Chemical Science Review and Letters ISSN 2278-6783

Research Article

Performance Evaluation of Solid State Digester for Biogas Production from Banana Wastes

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Abstract

The paper describes the performance study of a developed solid state digester of 1m^3 capacity, exclusively for treating banana wastes by the method of solid state anaerobic digestion. The reactor was designed based on 30 days hydraulic retention time and the performance of the plant was evaluated over weeks by means of gas production, TS and VS destruction. Initial seeding of the digester was done with 500 kg of fresh cow dung in the ratio of 1:1 with water and 100 *l* of slurry from a running biogas plant, later it was replaced with mashed banana peel wastes. During the entire operation, the effluent pH was found to be maintained in the range of 7.0-7.2 with an average daily gas production of 730 litres. Methane content was found to be in the range of 56 to 65% which was evident in biogas. The specific biogas production of banana wastes was found to be in the range of 0.023 to 0.027 m^3/kg of feed. The maximum specific gas production per kg of TS_{added} was 0.143 whereas the maximum specific gas production per kg of VS_{added} was 0.524. The maximum specific gas production per kg of TS destruction was 0.379 m^3 whereas the maximum specific gas production per kg of VS destruction was found to be 2.1 m^3. With the average daily gas production of 0.7 m^3, the solid state digester is able to save an amount of ₹ 9000/ year when the gas is used for thermal application and ₹ 4600/ year when the gas is used for electricity generation. The payback period was estimated to be 4 years and 6 months when the gas is used for thermal application and 8 years and 11 months when the gas is used for electricity generation.

Keywords: Banana wastes, Anaerobic digestion, Specific biogas production, Solid state digester

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Introduction

Energy is one of the major drivers of a growing economy like India. Efforts are needed to find alternate ways to replace fossil fuels with more environmental friendly alternatives as potential solutions to the current energy crisis and environmental problems associated with the harmful pollutant emissions. This emphasizes the need for renewable energy sources. Another important issue after the energy crisis is the environmental pollution due to disposal of wastes. Out of the wastes which are disposed off directly on land, biological wastes especially the agro-industry wastes can be effectively used as a feedstock for energy recovery through anaerobic digestion. Banana processing industries result in huge amount of wastes generation viz. peel, peduncle, degraded bananas etc. These banana wastes can be used as an alternate feedstock as they are a concentrated source of putrid organic wastes, ideal for anaerobic digestion which produces a valuable energy source in form of biogas. Thus it paves way for both wastes management and energy production.

Generally anaerobic digestion of wastes is being carried out in both fixed dome and floating drum biogas plants. For the past 30 years, there have 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. No biogas plants have been developed for treating a particular feedstock. As banana wastes contain high moisture, they can be treated by the way of solid state digestion. Hence a solid state digester offers a better option for anaerobic treatment of banana wastes. The present work was taken up to study the anaerobic treatment of banana wastes using solid state digester for enhanced biogas production. The specific objectives of the study were to design and fabricate a solid state digester and to evaluate and optimize the operating parameters in the developed digester for enhanced biogas production.

Materials and Methods

The banana wastes were collected from Faisal Chips Company, Selvapuram, Coimbatore. The type of wastes produced in the industry was banana peel and peduncle of variety Musa Nendran cultivar (AAB). These wastes were mashed by using a 15 hp crusher and were used as feedstock. The solid state digester was designed for a capacity of $1m^3$.

Performance evaluation of the digester

The developed digester was installed in Renewable energy field park of Bioenergy workshop, TNAU. The digester was seeded with cow dung for initial stabilization and the total solids content was maintained at 10%. After stabilization, the cow dung was completely replaced by mashed banana peel wastes. The influent and effluent characteristics and the performance of the solid state digester in terms of gas production, specific gas production, TS and VS destruction were estimated.

Daily Gas Production

The daily gas production was observed using wet type gas flow meter of three liters capacity by connecting the gas outlet to the gas flow meter.

