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Enhancemenct of Biogas in Domestic Biogas Plants by Varying Loading Rate and Digestate Recirculation

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***Abstract*—The world is facing acute fossil fuel shortage. By adopting biogas in households as cooking fuel we can reduce the burden on fossil fuels. In this paper the effect of two significant factors were investigated for enhancement of biogas production from food waste in a 20 l modified domestic biogas plant. Effect of loading rate and digestate recirculation on the biogas production from food waste was studied and presented in this paper. Initially, biogas production was tested in normal climate conditions of Kerala with a loading rate of 5.97 gTS/l/d. First, the loading rate was increased from 5.97 gTS/l/d to 8.44 gTS/l/d which yielded 79% increase in biogas from set 1. Then, 10 g digestate recirculation keeping loading rate at 6.2 gTS/l/d resulted in 92% increase in biogas volume when compared to set 1. Thus the study found that both operation of biogas at optimal loading rate and recirculation of digestate have significant effects on increase of biogas yield.**

***Keywords*—domestic biogas; food waste; Loading Rate; Digestate Recirculation**

I. INTRODUCTION

The rate of adoption of biogas in homes especially in urban homes is not fast enough owing to many factors such as the requirement of space for biogas digesters and the low to average output of biogas. In order for biogas to be a replacement fuel in homes rather than a substitute fuel for at least for cooking the rate of adoption have to improve. This can be improved by making biogas digesters smaller in size and reducing their hydraulic retention times (HRT) without affecting the production of biogas. This facilitates a need for improvement in efficiency of biogas generation and using other methods to enhance biogas production.

Thus enhancement of biogas production combined with educating the people about biogas and its relevance can bring about higher rate of adoption in homes. These enhancement techniques can also be used for larger biogas plants with some adjustments.

A. Factors Affecting Efficiency Of Biogas Production

1) Temperature

Anaerobic fermentation of substrate can take place at any temperature between 8 and 55°C. The value of 35°C is taken as optimum. The rate of biogas formation is very slow at 8°C. For anaerobic digestion, temperature variation should not be more than 2 to 3°C. Methane bacteria work best in the temperature range of 35 and 38°C [1].

2) pH

A pH value between 6.8 and 7.2 should be maintained for optimum fermentation and normal gas production. The pH above 8.5 or below 5.2 should not be used as it is difficult for the bacteria to survive above this pH [2].

3) Carbon:Nitrogen (C:N) ratio

A specific C:N ratio must be maintained between 20:1 and 30:1 depending upon the raw material used. The ratio of 30:1 is taken as optimum [3].

4) % Total Solids (%TS)

The water content should be around 90% of the weight of the total contents. Anaerobic fermentation proceeds well if the slurry contains 7 to 12% solid organic matter [4].

5) Agitation

The slurry should be agitated, either by stirrers or aerators, to improve the gas yield.

6) Loading rate (LR)

It should be optimum. If digester is loaded with too much raw material, acids will accumulate and fermentation will be affected.

B. Enhancement Of Biogas Production

Nowadays, families and houses are becoming smaller and cattle can only be found in a few rural households. So biogas plants that run on domestic waste rather than cow dung is on the rise. Thus enhancement of biogas production in household digesters is very important for improving the adoption rates of biogas technology in urban areas.

There are various techniques for enhancement of biogas production which includes pretreatment of substrate, use of additives, recycling of digestate and variation of several operational parameters like LR, solids concentration, particle size, agitation and hydraulic retention time [5].

In this study, two variations were carried out to assess the impact on the yield of biogas as well as the methane content. The methods applied were variation in LR, recycling of digestate.

II. MATERIALS AND METHODS

A. Construction of Biogas Plant

A modified fixed-dome vertical cylinder wet-fermentation type continuous biogas reactor with a capacity of 20 litres was designed. Fixed dome reactors are used commonly in China and India. In rural India floating-drum type biogas reactor is more common.

A typical reactor has an input tank as well as a slurry overflow tank. In the modified model, the input tank has been removed. Substrate is directly fed into the reactor. The overflow slurry can be collected in a bucket, not in to an attached tank. There is also an extra outlet valve with larger opening to allow for cleaning of the tank.

