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(Full length research article)

Use of Compact Biogas Plant for Biogas Production Utilizing Waste Food Materials, Fruits, and Vegetable Peelings of High Calorific Contents

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Abstract

In order to study the efficiency of compact biogas plant, two experiments taking waste food materials and vegetable peelings (cooked stale rice, flour, peelings of pineapple and potato) were conducted. Before initiating the experiment and to quicken the digestion process, dung slurry was inoculated in the plant digesters. In Experiment I, stale cooked rice, potato peelings, pineapple peelings and their mixture (1:1:1) were used. In Experiment II, waste flour obtained from flour mills and potato peelings were used as the feed stocks and the experiment was completed in 28 days. Feed stocks were blended using a blender and mixed with water before using in the experiments. Studies have revealed that production of biogas was higher when stale cooked rice (0.60 m^3) was used as the feedstock, followed by potato peelings (0.44 m^3), pineapple peelings (0.32 m^3) and the mixture of these three feedstocks (0.21 m^3). The yield of biogas from waste flour remained low and the values ranged between 0.01 to 0.04 m^3. Studies have further revealed that during cooking no soot was observed and the flame appeared to be blue, indicating that the biogas generated contained more Methane. Experiments on the heating potential of the biogas indicated that heating potential of potato peelings was higher, followed by those of pineapple peelings, stale cooked rice and waste flour. Further, heat values of the biogas of different feedstocks was calculated and it was observed that the heat value of stale cooked rice was higher (0.0922 m^3/day/Kg) than those of potato peelings, and the mixture of the feed stocks. Heat values of the biogas of flour remained lower. The liquid effluent, the slurry dispersed from the compact biogas was tested in the field for its nutritive value as organic fertilizer. Studies have shown that slurry could be utilized as a fertilizer. Its use as fertilizer resulted in high growth of tomatoes, dalo, cabbage, eggplants, capsicum and also of indoor ornamental plants

Keywords: *Biogas, Waste food, Calorific value*

1. Introduction

Fossil fuels (like coal, gas and petrol etc.) are the largest emitters of greenhouse gases such as carbon dioxide and methane which are negatively impacting the ozone layer, a protective cover above the earth that is essential for the survival of all species. Further, these greenhouse gases are also responsible for global warming and climate change. With the modernization of our society, our demands for energy are increasing with every passing day. Over exploitation of fossil fuels is fast and thus leading to their depletion, as fossil fuels are non-renewable in nature. However, the time required for generation of fossil fuels is millions of years. So, there is not enough scope to renew the sources of fossil fuels and therefore, it is high time that we start thinking and look out for some renewable sources of energy that can be used as an alternative to fossil fuels. Therefore, in order to reduce the emissions of green house gases (cabon dioxide, methane and nitrous oxide), we must adopt some mitigation measures and identify some alternative renewable energy resources like wind, water, steam, solar and biomass. The most abundant of all these appears to be the availability of wastes/biomass (Nag et.al., 1985 and Maheshwar *et.al.*, 1987) emanated from a variety of sources such as wastes obtained from agriculture (Chowdhary *et al.*, 1984 and Dar and Tondon, 1987),forestry residues , sugarcane industry, industrial

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wastes(Ranade *et.al*.,1987) , liquid wastes, municipal solid waste (Murphy and Keogh, 2004) , sewage, black liquor and finally animal wastes whose disposal is becoming problematic, but they are of great sources of biogas (Garg and Prasad, 2010; Prasad,2010).

The government of Fiji has implemented the National Energy Policy 2006 -2011 to reduce the countries dependence on fossil fuels. One of the major areas targeted is the development of the renewable energy technologies. Fiji has an agricultural based economy; hence most products are agricultural in nature. Agricultural waste is utilized to produce biogas however only animal waste biogas systems are used and Fiji has potential to develop 10,000 biogas plants, according to a report by a South African Energy firm (AGAMA,2006 a,b)) specializing in biogas systems. The cost of installing one dome shaped biogas plant is $10,000 and takes about 4 weeks to complete.