Gas Composition

The weekly observation of gas composition was done for finding the methane content of biogas. Methane content in the biogas produced was analyzed by using a gas chromatograph (NUCON 5765) equipped with a thermal conductivity detector and a 3-m Porapak Q (80-100 mesh) column. Helium was used as a carrier gas at a flow rate of 30 ml/min. The oven, injector and detector temperatures were 60, 60 and 90°C respectively.

Total solids and Moisture content

Moisture content was determined by drying known weight of sample in an electric oven at 103±2ºC up to the arrival of constant weight [1]. The remaining percentage of weight gives the total solids content in the sample. Weekly observation was taken for TS of influent and effluent.

Volatile solids

The volatile content was determined using muffle furnace [2] for influent and effluent on weekly basis. To measure the volatile content, known quantity of dried sample was taken in a closed crucible and kept inside the muffle furnace at 650ºC for six minutes and again at 750ºC for another six minutes. The loss in weight of the sample was found out.

$$\text{Volatile matter, (\%)} = \frac{\text{Loss in weight of the sample, g}}{\text{Weight of moisture fee sample, g}} \times 100$$

C:N ratio

Samples of feed material inside the digester are taken from the sampling ports provided and the carbon to nitrogen ratio was estimated by separately estimating the Total Organic Carbon (TOC) and Total Kjeldhal Nitrogen (TKN). Weekly observation of C:N ratio for the feed material inside the digester was taken.

Total Organic Carbon (TOC)

The TOC was found by following the wet digestion method of Walkley and Black as described by [3]. The diluted 20 ml sample was digested with 50-75 ml of 1 N $K_2Cr_2O_7$ with 20ml of Conc. H_2SO_4. After 30 minutes 10 ml of Ortho phosphoric acid was added. This was titrated against 1 N Ferrous Ammonium Sulphate (FAS) with diphenylamine as indicator. A blank was also run.

$$\text{TOC (\%)} = \frac{(\text{Bv} - \text{Sv}) \times \text{NFAS} \times 100 \times 0.03}{\text{Vs}}$$

where, Bv = Blank titre value; Sv = Sample titre value; NFAS = Normality of FAS; Vs = Volume of test Sample

Total Kjeldhal Nitrogen (TKN)

Available Nitrogen was estimated in the samples by micro kjeldhal method. To 1ml of sample, 2-3 ml of 25 per cent $KMnO_4$ solution was added followed by few drops of Conc. H_2SO_4. To this 10-15 ml of diacid (H_2SO_4 & $HClO_3$ in the ratio 5:2) was added and digestion was carried out in a Kjel plus digestion unit. 5 ml each of the digested samples was distilled with 20 to 50 ml of 40 per cent NaOH and the distillate titrated against 0.05 N H_2SO_4.

$$\text{Total Kjeldhal Nitrogen, mg/l} = \frac{\text{Titre value x 14 x Vol. of acid made up}}{\text{Volume of acid pipetted}} \text{ x 100}$$

Results and Discussion

The solid state digester was initially seeded with 500 kg of cow dung in the ratio of 1:1 with water. On the second day, the digester was seeded with 100 l inoculum of digested slurry having the VS of 1.4% from a running biogas plant using kitchen wastes as the feed material. The seeding with inoculum (30 *l*/day) was continued once in two days for a week. Loading of the digester with cow dung (50 *l*/ day) was continued daily for two weeks.

After the 20th day, steady state digestion was achieved with the pH of effluent in the range of 7.0-7.2 with the daily gas production of 730 *l*. Later, banana peel wastes were collected and mashed by using a crusher of 15 hp motor capacity. The mashed banana peel wastes were then fed in the solid state digester with daily loading of 60 kg (30 kg feed + 30 *l* water).

pH, TS and VS

The pH of the influent was found to be 5.2±0.2. The effluent pH values remained almost neutral (7.0-7.2) during the entire period indicating the stable operation of the reactor. TS content of the influent varied between 5.52 to 6.06 kg (9.2-10.1% of feed inlet) whereas the effluent was found to vary between 3.06 to 4.14 kg (5.4-6.9% of feed inlet). The VS content of the influent varied between 2.594 to 2.933 kg (47.51-50.5% of TS) whereas the effluent was found to vary between 0.783 to 0.983 kg (23.75-25.6% of TS). The influent and effluent pH variation, TS and VS content variation were depicted in **Figures 1-3**.

