Biogas Production From Fruit Waste Using Anaerobic Digestion – Laboratory Studies

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Abstract- *Fruit wastes are one among different types of wastes that need to be treated. Juice industries produce more than 50% of their fruit intake as waste. The current research work mainly focussed on managing and utilising fruit waste generated, by converting the waste to usable form such as biogas. Necessary data regarding the amount of intake, amount of waste generated and disposal option adopted were collected from 15 stalls of Paravur municipality.Different proportions of water, inoculum and fruit waste were used to determine the best proportion which gives optimum production after 24 hours. Result indicated that a mixing ratio of 10:1:2.5 (water, inoculum and fruit waste) gave maximum production of 6140 ±5 ml after 24 hours. Batch studies were conducted in a 5L and 20L reactor. BOD, COD, DO, pH, VFA, TS, TVS and volume of gas production were analysed for a period of 5 days in the batch reactor of 5L capacity.A maximum production of 6800±4 ml was obtained after 48 hours, at a pH of 6.5±0.05. The total solids and total volatile solids at 48hours were found to be 3.31 ± 0.02% and 78.6%±0.03 respectively. COD was found to increase till 48 hours to 164±1.05 mg/l. DO was having a maximum value of 9.8 ±1.05 mg/l, in the 24th hour. VFA was 119.93±1mg/l in the 48th hour. Pilot scale study of the reactor indicated the process stability of anaerobic digestion.*

Keywords- Fruit waste, Biogas, Inoculum, Scale up study, Bioreactor

I. INTRODUCTION

Developmental activities are taking place in all the fields, but these activities become more beneficial and effective if they meet the needs of sustainable development. Sustainable development means, a development in present to meet our needs without comprising the need of the future generation to meet their needs. So it is necessary to introduce a factor of sustainability in all the activities. This can be done by implementing innovative ideas in social, economic and environmental aspects of a country. Rapid industrialisation, urbanisation etc has reduced the total percentage of land available, which force the people to dump the organic as well as inorganic refuses in every nook and corner of the cities of all the developing countries(Minghuaet.al 2009). Quantum of waste generated and dumped will increase greatly in the coming years, as our nation is on its path to become a fully industrialised country by 2020 (CPCB 2004). This unhygienic manner of disposal of waste causes threats to both environment and humans (Gupta et.al 2007). The health and environmental impacts that people perceive with solid waste disposal substantially impact their subsistence practices. Symptoms of poor health were found to increase significantly in peoples who visit the dumping site frequently, people who burn their trash near their home and people who are exposed to smoke and odours from the dump site (CPCB 2004 and Gupta et.al 2007). Improper management of these wastes will release considerable amount of GHGs, which includes CH_4 and CO_2. Methane is about 2.5 times stronger than carbondioxide, in causing greenhouse effect (Ramachandra et.al 2009). Conversion of waste to other forms and its subsequent utilisation is the only solution to get rid of the potential threat of these wastes. Organic waste can be converted to biogas by anaerobic decomposition. Biogas production by anaerobic digestion (AD) is an eco-friendly process which utilises increasing amount of organic matter produced worldwide. A wide range of waste streams, including industrial and municipal waste waters, agricultural, municipal, and food industrial wastes, as well as plant residues, can be treated with this technology. It offers significant advantages over many other waste treatment processes (Classen et.al 1999). The main product of this treatment, i.e., the biogas, is a renewable energy resource, while the by-product, i.e., the digester residue, can be utilized as fertilizer because of its high nutrient content available to plants (Zhang et.al 2011). The performance of the AD process is highly dependent on the characteristics of feedstock as well as on the activity of the microorganisms involved in different degradation steps (Wards et.al 2008). Each stage is characterised by the presence of specific bacteria and the biogas is produced by the combined action of all these bacteria, in which the byproduct of decomposition in one stage becomes the food for the microbes in the other stage(Yong et.al 2010).

India produces all varieties of fruits due to its diverse climate and hence it ranks second in the production of fruits after China. As per the National Horticultural Database published by National Horticulture Board, during 2014-2015, India produced 86.602 million metric tons of fruits. The total area under cultivation of fruits stood at 6.11 million hectare (Batstone et.al 2002).India has more than 4000 fruit processing units having a capacity of more than 12 lakh MT. 20% of the total fruits processed is meant for exports and remaining for defence, institutional sectors and house hold consumption. 50% of the export is contributed by mango and mango based products(APFPEDA). Processing is done to increase the shelf life of fruits. It includes preparation of raw materials, trimming, peeling, cooking and canning. A large volume of effluent and solid waste are generated from processing. Solid wastes are the organic materials, which includes discarded fruits and vegetables(PPAH,2007). Processing industries produces more than 50% of their intake as waste. This work focussed on testing the feasibility of using fruit waste for biogas generation and to provide an effective technique for fruit waste management.

II. MATERIALS AND METHODS

A. Data Collection

Data were collected from 15 fruit stalls in ParavurMuncipality, Kollam district. This includes the quantity of fruit waste generated as well as the disposal methods, if any, adopted by them.