The discovery of biogas plants (GATE, 1989; Maheshwar *et al.*, 1989) has lead to the use of cattle dung. But due to many problems and difficulties associated with their installation/functioning, like disposal of slurry (digestate), installation, space occupancy and requirements of huge quantity of feed stocks required for feeding the digesters has led to the development of an easy to operate compact biogas plants by Appropriate Rural Technology Institute of India (Karve, 2009). In these Compact biogas plants food sources of high calorific value could be used which produces biogas with high methane contents through the process of methanogenesis thus replacing the current practice of using wastes of low caloric contents like cattle dung, distillery effluents, municipal solid waste or sewerage effluents, which produces methane on fermentation in conventional biogas plants. Further, the methane produced through compact biogas plants was observed to be more pure than the biogas produced from animal wastes (See table1 for comparison). In the present studies, we assessed the quantity of biogas produced when i) cooked stale rice, waste flour, potato and pineapple peelings or their mixture was fed to the compact biogas digesters, ii) we had also tried to investigate the heat value of the gas generated from these feedstuffs, iii) efforts were also made to assess the nutritive value of the slurry by using it as a fertilizer for growing the seedlings of a variety of vegetable and indoor ornamental plants.

2.1 Materials and Methods

Experiments on biogas production using Compact biogas plant were conducted in the biogas facility of the School of Mechanical Engineering, College of Engineering, Science and Technology, Samabula, Fiji National University, Suva, Fiji. The Compact biogas plants used in the studies were installed outside the workshop of the College, hence exposed to ambient day length and temperature conditions. These compact biogas plants were provided by the Department of Energy, Suva, Fiji to CEST, FNU.

Structure of the compact biogas plant (see Fig. 1)

The Compact Biogas Plant facility consists of Two PVC water tanks (one bigger than the other), with the top of each tank is cut open so that the smaller one can fit into the bigger tank and move like a “telescope“. The bigger tank (or drum) serves as a digester, and the smaller, placed upside down in the bigger one serves as the gas holder.

The inlet flexible pipe, a bit longer than the height of the tank, is fitted at the bottom side of the bigger tank. At the free extremity of the pipe, a funnel is fixed to facilitate the pouring of fluid feedstock material. The pipe with the funnel is fixed loosely to the top of the tank, in upright position. The effluent outlet is fitted to the upper part of the bigger tank and determines the maximum level of matter in the tank. The gas outlet is fitted to the smaller inner tank and directed toward a gas stove.

A frame structure is built above the tanks to hold the gas tank in position to prevent these from tilting or falling when full of biogas.It is possible to put a weight on the upper tank to increase gas pressure in the tank.

Experimental procedure/protocol

Before initiating the studies, the digesters of the compact biogas plant were charged with fresh cow dung and water in the ratio of 1:5 and the mixture was thoroughly stirred and allowed to ferment for two weeks.

The waste feed stocks used in the studies (Experiment I and II) , were blended in a mixer grinder, and mixed with tap water (see tables 2 and 3 for details of the type of feed stocks and the quantity of each feed stock used daily in the digesters) and fed to the digesters through the inlet pipes. This procedure was adopted for all the feed stocks used in the studies. A total of two experiments were conducted.

Experiments I. a & I. b

This experiment was initiated on April 1, 2010 and terminated on May 14. In this experiment, both 100 liter capacity and 500 liter capacity digesters were used (Table 2).

In experiment I a , only 100 liter capacity digesters were used and the following three feed stocks or their mixture each in replicate of four were used.

i) Stale cooked rice: The left over stale cooked rice were collected from the hotels/restaurants. Biogas production from this feedstock was recorded for 13 days.

ii) Potato peelings: Collected daily from the canteen operators of Fiji National University and Biogas production was recorded for 15 days.

iii) Pineapple peelings: Collected from the dealers/sellers from the market. Biogas production was recorded for 19 days.

iv) Mixed feedstock (stale cooked rice +potato peelings+ Pine apple peelings, (in the ratio of 1:1:1).

In experiment I. b, a 500 liter capacity digester was used and only the mixed feedstock was used. Feed stock was tested in replicate of four. Biogas production was recorded for 19 days.

