



Biomethanation of fruit processing industry waste-water through high-rate reactor

J GITANJALI¹, L MEKALA², O RIYAZ AHMED³, K BALAJI RAO⁴ and S KAMARAJ⁵

Tamil Nadu Agricultural University, Coimbatore, Tamil Nadu 641 003

Revised: 10 March 2014; Revised accepted: 28 October 2014

ABSTRACT

The present paper reports a study conducted at Tamil Nadu Agricultural University, aiming at developing a high-rate reactor for treating the food processing waste-water. It was found that the waste-water had low strength biodegradability by conducting batch experiment with and without mixing cattle-dung in different volatile solid proportion and cattle-dung ratio. The BOD and COD of the waste-water were found to be 540 and 2000 mg/L respectively and pH of the processing waste-water was 1.37 that lies in the acidic range. In the batch studies conducted, the maximum gas production was recorded per kg of Total Solid Content and Net Volatile Solid Content added was observed in crushed and over ripen sample as 87.95, 91.51 L and 82.05, 84.24 L respectively. The minimum gas production per kg of total solid content and volatile solid content added was observed in waste-water sample as 2.22 and 2.42 L respectively for the digestion period of 21 days. The high-rate reactor for treating the food processing waste-water was installed at a reputed firm. The COD removal efficiency, TS removal efficiency and VS removal efficiency was found to be about 50, 36 and 29% respectively. The biogas generation potential is estimated to be 60 m³/day. The industry saved not only electric power of 96 kWh/day, but also the sludge was used as manure, thus the waste disposal was in an environmentally friendly approach.

Key words: Biogas batch study, Biogas yield, High-rate reactor, Net volatile solid content, Total solid content

In India, only 20% of food and vegetable waste is being processed to avoid environmental problems, while remaining quantity goes as waste due to lack of transportation and storage facility. Fruits and vegetables are more prone to spoilage than the cereals attributable to their nature and composition, and this spoilage occurs at the time of harvesting, handling, transportation, storage, marketing and processing (Vijaya *et al.*, 2010). During canning and preparation of juices, squashes, jams, jellies, dried products, pickles etc., large quantities of waste material is being left over and disposal of this material becomes difficult and pose serious disposal problems. Although India has 17% of the world's population, it accounts for only 4% of the world's primary energy consumption (553 kWh per capita consumption) with renewables being a small share of 11% in the total energy usage (Anon. 2011, Pillai and Banerjee 2009).

There are about 18 550 processing units in India, which disposes large quantities of fruit and vegetable product. About 90% of these units are in small scale sector with an annual

production of about 50-250 tonnes (Srivastava *et al.* 2014). These units have no organised method for waste disposal. Most of the solid waste are dumped outside and are taken care of by the stray cattle. In certain large scale units, these wastes are taken away by farmers for cattle feed and field manure. Many food processing industries are facing problem in disposal of waste and moreover there is a need of huge quantity of fire wood to meet boiler requirements. The processing of waste through biomethanation has vast scope to satisfy the industry requirements.

In this context, a study was undertaken to understand the possibility of producing biogas from fruit processing waste-water, which has low strength biodegradability by conducting batch experiment with and without mixing cattle-dung in different volatile solid proportion and cattle-dung ratio. The power is produced by the utilization of this generated gas to meet the energy need of the industry. Hence we took biomethanation using high-rate reactor possibly to obtain clean and green energy in the fruit processing industry.

MATERIALS AND METHODS

The types of waste produced in the industry are peel, pulp, seed, crushed and over ripen of papaya fruit. The wastes were collected from M/s Vee Yel Fruit industry at Mettupalayam, Coimbatore. The pH of samples was

¹Research Scholar (e mail: jogitanjali@gmail.com), ³M Tech Student (e mail: shalihworld@gmail.com), ⁴B Tech Student (e mail: kbalajirao2007@gmail.com), ⁵Professor and Head (e mail: kamarajs@hotmail.com), Department of Bio-Energy; ²Assistant Professor (e mail: mekalanarayanan@gmail.com), Erode Sengunthar Engineering College, Erode, Tamil Nadu 641 013.

estimated using the electrometric method. Total solids (TS) and volatile solids (VS) are determined by using the procedure put forward by APHA. The COD and BOD of the samples were analyzed following the Dichomate method. The Total organic carbon (TOC) was estimated following the wet digestion method of Walkley and Black (Faina *et al.* 2012).