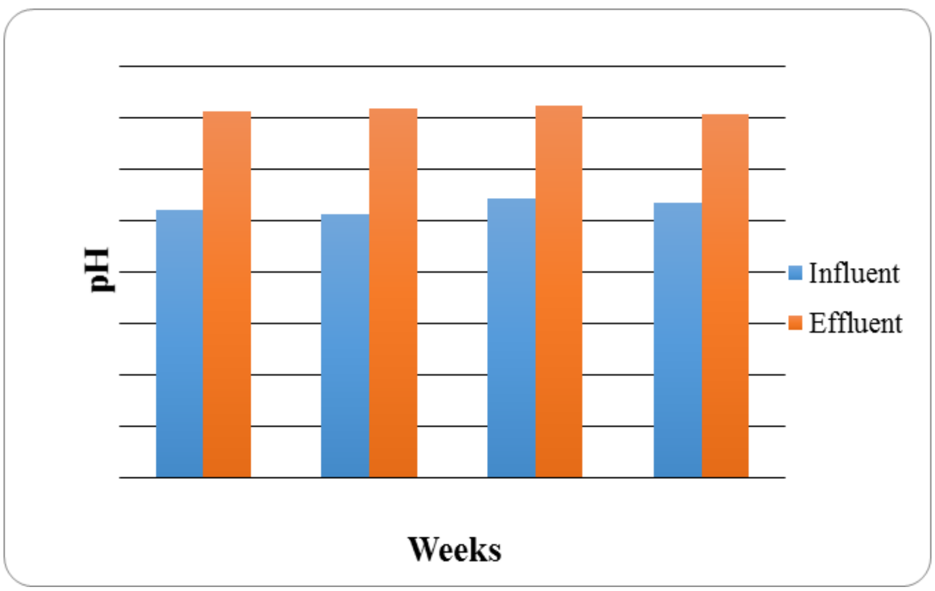

Figure 1 pH of influent and effluent over weeks

Methane content of biogas and C:N ratio

The methane content and the C:N ratio of samples inside the digester was measured on weekly basis and was found to have a direct effect on methane content of biogas. In the first week was found to be 65%. In the subsequent weeks, the methane content was found to be in the range of 56-59%. The higher methane content in the first week may be due to the effect of seed culture. After feeding banana wastes, the methane content was found to be comparatively less but in the optimum range for biogas production of 50-75% as reported by [4].