In experiment I a and I b, feed stocks were fed twice a day, once in the morning (between 09:00-10:00-h) and (then in the afternoon at 16:00 h). Production of biogas, *vis a vis* the height of the drum was recorded daily in the morning before adding another installment of the feedstock.

Experiment II

This experiment was initiated on May 23 and terminated on June 19, 2010, i.e., at the end of 28 days. In this experiment only a 500 liter capacity digester was used and the following two feed stocks each in replicate of two were used (see Table 3).

i) Potato peelings: Collected daily from the canteen operators of Fiji National University

ii) Waste flour: Samples were collected from the Fiji Flour Mills. The flour was a mixture of the left over (spillage) flour, which included a mixture of flour of wheat, corn and cassava.

In this experiment II, the digesters were fed daily (See table 3 for details of the loading rate of each feed stock). Digesters were fed only once a day with the feedstock at 24 hour interval between 12-1.0 PM

1. Calculation and recording of volume of biogas produced:
In order to calculate the volume of gas produced, rise in the height of drum was recorded daily using a measuring tape and calculated as follows:

Volume of Gas (m^3) = π X [Radius (m)]^2 X height of gasholder (m)

Volume of Gas (L) = Volume of Gas (m^3) X 1000

2. Use of the Liquid Slurry as fertilizer: The liquid slurry produced was collected and used as an organic fertilizer to fertilize the growing seedlings of some vegetables and indoor ornamental plants.

3. Heat Value of the biogas generated by Compact Biogas Plant: The heat value of the biogas was determined and measured as follows

One liter of tap water was taken in an aluminum pot. Initial temperature of the water was noted using a centigrade thermometer. The gas stove was ignited and the water was heated the final temperature of water was recorded. The initial and final heights of the gasholder were also noted. The heating experiment was repeated five times.

The specific heat capacity of the water was taken as 4.187 KJ/kgK. The temperature was converted to Kelvin by adding 273.15K to degrees Celsius reading to use in calculating the heat value.

4. Calculation of Methane contents of the biogas

The methane contents of the Biogas generated using compact biogas plant was calculated using the following formulas

- Change in temperature = Final Temperature(T_f) – Initial Temperature (T_i)
- Heat Value (KJ), Q = MC(T_f-T_i), where M = mass in kg, C = 4.187 KJ/kgK, T_f-T_i in Kelvin
- To change ˚C to Kelvin, add ˚C+273.15 to convert to K
- Volume of Gas(m^3) = π * [Radius (m)]^2 * height of gasholder(m)
- Volume of Gas (L) = Volume of Gas (m^3) * 1000

Heat Value (MJ/m^3) = Heat Value (KJ)/Volume of Gas(m^3)/1000

Fig. 1Photo showing compact biogas plant set up , 500 liters

Table 1 Comparison between conventional biogas system and compact biogas system

Comparison is based on equal volume of methane generated for each system	Conventional Biogas System	Compact Biogas System
Amount of required feedstock	40kg +40 liters water	1-1.5 kg +15 liters water
Nature of required feedstock	Dung	Any sugary and starchy materials
Amount and Nature of slurry to be disposed off	80 liters sludge	15 liters. Watery
Reaction time for full utilization of feedstock	40 days	48-72 hours
Standard size for household	4-8 cubic meters	1-1.5 cubic meters
Methane content by weight	25%	60%
Operation	Skilled person	Any individual can operate
Slurry	Sludge	Watery
Expenditure on construction	Expensive	Cheap
Flame	Orange flame	Invisible bluish flame
Source: Karve, A., 2009. Accessed on www.arti-india.org		

Table 2 Types of feed stocks and quantity used in the studies
(Experiment I)

Type of Feedstock	Daily Amount of Feeding for 100 liter Biogas Digester	Daily Amount of Feeding for 500 liter Biogas Digester
Cooked stale Rice	100g +1 litre water	-
Potato Peelings	100g +1 litre water	-
Pineapple Peelings	100g +1 litre water	-
Mixture (Cooked stale rice, Potato and Pineapple peelings),	100g +1 litre water	500g + 4 litres water