Batch digestion studies were carried out to study the bimethanation characteristics of waste generated in the industry. Anaerobic digestion of these wastes and processing water was carried out using 2.5 litre amber colored glass bottles with a plastic stopper. Two third of the bottles were filled with the samples. The mouth of these glass bottles were covered using one-hole rubber-cork to keep it air-tight. Glass bent tube is inserted through the rubber-cork hole and sealed to prevent gas leakage. One glass tube is taken through the stopper and it acts as an outlet for the biogas. To this glass bent tube 40 cm long rubber tube with a pinch cock was connected. The daily gas production was estimated by water displacement method. This method is used to record the daily gas production readings.

The various treatments used for study are i) peel 5% TS, ii) peel 10% TS, iii) peel 16.9% TS*, iv) over ripen 5% TS, v) over ripen 9.1% TS*, vi) waste-water, vii) crushed 5% TS, viii) crushed 10% TS*, ix) seed without grinding 5% TS, x) seed without grinding 10% TS, xi) seed without grinding 12.7% TS*, and xii) cow-dung (*TS of waste as such).

For measuring the volume of gas produced, a 1000 ml measuring jar along with a water bath was used. The measuring jar was filled with water and kept in the water bath. Each rubber tube was introduced below the glass jar in the water bath. The gas replaced the water in the jar. The displacement of water in the measuring jar was noted. The displacement volume of water gave the volume of the gas. In the same way the gas production in the different bottles were noted. The daily gas production was recorded for different bottles until the gas production started declining. Daily Biogas Production (DBP), Weekly Biogas Production (WBP), Cumulative Biogas Production (CBP), Total Biogas Production (TBP), Average Biogas Production (ABP), Occurrence of Maximum biogas production and Total Biogas Production (TBP) were recorded and estimated. The methane content was determined by using saccharometer (Polycarpus 2012) and total biogas production was multiplied by average methane content of biogas expressed in litre (L).

RESULTS AND DISCUSSION

Characteristics of the samples

The results of the physico-chemical characteristics of the solid and liquid waste generated in the industry are presented in this section and the values are given in the Table 1.

The optimum pH for methanogenesis is 6.8-7.2 (WEF and ASCE 1992). The pH of the digester is a function of concentration of volatile fatty acids produced, bicarbonate alkalinity of the system and the amount of carbon dioxide

Table 1 Characteristics of the waste-water and solid sample

Parameters	Waste-water	Peel	Seed	Crushed	Over ripen
pH	1.37	4.8	5.7	7.2	6.1
TS%	0.75	16.9	12.7	9.9	9.1
VS%	93	98.2	90.0	96.7	96.7
BOD mg/L	540				
COD mg/L	2000				

produced (Yujun *et al.* 2013). The pH of the waste-water is 1.37 which lies in the acidic range that affects the stability of the reactor and thereby the gas production. Hence it is necessary to adjust the pH by adding the solid waste and treated water which has high pH value compared to waste-water to the optimum condition for the effective gas production. The Total solid content and Volatile solid content of waste-water were found to be 0.75 and 93% respectively. It is found to be sparingly less since the water is used only for cleaning the papaya fruit. Similar values for the total solid and volatile solid contents were reported (Yujun *et al.* 2013) for fruit and vegetable wastes (FWW). The COD and BOD of the waste-water were found to be 2000 mg/L and 540 mg/L respectively, which indicate that the waste-water is less strength waste-water. Even though the COD is less it can be effectively used for the generation of biogas by mixing it with the other solid wastes generated while making jam. The BOD: COD ratio varied around 0.27 which even though is less can produce biogas effectively. The COD of feed used in the reactor is found to be 25 400 mg/L due to the addition solid waste to the waste-water. The pH value of the solid wastes was found to be in the range of 4.6 to 7.4 which was mixed with the waste-water to increase the biogas generation. The Total solid content of the sample was found to be in the range of 9.1 to 16.9%. The Volatile solid content of sample was found to be in the range of 90 to 98.2%.

Result of batch digestion studies

The batch anaerobic digestion was carried out to investigate the bimethanation characteristics. The biogas production started after 24 hours of the bottling and reached maximum after first week. The batch digestion was continued up to the fifth week at which the gas production started declining. The gas production behaviour was entirely different in all the treatments. The result of batch digestion studies are presented in this section.

Gas production potential of waste-water under different treatments

Daily biogas production: The rate of change of gas production is found minimum in the case of seeds of 5, 10 and 12.7% TS treatments as 0.135 L, 0.142 L and 0.146 L respectively. The rate of change of gas production is found maximum in the case of over ripen of 9.4% TS as 0.361 L.