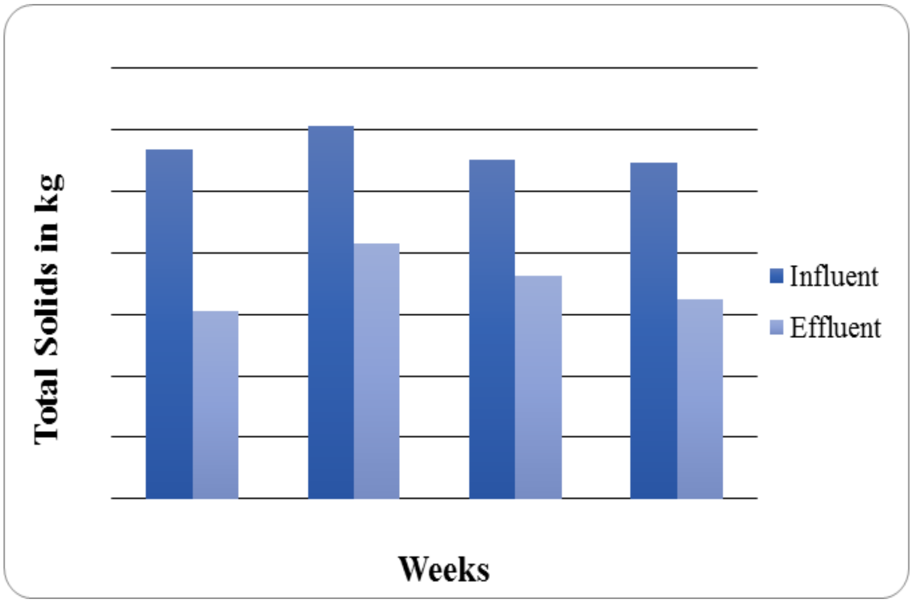

Figure 2 TS of influent and effluent over weeks

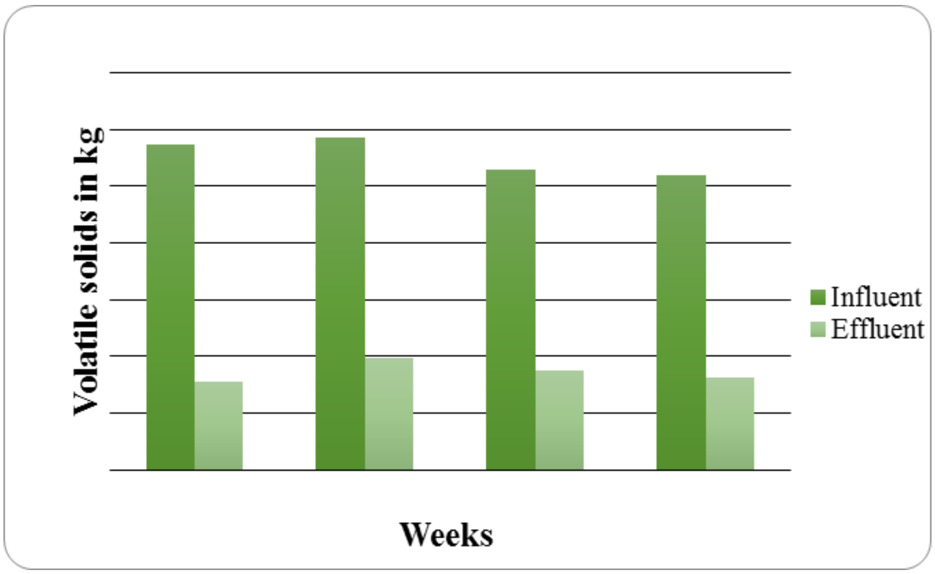

Figure 3 VS of influent and effluent over weeks

The higher methane content of 65% obtained in Week I was due to the optimum value of C:N ratio of 28.29 prevailed in the digester as shown in **Table 1**. In the subsequent weeks the C:N ratio of samples was found to be in the range of 23.35 -25.95, which was comparatively less but in the optimum range for biogas production of 20-30 as reported by [5] and [6]. The higher methane content of 65% obtained in Week I was also due to the optimum pH of 7.1 prevailed in the digester.

The maximum TS and VS destruction of 3.7% and 3.213 % was observed at Week I and the minimum TS and VS destruction of 3.15% and 2.93 % occurred at Week III. **Figure 4** shows the TS and VS destruction of the solid state digester over weeks.

Table 1 Weekly methane content of biogas with respect to C:N ratio and pH

Weeks	C:N ratio	Effluent pH	Methane content of biogas, %
I	28.29	7.11	65
II	25.95	7.18	59
III	23.35	7.23	56
IV	25.72	7.05	58