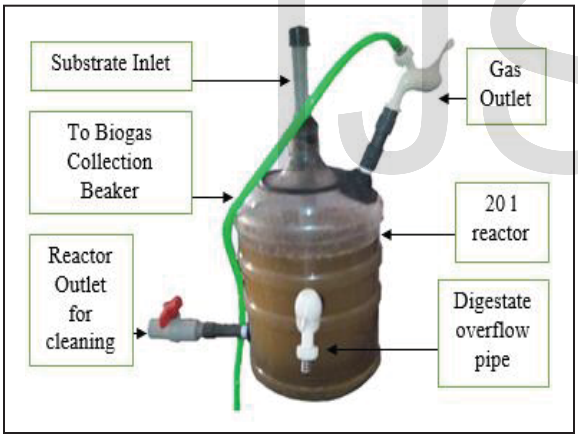

Fig. 1: Modified Biogas Plant

B. Preparation of Inoculum

Fresh cow dung, which was just one day old, was used to make inoculum. 3 kg of cow dung were mixed with 10 litres of water for the inception. The inoculum was fed into the digester through inlet chamber.

C. Characterization Of Substrate (Food Waste)

The waste having more carbohydrates and fats but low in protein was chosen to bring the C:N ratio in the desired range of 20:1 to 30:1.

Food waste used in the reactor had the following constituents:

- Rice: 55% ± 10% by weight
- Cooked fruits & vegetables: 20 % ± 10% by weight
- Fruit & vegetable peels: 15 % ± 10% by weight
- Cooked/Uncooked meat: 10 % ± 5% by weight

D. Colllection of Substrate

Food wastes was collected and characterized by different constituents regularly (on weekdays) from the Govt. Engineering College Men's hostel mess B. After characterization, 100 g/d (wet weight) substrate was collected and its homogenization was done in a kitchen blender. Water was added (300 ml) to it to bring the quantity to 400 ml and the substrate slurry was added to the reactor, thus setting the HRT to 40 days.

$$\text{HRT} = \frac{[\text{Effective volume of reactor (l)}]}{[\text{Volume of substrate per unit time (l/d)}]} \quad (1)$$

$$= 16(\text{l}) / 0.4 (\text{l/d}) = 40 \text{ days}$$

The effective volume of the reactor was kept at 16 litres, 4 litres was left free for biogas build-up in the reactor itself.

E. Typical Values For Various Parameters Of Food Wastes

Typical values for various parameters of food wastes are listed in reference [6], [7] and [8]. From these values we can infer that food wastes usually have very high levels of moisture (74-90%), and also the (volatile solids)/(total solids) ratio is very high (80-97%). The least amount of moisture can be found in fish and other meat wastes (around 45%).

For optimum operation of biogas, a C:N ratio of 16 to 25 is required. C:N ratio of food wastes is generally ideal for biogas generation (14.6-36.4). But it gets lowered in raw vegetable peels (C:N ~ 11) and is the lowest in meat (C:N ~ 3). So the proportions of meat and vegetable peels have to be low or additives have to be provided to make up for the carbon shortage.

F. Enhancement of Biogas Production

During three weeks, three sets of experiments were conducted to investigate the effects of two influencing factors namely increase of loading rate, recirculation of digestate on biogas production. The experiments were started after the lag phase when the biogas had begun to burn.

In the first week, the biogas reactor was allowed to operate under normal household conditions existing in Kerala. LR of substrate was set as 100 g/d (5.97 gTS/l/d). The following parameters viz. reactor temperature, %TS, pH and yield were measured.

The results of the first set of experiment were used for comparing the biogas yield for finding out the effects of the above mentioned factors in the biogas production.

In the second set, LR of the solid food waste collected was increased to 150% of the set 1, i.e. 100 g of solid food waste was increased to 150 g thus making LR to 150 g/d (8.44 gTS/l/d). And 300 ml of water was added to make the substrate. Thus the solids concentration was increased significantly.

In the third set, LR was returned to original and 10 g of overflow digestate was recirculated into the substrate. To 100 g solid food waste 10 g of recirculated digestate was mixed each day to make final LR of 110 g/d (6.2 gTS/l/d). To this 300 ml water was added to get the final substrate. Thus there was a slight increase in the solids concentration from set 1.

