)$$

or $$H^1 = \frac{H}{2.5} \times 1.9 \quad (2.5)$$

10) Other dimensions: The size of the inlet and outlet openings (also called boxes) in the register normally 0.6m×0.6m for digester of any capacity. This size is selected so that man can go inside during the construction period. The digester wall is 230mm thick and the walls of the inlet and outlet boxes are 115mm thick. For curved bottoms, two brick layers are provided, the lower layer being 115 mm thick and upper layer 75 mm thick. Concreting, whether lain or reinforced should be 100mm thick.

Parameter	Value	Parameter	Value
G	7.2 m^3/day	h	0.564m
V_s	18m^3	b	1.304m
H	1.789m	l	1.956m
D	3.578m	d_h	0.806m
d	0.286m	r	2.388m
H^1	1.359 m		

Table 1: Design Parameters

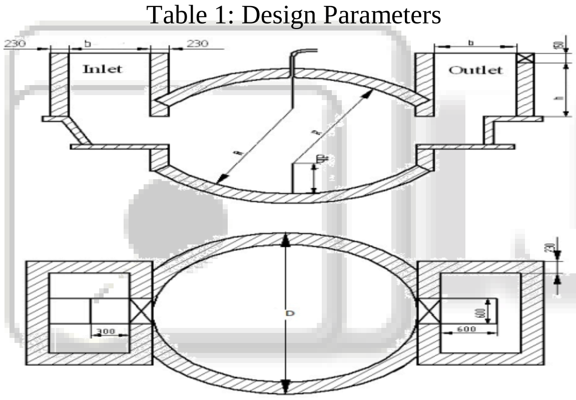

Fig. 2: Design Layout with calculated dimensions

B. Construction:

1) Plant Layout:

Construction work starts with the process of layout works. This is the activity carried out to mark the dimensions of the plant in the ground to start the digging work. After completion of layout work, the work for digging the pit has to be started. Tools like crow-bar, picks, spade, shovel and basket can be used.

Fig. 3: Plant layout and Excavation works

The digester foundation is placed using cobblestones and/or gravel as aggregate then filled with concrete or plain cement. The foundation should be 15 cm thick. The spherical (dome-shaped) gas holder has to be constructed by the method as shown in the fig 4. The plastering the wall and the dome are carefully carried out by experienced person. The queering is required for the 21 days; afterwards the feedstock is fed to the digester

Fig. 4: Construction work

The completed biogas plant is shown in the fig.5 and the flame is coming from the stove.

Fig. 5: Completed biogas plant and flame from burner

Materials	Quantity	Materials	Quantity
Bricks	1500 Nos	Cement	8 bags
Stone chips	30 cu. ft	Sand	60 cu,ft
Coarse sand	60 cu. ft	GI pipe ½" dia with socket	7 inch
Ac pipe 6" dia	6 ft	Iron bars 6mm dia	20 kg
Hose pipe	1 No	Biogas Stove	1 No

Table 2: Materials Used For the Construction

IV. RESULTS AND DISCUSSION

Analysis of biogas produced in the reactor

A. Syringe Method:

Syringe method was used for the measurement of amount of methane and carbon dioxide in gas produced. A syringe fitted with flexible tube and dilute sodium hydroxide (NaOH) solution was used for carbon dioxide percentage estimation, since NaOH absorbs CO_2 but does not absorbs methane.

B. Procedure Followed:

1) Prepare 100 ml of dilute sodium hydroxide solution by dissolving granules of NaOH in about 100 ml of water.
2) Take 20-30 ml sample of biogas produced during experiment into the syringe (initially fill syringe with H_2O to reduce air contamination) and put end of the tube into the NaOH solution, then push out excess gas to get a 10 ml gas sample.
3) Now take approximately 20 ml of solution and keep the end of the tube submerged in the NaOH solution while shaking syringe for 30 seconds.
4) Point it downwards and push the excess liquid out, so that syringe plunger level reaches 10 ml. Now read the volume of liquid, which should be 3-4 ml indicating about 30-40% of gas absorbed so we can say that balance of 55-65% is Methane.

5) If the flame does not produce properly then the methane is less than 50% (a reading of less than 5 ml of liquid) it is having Nitrogen or some other gas present.

C. Composition of Biogas:

- Methane 55 - 65%
- Carbon dioxide 30 - 40%
- Nitrogen 2 - 3%
- Water vapor 0.5%

The test of biogas is carried out by using bottle as the digester because it is difficult to test behavior of the biogas in the large digester

From the result it has been seen that in set2 which contain kitchen waste produces more gas, compare to other two set. In set2 with kitchen waste produces average 250.69% more gas than set 1 (with 200gm cow dung) and 67.5% more gas than set 3 (with 400gm cow dung). Means kitchen waste produces more gas than cow dung as kitchen waste contains more nutrient than dung. So use of kitchen waste is the more efficient method of biogas production

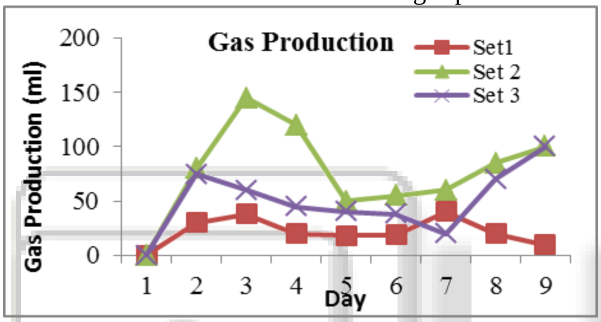

Fig. 6: Gas production v/s Day

Graph Analysis fig 6- It can be seen from the graph that gas production increases first up to day 3 but then it starts decreasing as acid concentration increases in the bottles and pH decreases below 7 after 4-5 days water was added to dilute which increases the pH, gas production again starts increasing. Therefore, we can infer that acid concentration greatly affects the biogas production.

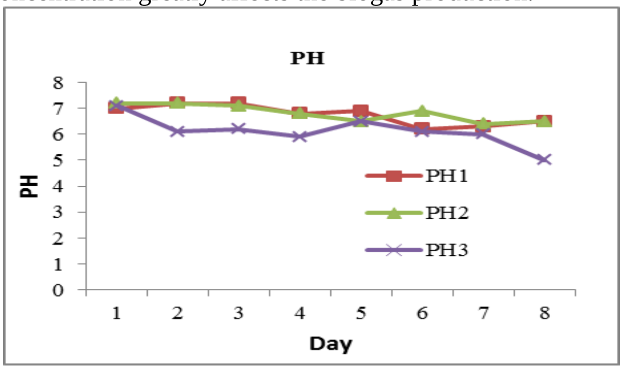

Fig. 7: PH v/s Day

Graph Analysis fig 7– This graph shows that first the ph is on higher side, as reaction inside the bottles continues it stars decreasing and after day 3 it becomes acidic. Then water added to dilute and thus pH increases.

V. Conclusion

The concept of kitchen waste utilization in a fixed dome biogas plant for biogas Production offers effective Waste Management and Resource Development solutions with positive measures for the economy, improved air quality and sustained energy security.

It is interesting to note that in our study it was found that, the average daily biogas production per kg of dry kitchen waste is $0.035m^3$/day. So by using the 10 days biogas will be equivalent to consumption of 1 day LPG in the 350 capacity hostel.

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