Table 3 Types of feed stocks and quantity used in the experiment
(Experiment II)

Days of Feeding the digester	Quantity of Waste Flour+ water	Quantity of Potato Peelings+Water
1.	200g +1.5litres water	200g +1.5litres water
2.	200g +1.5litres water	200g +1.5litres water
3.	300g + 2.25litres water	300g + 2.25litres water
4.	400g + 3litres water	400g + 3litres water
5.	500g + 3.75litres water	500g + 3.75litres water
6.	600g + 4.5litres water	600g + 4.5litres water
7.	700g + 5.25litres water	700g + 5.25litres water
8-28	400g + 3litres water	400g + 3litres water

Fig.2 Sowing cabbage plant grown in plastic bottle and fertilized using compact biogas plant slurry

Fig.3 Photo Showing Dalo Plants fertized with slurry (1 month old Dalo plant)

Fig. 4 Photo showing Tomatoes grown using compact biogas slurry

Table 4 Mean height of the gasholder and the quantity of biogas produced daily when 100 L and 500 L capacity Compact Biogas Digesters were used

Days of observation	100 litre Compact Biogas Digester								500 litre Compact Biogas Digester	
	Stale Rice Feedstock		Potatoe Peelings Feedstock		Pineapple Peelings Feedstock		Mixed Feedstock (I)		Mixed Feedstock (II)	
	Daily Height of Gasholder (m)	Daily Volume of gas produced (m³)	Daily Height of Gasholder (m)	Daily Volume of gas produced (m³)	Daily Height of Gasholder (m)	Daily Volume of gas produced (m³)	Daily Height of Gas holder (m³)	Daily Volume of gas produced (m³)	Daily Height of Gasholder (m)	Daily Volume of gas produced(m³)
1	0.07	0.12	0.02	0.04	0.01	0.02	0.02	0.03	0.04	0.03
2	0.16	0.26	0.07	0.12	0.02	0.04	0.04	0.06	0.07	0.03
3	0.26	0.43	0.09	0.15	0.03	0.06	0.06	0.09	0.09	0.04
4	0.33	0.56	0.13	0.21	0.05	0.08	0.08	0.14	0.12	0.06
5	0.38	0.64	0.16	0.28	0.06	0.1	0.11	0.18	0.14	0.07
6	0.41	0.69	0.19	0.33	0.07	0.12	0.13	0.22	0.15	0.08
7	0.41	0.69	0.25	0.42	0.09	0.15	0.15	0.25	0.16	0.08
8	0.43	0.72	0.29	0.5	0.12	0.2	0.16	0.27	0.17	0.08
9	0.43	0.73	0.32	0.54	0.15	0.25	0.19	0.32	0.18	0.09
10	0.43	0.72	0.29	0.49	0.14	0.24	0.28	0.47	0.21	0.11
11	0.43	0.73	0.32	0.54	0.19	0.32	0.31	0.53	0.23	0.12
12	0.43	0.73	0.35	0.59	0.2	0.34	0.35	0.58	0.25	0.13
13	0.43	0.73	0.37	0.63	0.25	0.42	0.38	0.64	0.29	0.15
14			0.41	0.7	0.29	0.49	0.4	0.67	0.3	0.15
15			0.42	0.71	0.34	0.58	0.42	0.7	0.32	0.16
16			0.45	0.76	0.35	0.59	0.43	0.72	0.35	0.18
17					0.4	0.68	0.41	0.7	0.36	0.18
18					0.4	0.68	0.41	0.7	0.38	0.19
19					0.41	0.7	0.41	0.7	0.4	0.21
Mean + SD	0.35 ± 0.12	0.60 ± 0.20	0.26 ± 0.13	0.44 ± 0.23	0.19 ± 0.14	0.32 ± 0.24	0.25 ± 0.15	0.42 ± 0.26	0.22 ± 0.11	0.21 ± 0.06

Mean temperature during the experimental period fluctuated between 28˚C ~ 32˚C.