G. Physicochemical Analysis

For the physicochemical analysis of the substrate the following parameters were measured daily viz. %TS, pH of the substrate, reactor temperature and yield of biogas. The Methane (CH_4) and carbon dioxide (CO_2) concentration in biogas was measured for each set was measured in a gas chromatograph.

%TS was measured using the standard methods and pH was measured using the pH meter. The reactor temperature was measured using a thermometer.

1) Measurement of Biogas

The biogas was collected and measured in a graduated beaker by means of water displacement method. In this method, the amount of gas produced is equal to the amount of water displaced in the beaker. It was measured daily, and noted in units of litres/day.

2) Methane Concentration

Methane and carbon dioxide concentration (percentage by volume) were measured using gas chromatography (GC) with thermal conductivity detector (TCD) and corresponding chromatographs were obtained.

III. RESULTS AND DISCUSSION

The reactor was first operated with cow dung as inoculum for the early generation of gas from the biogas plant. After the 5th day, food wastes of given proportion was added as substrate daily. At the end of 21st day the reactor started producing measurable amounts of biogas. Thus the lag period was about 3 weeks.

During lag phase substrate undergoes hydrolysis and acidogenesis. During hydrolysis bigger organic molecules are broken down to the smaller ones and are stabilized, whereas in the acidogenesis, fermentation of glucose and other molecules takes place. The next phase is acetogenesis in which only carbon dioxide and hydrogen are formed. The final stage, methanogenesis, is represented by burning of biogas with a blue flame.

A. Biogas Yield

The graph denoted in fig. 2 represents the biogas yield for all three sets of experiments, after the lag phase. It is clearly evident that biogas production has positive effects while varying loading rate and while recirculating digestate.

1) Biogas Plant Operated Under Normal Household Conditions in Kerala– Set 1

The daily biogas yield, %TS and pH are detailed in table I. The mean values are shown in table II. Mean biogas was recorded as 0.48 l/d. Mean %TS was 7%, while mean pH was 7.2 which is in the neutral range. The average difference between outside temperature and reactor temperature was around 3°C.

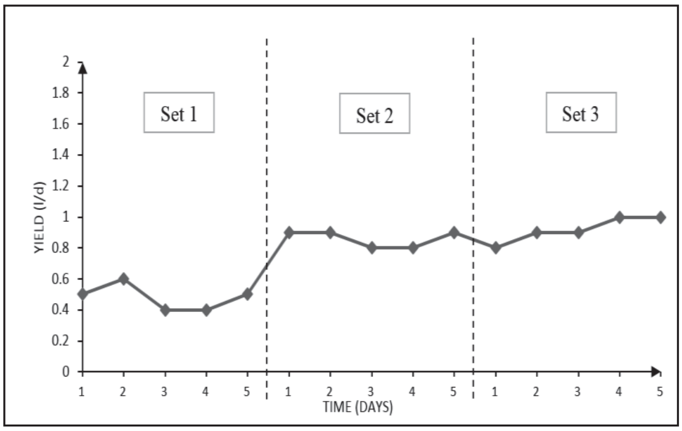

Fig. 2: Biogas yield in set 1, 2 and 3 after lag phase

TABLE I. EFFLUENT CHARACTERISTICS FOR SET 1 EXPERIMENT

Day	Reactor Temp (°C)	% TS	pH	Yield (l/d)
1	36.4	6.425	7.28	0.5
2	36.9	7.575	7.25	0.6
3	33.3	8.225	7.26	0.4
4	31.2	6.65	7.15	0.4
5	36	6.15	7.05	0.5

For a biogas plant to operate smoothly the variation in maximum temperature difference is around ±3°C.The temperature dropped by 3.6°C on the third day and a subsequent decrease of 2.1°C on the fourth day before it returned to normal. It is possible that this temperature fluctuation caused an inactivation of microorganisms resulting in a drop in the yield of gas.