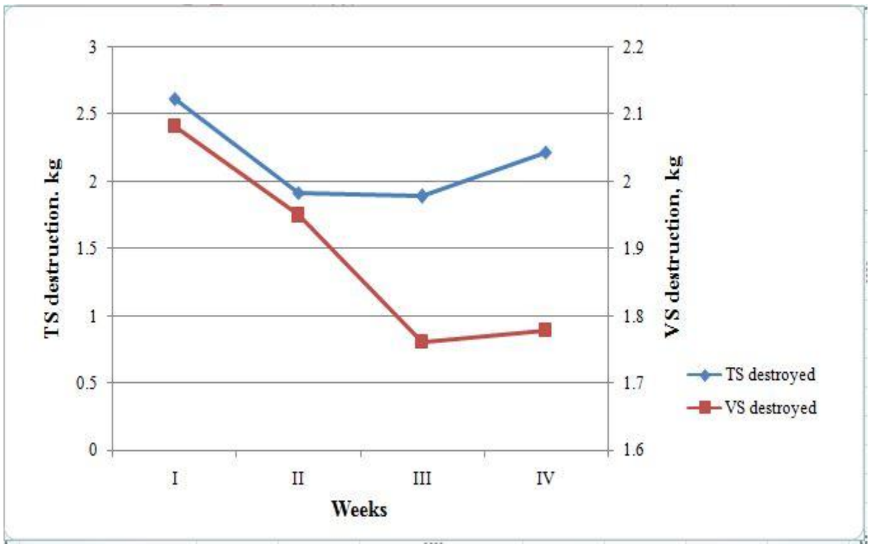

Figure 4 TS and VS destruction over weeks

Gas production and Specific gas production

The gas 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 had been worked out, which was found to be in the range of 0.023 to 0.027 m^3/ kg of fresh feed. **Table 2** shows the gas production and specific gas production over weeks. The maximum specific gas production of 0.143 m^3/ kg of TS_{added} were obtained at Week I and the minimum specific gas production of 0.118 m^3/ kg of TS_{added} was obtained at Week II. The maximum specific gas production in terms of m^3/ kg of VS_{added} was 0.524 for Week I and the minimum specific gas production of 0.358 m^3/ kg of VS_{added} was obtained at Week II. **Figures 5** and **6** shows the gas production in terms of TS and VS added over weeks.

Table 2 Gas production and specific gas production over weeks

Parameters	Weeks			
	I	II	III	IV
Mean daily gas production, m^3	0.810	0.717	0.715	0.698
Specific gas production, m^3/ kg of fresh feed	0.027	0.024	0.024	0.023
Specific gas production, m^3/ kg of TS $_{added}$	0.143	0.118	0.130	0.128
Specific gas production, m^3/ kg of $TS_{destroyed}$	0.310	0.374	0.379	0.315
Specific gas production, m^3/ kg of VS_{added}	0.524	0.358	0.412	0.454
Specific gas production, m^3/ kg of $VS_{destroyed}$	2.1	1.45	1.74	2.03
Biogas Productivity, *l*/ *l* feed	13.51	11.95	11.93	11.64
Volumetric gas production, m^3 / m^3 of digester	2.84	2.51	2.51	2.44