Table 5 Mean height of the gasholder and the quantity of biogas produced daily when 500 litre capacity Compact Biogas Digester was used (Experiment II)

Day	FEEDSTOCKS			
	Waste Flour		Potato Peelings	
	Mean Daily Height of Gasholder (m)	Mean Daily Volume of gas produced (m^3)	Mean Daily Height of Gasholder (m)	Mean Daily Volume of gas produced (m^3)
1.	0.05	0.04	0.02	0.01
2.	0.03	0.02	0.03	0.02
3.	0.03	0.02	0.03	0.02
4.	Gas released			
5.	0.07	0.04	0.01	0.00
6.	0.02	0.01	0.02	0.01
7.	0.02	0.01	0.02	0.02
8.	0.02	0.01	0.01	0.01
9.	0.07	0.05	0.05	0.04
10.	0.03	0.02	0.03	0.03
11.	0.03	0.02	0.02	0.02
12.	0.04	0.03	0.03	0.02
13.	0.12	0.09	0.07	0.06
14.	0.08	0.06	0.02	0.01
15.	0.05	0.03	0.05	0.04
16.	0.05	0.04	0.06	0.04
17.	0.06	0.04	0.06	0.05
18.	0.07	0.05	0.04	0.03
19.	Gas released			
20.	0.07	0.05	0.01	0.01
21.	0.07	0.06	0.03	0.03
22.	0.06	0.04	0.06	0.04
23.	0.06	0.04	0.05	0.04
24.	0.06	0.05	0.05	0.04
25.	0.06	0.04	0.05	0.03
26.	0.04	0.03	0.04	0.03
27.	0.05	0.04	0.04	0.03
28.	0.05	0.01	0.05	0.01
Mean + SD	0.05 ± 0.03	0.04 ± 0.02	0.03 ± 0.02	0.03 ± 0.01

Mean temperature during the experimental period fluctuated between 28˚C ~ 32˚C.

3. Results

Experiment 1 (Table 4)

Volume of biogas produced

Studies have revealed that the daily gas production in a 100 liter digester ranged between 0.12-0.73 m^3 (mean 0.60 ± 0.20 m^3) when stale cooked rice were used as the feed material. Potato and pineapple peeling yielded 0.04-0.76 m^3 (mean 0.44 ± 0.23 m^3) and 0.02-0.70 m^3 (mean 0.32 ± 0.24 m^3) respectively. When the mixture (Mixture 1(of these three feed stocks were fed to100 liter digesters, the volume of gas production ranged between 0.03-0.7 m^3 (mean 0.42 ± 0.26 m^3). When the mixture (Mixture 2) was fed in a 500 liter digester the gas production ranged between 0.3-0.21 m^3 (mean 0.21 ± 0.06 m^3).

Experiment II (Table 5)

Volume of biogas produced

When waste flour was used as the feed stock, biogas production values ranged between 0.01 to 0.09 m^3 (mean 0.03 ± 0.01 m^3). Use of potato peelings yielded 0.01-0.04 m^3 (mean 0.03 ± 0.01 m^3) biogas.

Use of Slurry as a fertilizer

The slurry consisted of watery blackish liquid. It was easy to handle with very less offensive smell. This was utilized as an organic fertilizer for dalo, chillies , cabbages, tomatoes, egg plants, and also for indoor ornamental plants. Luxuriant growth of all seedlings was observed and most of the plants were seen flowering and fruiting (Fig 2-4).

Heat Value of Biogas generated by Compact Biogas Plant

The heat value generated was measured and it was observed that the heat value of different feed stocks was in the following order:

Potato peeling > pineapple peelings> stale cooked rice> mixture of feedstock and flour

Heat value of biogas of different feedstock's used in compact biogas plant (MJ/kg)

Starch	Stale cooked rice	Potato peelings	Pineapple peelings	Mixture of feed stocks
18.2	18.69	23	19.85	18.29

Discussion

Generation of biogas

Studies have demonstrated that with the use of feedstock's containing starchy or sugary material high volume of biogas through the use of compact biogas can be produced.