Weekly biogas production: The weekly gas production (Fig 1) was to be maximum in the first week in all treatments and studies. It is found to be decreasing in the second week.

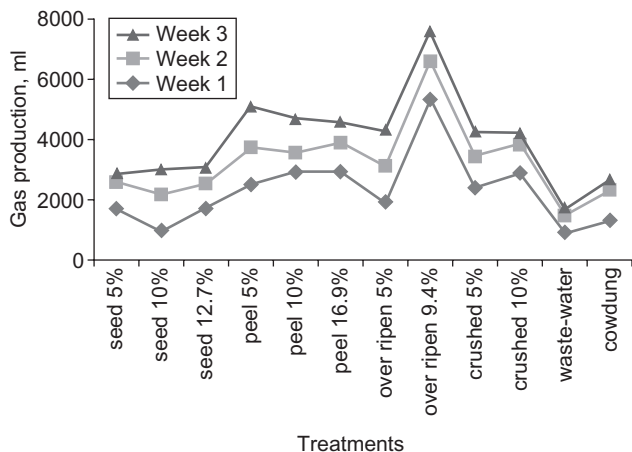


Fig 1 Weekly gas production

In the third week the study revealed that the gas production tend to be constant. The gas production stops after third week in all the treatments.

Cumulative biogas production: The rate of change of gas production (Fig 2) is found minimum in the case of seed samples of all % TS and waste-water treatments. The rate of change of gas production is found maximum in the case of over ripen, peel and crushed samples.

Total biogas production: The study reveals that the total gas production (Fig 3) in seed, peel, overripen and crushed samples are 3.070±0.146 L, 4.570±0.217 L, 7.600±0.361 L and 4.200±0.200 L respectively.

Methane percentage of biogas obtained under different treatments: The readings obtained were similar to the

Table 2 Methane content and total methane content

Treatment	Methane content (%)			Total methane production, L
	8 th day	16 th day	Mean	
Peel	54	61	57.5	2.57
Crushed	58	63	60.5	1.71
Over ripen	60	65	62.5	2.74
Seed	52	55	53.5	2.76
Waste-water	48	50	49.0	0.81
Cow-dung	64	65	64.5	1.72

readings when studied using the Orsat apparatus. The methane concentration was highest during the fourth to sixth week, which substantiates the reading taken in these weeks (Gizem *et al.* 2014). The methane content of the biogas was found to vary between 48% and 65% for different treatments. The highest methane content was observed in the treatment overripen and cowdung as 65%. There was not much difference between the treatments and also between the weekly data. The methane percentage and total methane production for the digestion period are given in the Table 2.

Gas production vs total solid and net volatile solid reduction: The quantity of biogas generated with respect to total and volatile solids added are represented in the Table 4. The maximum gas production per kg of TS and Net VS added was observed in crushed and over ripen sample as 87.95, 91.51 L and 82.05, 84.24 L respectively. And the minimum gas production per kg of TS and VS added was observed in waste-water sample as 2.22 and 2.42 L respectively. The similar result has been reported