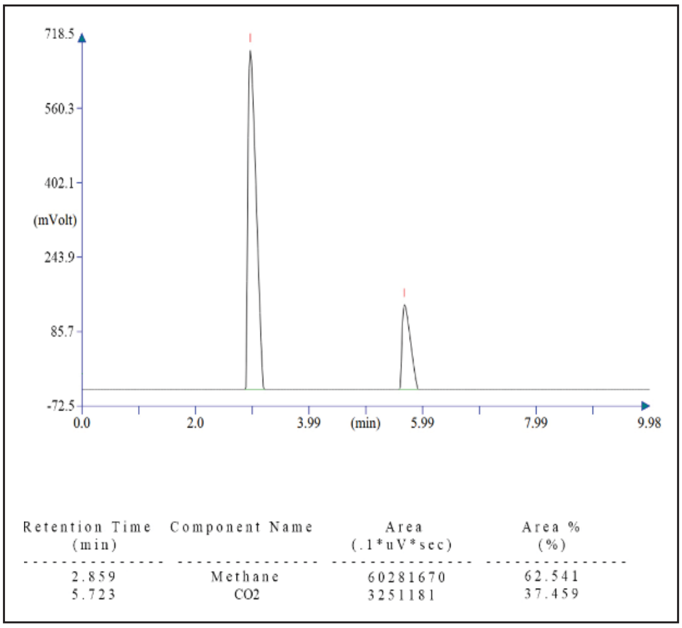

Fig. 3: Chromatograph for Set 1

TABLE II. MEAN, STANDARD DEVIATION AND VARIANCE OF EFFLUENT PARAMETERS

	Reactor Temp (°C)	%TS	pH	Yield (l/d)
Mean μ	32.4	7.005	7.198	0.48
Standard Deviation σ	2.871	0.775	0.087	0.075
Variance σ^2	8.24	0.601	0.007	0.006

From the chromatogram in fig. 3, the concentration of methane (% by volume) was found out to be 62.54%. A negative error of 5% can be attributed, as the trace elements present in the biogas are not recognized or sampled by the gas chromatograph.

2) Biogas Plant Operated Under Increased Loading Rate– Set 2

Here, an increase in biogas produced can be observed, which shows the significant influence of optimum loading rate on biogas production. Biogas could decrease with increase of loading rate beyond optimal value due to choking of digester and/or increased acidification. Thus maximum LR can be decided by correlating with a maximum %TS of 12%.

TABLE III. EFFLUENT CHARACTERISTICS FOR SET 2 EXPERIMENT

Day	Reactor Temp (°C)	%TS	pH	Yield (l/d)
1	37.5	11.733	6.85	0.9
2	37.1	10.4	6.77	0.9
3	36.9	9.067	6.59	0.8
4	36.5	8.5	6.35	0.8
5	36.5	9.4	6.5	0.9

The solids concentration (%TS) reached up to 11.73 %, consequently biogas yield also increases to 0.9 l/d. A solid concentration of 8 – 12% is the optimum concentration for biogas production. Thus if the loading rate is adjusted to obtain the optimum solids concentration (%TS) then the biogas production may be maximised.

The methane percentage is 68.16% which shows an increase when compared to set 1. The increase in solids concentration (%TS) provides more quantity of solids to be digested for the methanogens thus increasing their activity and subsequently improves the output. This shows that biogas plant operating under optimum LR will result in increase of biogas yield.

TABLE IV. MEAN, STANDARD DEVIATION AND VARIANCE OF EFFLUENT PARAMETERS

	Reactor Temp (°C)	*%TS*	*pH*	*Yield (l/d)*
Mean μ	36.9	9.82	6.612	0.86
Standard Deviation σ	0.379	1.139	0.181	0.049
Variance σ^2	0.144	1.296	0.033	0.002