Studies have further revealed that the volume of biogas produced through the use of flour and potato peeling in experiment II was low even though the amount of feed stocks fed daily to the digesters were higher than those used in experiment I. It may be due to the fact that in Experiment I, the feed stock s were fed to the digesters twice a day (morning and afternoon) compared to only once a day as has been done in Experiment II. It appears that for proper fermentation or the reactions to proceed at a steady state, addition of feed stocks in digesters in small installments is better than adding the large amount of the feed stock in the digesters in one installment.

These results are similar to those reported by Tafdrup, (1994) who had indicated that considerable increases in gas production may primarily be due to co-digestion of the manure with organic wastes.

Karve the originator of compact biogas technology in India has postulated that 2kg of feedstock produces about 500g of methane. This equates to 0.3743m3/kg/day. According to our observations (see table 3),the mass of biogas produced with the use of stale cooked rice is equal to about 62g, potato peeling 38g, mixture of Feedstock 30g, pineapple peelings 28g, while with the flour,it was the least. This trend appears to be similar to the volume of gas produced by Karve. Since density = mass/volume. The density of methane at normal temperature (20°C) and pressure is 101 kpa. If Karve's findings are used for comparison it indicates that the stale cooked rice generated about 25% methane, potato peelings generated 15% methane, mixture of feedstock generated 12% methane, pineapple peelings generated 11% methane and flour generated about 10% methane, compared with the findings of Karve, i.e. 0.3743m3/kg/day.

Lower methane contents in our experimental feedstocks may be attributed to a variety of reasons. Our feed stocks were different and perhaps had low calorific value than those used by Karvey. Further, the ambient temperature (28ºC ~ 32ºC) at which we conducted the experiments may not be sufficiently high, for accelerating the process of fermentation, as it occurs best at high temperatures (near 40 ºC).

These studies, have clearly demonstrated that by using feedstock's of high calorific contents, microbes are able to work efficiently and the process of fermentation/ methanogenesis is enhanced resulting in the generation of biogas with high methane contents. .

Use of slurry as an organic fertilizer

Our studies have clearly established that the liquid effluent dispersed from the compact biogas plants can be used for kitchen gardening for growing a variety of vegetable crops and indoor ornamental plants. Studies have shown a luxuriant growth of all seedlings and the vegetable plants were seen bearing flowers and fruits, indicating that the slurry from compact biogas plants can be a good source of organic fertilizer like the slurry produced from the conventional biogas plants which use animal wastes as the feedstock for the digesters. The advantage in the use of compact biogas lies in the fact that the amount of slurry produced through compact biogas plant is small and hence easily manageable for using in kitchen gardens. On the other hand the slurry obtained from the conventional biogas plants is large enough and have to be transported to long distances for using in the agricultural farms.

Further, the space requirements for compact biogas system are only about 4 cubic meters and require only a few kilograms of feedstock, and the disposal of effluent slurry per day is only less than 2-5 liters (Anonymous, 2007).

According to Tafdrup (1994), the effluent of compact biogas plant is nutritionally defined fertilizer that supplies fresh manure.

From the point of view of the conversion of feedstock into methane (as developed by the ARTI technology), it is 20 times more efficient than the conventional system. Also, looking at the reaction time it is 40 times efficient. Hence, the new system appears to be 800 times more efficient compared with the conventional biogas system.

Further, the operating procedures are simple, easy and more advantageous.

Conclusions

Using compact biogas plants, a number of benefits can be derived, these are namely:

- Utilization of kitchen waste for biogas generation – By using kitchen waste as a source of biogas, there will be a reduction in the volume of household garbage. IF CBP is installed and operate in large number of households, it will only require lesser area for landfill.
- Reduced dependence on imported fossil fuel like LPG. Utilization of slurry for gardening – Because of the reduced volume of slurry generated from CBGP, it can be easily managed and used in households for using in kitchen gardening.
- Since CBGP are simple to use and fabricate, therefore, the design can easily be replicated and installed at village level. This can help in the large scale implementation of the biogas projects by the Fiji National Biogas Program, which can reach to the grassroots.

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