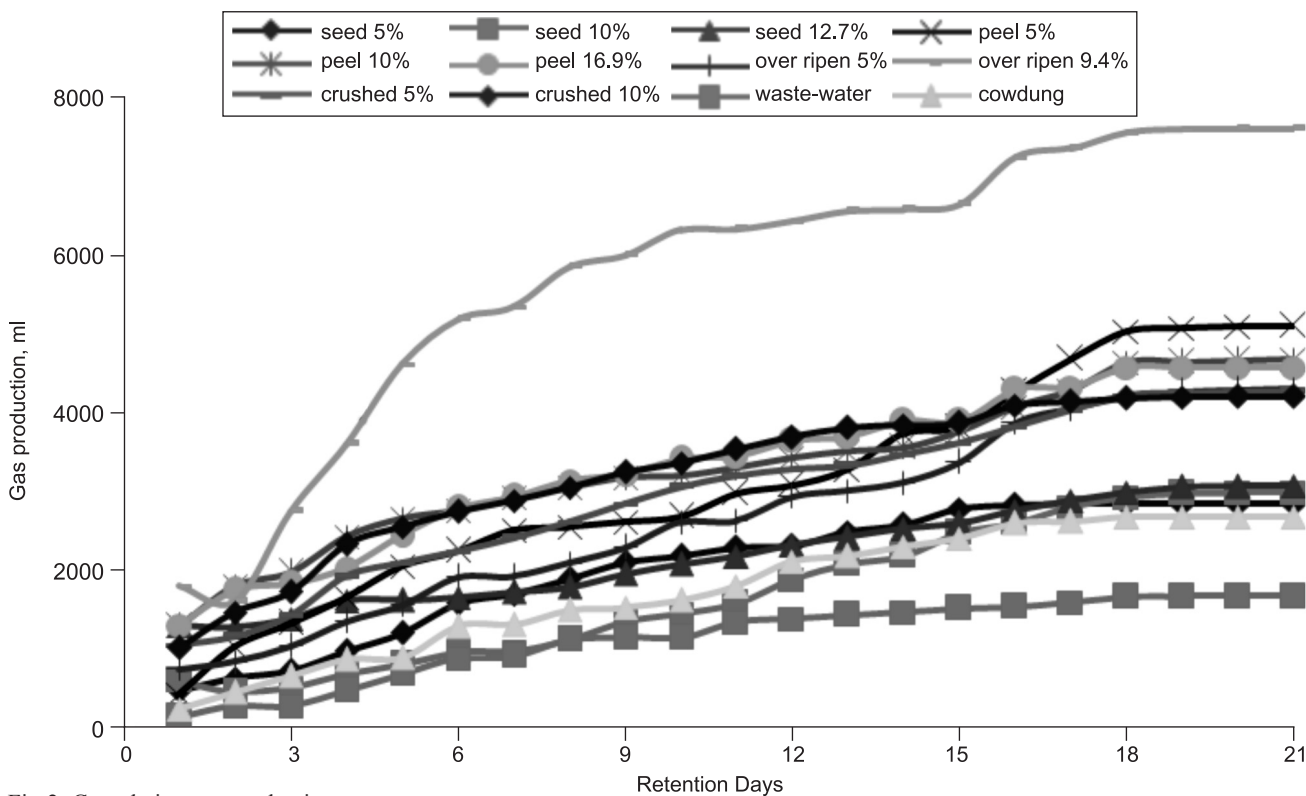


Fig 2 Cumulative gas production

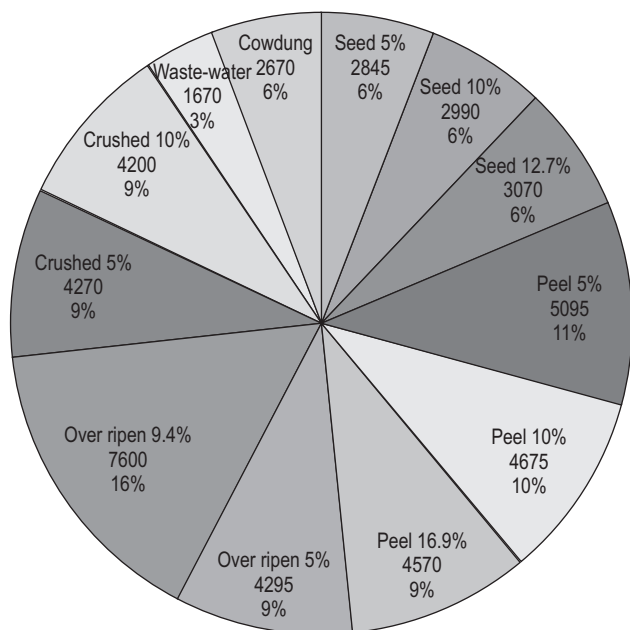


Fig 3 Total gas production

(Llaneza *et al.* 2008) who carried out biogas generation from apple pulp.

Design of UASB hybrid reactor

The design of UASB hybrid reactor was based up on the flow rate, organic loading rate, inflow COD concentration and the velocity of the waste-water by making certain assumptions. The design of the hybrid reactor is presented under the reactor dimensions and GLS separator design.

Reactor dimensions: The reactor dimensions are given under the four topics and represented in Fig 4.

Effective volume of the reactor: The effective volume of the reactor was based up on the flow rate and retention time of the waste-water in the reactor. The retention time of waste-water in the reactor has been taken as 6 hr based on the successful research works (Jeihanipour 2013). The volume has been arrived as 16 m³.

Total volume of the reactor: The total volume of reactor was calculated by considering the effectiveness factor. The effectiveness factor varies from 0.8-0.9 (Iqbal *et al.* 2013). Hence the effectiveness factor was assumed to be 0.85. This gives the total reactor volume of 15 m³.