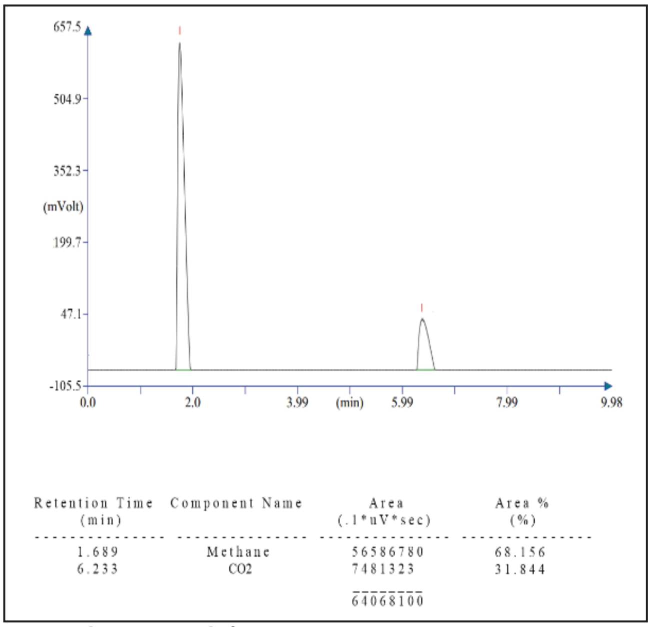

Fig. 4: Chromatograph for Set 2

3) Biogas Plant Operated With Digestate Recirculation– Set.3

In this set, a substantial increase in the production of biogas can be observed. The LR is returned to same value as first set (100 g/d) and 10 g of digestate slurry is recirculated into the reactor by adding to the substrate. Thus it makes the LR to 110 g/d (6.2 gTS/l/d).

By recirculating the digestate, active microorganisms responsible for the decomposition of the substrate and subsequently a part of the methane and carbon dioxide produced are also recirculated, i.e. the loss of microorganisms due to digestate overflow is reduced. This enables enhanced digestion of the substrate and thus allows for enhanced production of biogas as a result.

TABLE V. EFFLUENT CHARACTERISTICS FOR SET 3 EXPERIMENT

Day	*Reactor Temp (°C)*	*%TS*	*pH*	*Yield (l/d)*
1	36.5	7.11	6.64	0.8
2	37.3	8.693	6.63	0.9
3	35.8	7.89	6.59	0.9
4	35.8	6.412	6.58	1
5	36.1	6.79	6.46	1

The results show a significant increase in biogas yield as well as methane concentration. The methane % from the chromatogram is 74.82%.

This method proves to be very effective for enhancement of biogas for domestic biogas plants as it can be applied to any household biogas plant very easily.

TABLE VI. MEAN, STANDARD DEVIATION AND VARIANCE OF EFFLUENT PARAMETERS

	Reactor Temp (°C)	*%TS*	*pH*	*Yield (l/d)*
Mean μ	36.3	7.379	6.622	0.92
Standard Deviation σ	0.562	0.818	0.127	0.075
Variance σ^2	0.316	0.668	0.016	0.006

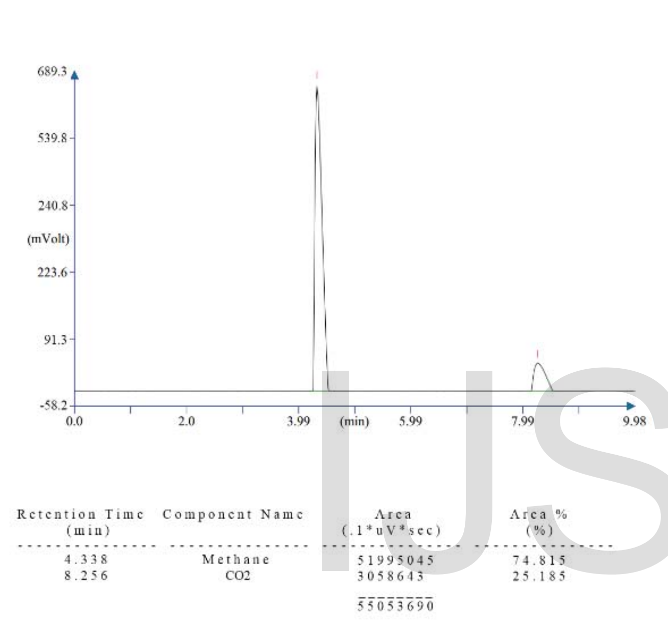

FIG. 5: Chromatograph for Set 3

IV. CONCLUSION

Set 3, with digestate recycling, and set 2, with optimum loading rate resulted in significant increase in biogas outputs (79%).

The recycling of digestate was found to result in higher biogas yield and is also an effective method for easy and economical biogas enhancement for domestic biogas plants. It can be easily replicated in household biogas plants.

Loading rate increase have to be correlated with %TS so that it does not become counterproductive in the enhancement of biogas yield.

If the optimum loading rate and recycling of digestate is applied in conjunction with each other, then biogas yield can certainly be enhanced

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