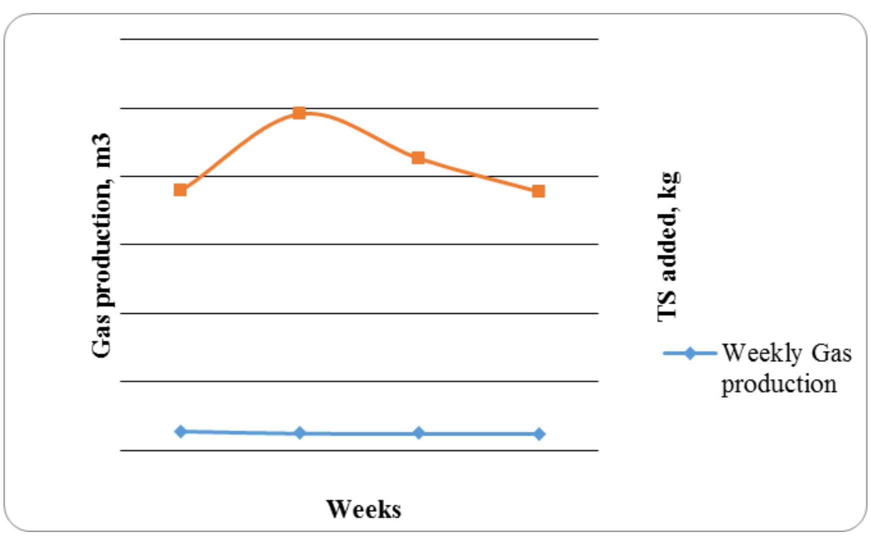

Figure 5 Gas production Vs TS addition

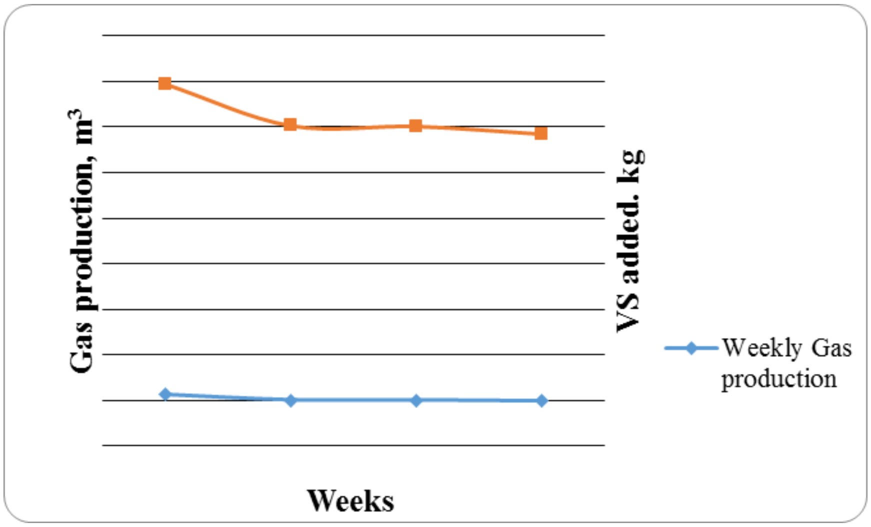

Figure 6 Gas production Vs VS addition

The maximum specific gas production of 0.379 m^3/ kg of TS $_{destroyed}$ was obtained at Week III and a minimum of 0.31 m^3/ kg of $TS_{destroyed}$ was obtained at Week I. The maximum specific gas production in terms of m^3/ kg of $VS_{destroyed}$ was 2.1 for Week I and the minimum specific gas production of 1.45 m^3/ kg of $VS_{destroyed}$ was obtained at Week II. **Figures 7** and **8** shows that the gas production in terms of TS and VS destruction over weeks;