Area of the reactor: From the flow rate and the velocity



Fig 4 Fabricated high-rate reactor

of the waste-water, the area of the reactor has been arrived. An important assumption about the velocity of waste-water was made. The up flow velocity of waste-water having partially soluble COD was in the range of 1.0-1.25 m/hr based on previous research work (Jiankai *et al.* 2014). The velocity of waste-water was assumed to be 1.0 m/hr and the area of the reactor was found to be 2 m².

Compartmental dimensions: The area has to be considered to maintain uniform distribution of waste-water thereby increasing the microbial activity for effective gas production (Lettinga *et al.* 1997). The height of the reactor is found to be 5.4 m as it comes under 4 to 5.9 m range (Jeihanipour 2013). The GLS height was assumed to be 1.75 m and hence the total height of the reactor was found to be 7.15 m.

Design of gas liquid solid separator: The gas liquid solid separator is an important component in the UASB

Table 4 Biogas generation in percentage per kg of TS and VS added

Treatment	Total biogas production, mL	Average TS content (%)	Average VS content (%) in TS,	Net VS content, Per cent	Biogas production in L/kg of TS added	Biogas generation in L/kg of net VS added
Peel	4570	16.80	96.83	16.27	54.36	56.18
Seed	3070	12.33	90.30	11.13	49.78	55.14
Crushed	4200	9.55	96.20	9.18	87.95	91.51
Over ripen	7600	9.26	97.43	9.02	82.05	84.24
Waste-water	1670	0.75	93.00	0.69	2.22	2.42
Cow-dung	2670	19.80	62.00	12.27	26.96	43.52

anaerobic reactor. And cross of GLS is represented in the. The design is based on slope angle and the diameter (Malina and Pohland 1992). The slope angle must be around 45-60°. The diameter was decided after assuming a 10 cm overlap it makes with the wedge to support. This gave a diameter of 1.73m and the height of GLS was 1.75m (funnel-0.86m and tube-0.89m).

Performance evaluation and power generation

Power generation through biogas is an attractive option for the industry for captive power generation, which is the need of the hour. To combat the problem of power cut it is essential to develop captive power generation. The industry has the solid waste generation of 4 000 kg and water consumption upto 5 000 litre. The total COD level is 25 400 mg/L reactor is evaluated by maintaining the COD level of 5 000, 10 000, 15 000, 20 000 and 25 000 mg/L with a retention period of one day. The COD removal efficiency, TS removal efficiency and VS removal efficiency was found to be about 50, 36 and 29% respectively. The biogas generation potential is estimated to be 60 m³/d. The power generation is calculated to be 96 kWh/day. A 15 kW generator is chosen to generate power.

Cost benefit analysis

The total cost of the system works about ₹ 10 lakh for the high-rate reactor, biogas storage system, Shedder, generator, overhead tank, gas distribution line, feeding system and effluent handling system. The yearly electricity generated is 96 units at a purchase rate of 3.50 per unit by the government, it is able to generate an income of ₹ 115 632 per year compared to the investment at ₹ 10 lakh, payback period is about 8.15 years. The digested slurry from the high-rate reactor is dried and it is possible to get a manure of 58.4 tonnes/year. At a selling rate of ₹ 1 500/tonnes, the cost of manure works about ₹ 87 600 and payback period is about 4.92 year.

- The food processing industry's waste-water (COD: 2 000 mg/L) which was of less-strength with respect to biogas production, was effectively used for the generation of biogas by mixing it with the peel, crushed, seed and over ripen of the fruits (COD: 25 400 mg/L).
- The maximum gas production per kg of total solid content and net volatile content added was observed in crushed and over ripen sample as 87.95, 91.51 L and 82.05, 84.24 L respectively. The minimum gas production per kg of total solids and volatile solids added was observed in waste-water sample as 2.22 and 2.42 L respectively with the digestion period of 21 days.
- Biogas generation potential of the reactor installed in the industry was estimated to be 60 m³/day and the power generation was calculated to be 96 kWh/day. The COD removal efficiency, total solids removal efficiency and volatile solids removal efficiency of the reactor, was found to be 50.0, 36.0 and 29.0% respectively.
- Total cost of the system was 10 lakh, while the income

through electricity generation and manure production were ₹ 115 632 and 87 600 respectively with the pay back period of 4.92 year. On summarising, the reactor installed in the food processing industry proved its superiority with the respect to functional observations and cost economics.

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