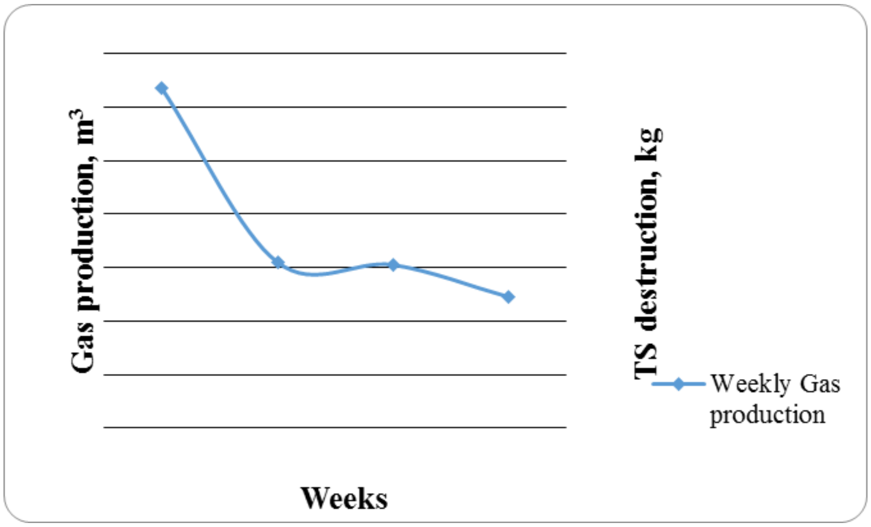

Figure 7 Gas production Vs TS destruction

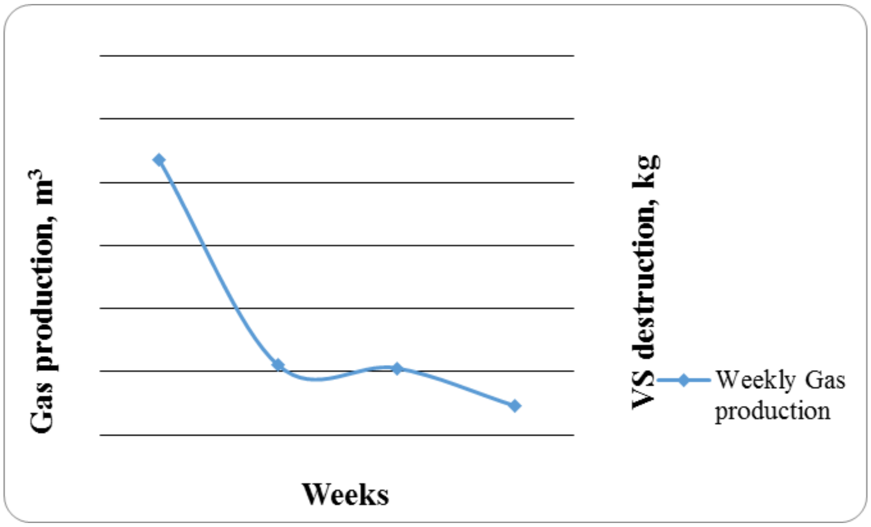

Figure 8 Gas production Vs VS destruction

The maximum biogas productivity of 13.51 *l/l* of feed was observed at Week I and the minimum of 11.64 *l/l* of feed was observed at Week IV. The volumetric gas production (m^3/m^3 of digester) was found to be higher with the value of 2.84 at Week I and lower with the value of 2.44 m^3 / m^3 reactor at Week IV. There was steady decrease in the values of volumetric gas production. Also the biogas production was found to be maximum of about 850 *l* during the first week but after feeding banana wastes, it then gradually decreased to around 670 *l* in the fourth week.

The maximum gas production may be due to the effect of seed culture since the specific biogas yield of cow dung i.e. 0.04 m^3/kg [4] was more compared to the specific biogas yield of banana wastes (0.02 m^3/kg).

Cost economics

The total cost of the plant (construction cost, equipment cost and investment charge) was ₹ 41,300. The average daily gas production was found to be 0.7 m^3 which saves an amount of ₹ 9000/ year when the gas is used for thermal application and ₹ 4600/ year when the gas is used for electricity generation. From the estimation it has been found that the digester has the payback period of about 4 years and 6 months when the gas is used for thermal application and 8 years and 11 months when the gas is used for electricity generation.

Conclusion

The design of solid state digester proved its performance for its designed capacity for production of biogas from banana wastes. The solid state digester was optimized with the daily gas production of 0.7 m^3 with methane content in the range of 56 to 65%. The maximum specific gas production per kg of TS destruction was 0.379 m^3 whereas maximum specific gas production per kg of VS destruction was 0.406 m^3. With an average daily gas production of 0.7 m^3, the digester saves an amount of ₹ 9000/year when used for thermal application and ₹ 4600/year when the gas is used for electricity generation. The developed solid state digester was found to be economically viable with the estimated payback period of 4 years and 6 months (for thermal application) and 8 years and 11 months (for electricity generation).

Acknowledgement

The authors are highly thankful to the Ministry of New and Renewable Energy (MNRE-GOI) for providing the necessary funds to carry out this research work.

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Publication History
Received 12th Dec 2017
Revised 04th Jan 2018
Accepted 05th Jan 2018
Online 30th Jan 2018