B. Experimental set up

Fruit waste collected from a fruit stall in Paravur Municipality, was used as the substrate for biogas production. A batch reactor of 5L capacity was taken for the study.A 5L conical flask inserted with cork was used as the reactor. Biogas production was measured by water displacement technique. The biogas production was optimised at a proportion of 10:1:2.5(water: inoculum: waste).The experiment was conducted at a mesophilic temperature of 37˚C under anaerobic condition. Contents were mixed in the selected proportion and the reactor was kept for anaerobic digestion for 24 hours. It was then analysed for parameters such as TS, TVS, pH, COD, BOD, DO,VFA and volume of biogas production. Volume of biogas production was measured by water displacement method and the remaining parameters were found out by standard methods (APHA, 2005). All experiments were performed in triplicate. The gas formed was collected in a balloon. The presence of methane was checked by flame test, in which the gas collected in the balloon was allowed to flow towards a burning candle. Presence of methane can be confirmed, if the gas burns with a blue coloured flame.

C. Pilot Scale Study

A batch reactor of 20L capacity was made for the study.Reactor has an internal diameter of 23cm and a total height of 50cm. It was provided with aninlet port and an outlet port, for feeding and for collecting the digested slurry respectively, a port for collecting the gas produced and a control valve to control the flow of gas. Inlet port was made of two pipes of diameters 25mm and 50mm. An increase of area was provided to enable more feeding of substrate at a time. Exit pipe was of 25mm diameter and it was provided at height of 20cm from the bottom of the reactor. A slope of 1H:1V was provided to the exit pipe, which was kept as an indicator for gas production. Once the gas produced gets filled in the space provided, it begins to compress the contents of the reactor and hence moves out through the exit pipe, which indicates the gas production. The reactor was filled with water, inoculum and substrate in the proportion 10:1:2.5 and kept for anaerobic digestion for 24hours at a mesophilic temperature of 37˚C. The enlargement of balloon indicates the biogas production. The presence of methane was confirmed by flame test. The sample before and after digestion was collected and the parameters such as total solids, pH, total volatile solids, volatile fatty acids, BOD and COD were analysed.

III. RESULT AND DISCUSSION

A. Data Collection

Data were collected regarding the amount of fruits intake, daily waste generated as well as the disposal option adopted by the stall owners, if any. Type of fruits and the amount of fruits to each stall varies. Some takes fruits daily and some takes alternately. Data collected from the stalls are shown in Table1.

Table 1: Fruit waste generated from different stalls in Paravur and mode of disposal

Stall Category	Amount of fruit intake (Kg)	Waste generated (Kg)	Disposal method
A (Waste generation >50kg)	400	60	Open dumping
	310	50-60	Open dumping
	420	60	Open dumping
	525	65	Open dumping
B (Waste generation 30 to 50 kg)	300	50	Open dumping
	360	40 to 50	Open dumping
	450	50	Open dumping
	300	30	Open dumping
	400	45	Open dumping
	400	45	Open dumping
	250	40	Open dumping
C (Waste generation 10 to 30 kg)	200	10 to 15	Open dumping
	180	10	Collected by farm owners
	230	15	Collected by farm owners
	165	10	Collected by farm owners

The fruit stalls were divided into three categories based on the amount of waste generated. Fruit stalls having a waste generation greater than 50 Kg were categorised as A, those has 30 to 50 Kg waste generation as B and 10 to 20 Kg waste generation as C. From the study conducted, it was found that out of 15 stalls, 4 stalls belongs to category A, 7 stalls belongs to category B and 4 stalls belongs to category C. 75% of the total fruits stalls generates a daily waste of more than 40 Kg and only 25% generates waste less than 20 Kg daily. Another major observation is that, the disposal option adopted by 80% of the stalls is open dumping. This means that stall owners will often dump the waste into road sides or some other areas which may or may not be collected by municipality agents. The remaining stall owners go for a different option. Instead of dumping the waste, they used to sell their waste to some farm owners at a lower price. It is clear that, out of 15 stalls, 12 stalls does not have a proper waste disposal method. This indicates the necessity to implement a better waste management technique at cities.

B. Scale up study

Selection of Mix proportion

The volume of biogas production for various proportions is given in Table 2

Table 2: Selection of Mix proportion

Proportions	Volume of gas production (ml)
10:1:1 (P1)	2560 ±7
10:1:1.5 (P2)	4034 ±4
10:1:2 (P3)	5120 ± 5
10:1:2.5 (P4)	6140 ± 5
10:1:3 (P5)	5900 ± 4

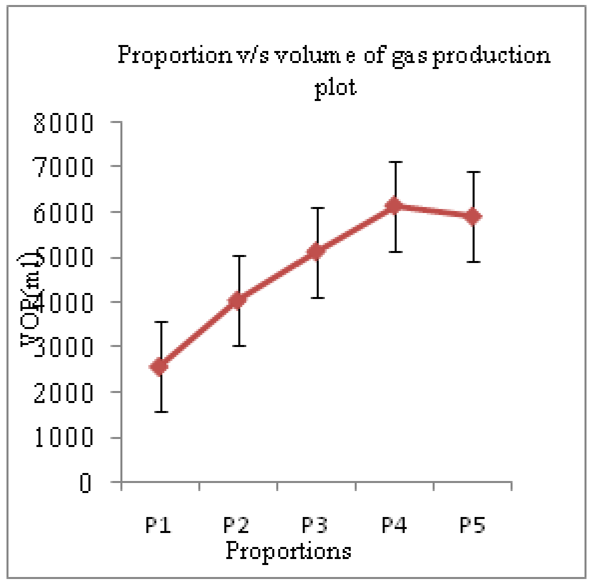

Fig 9: Variation of volume of gas production with proportion

Different proportions of water, inoculum and fruit waste were used to determine the best proportion which gives optimum production after 24 hours. The amount of inoculum and water was kept constant for each proportion and the substrate only varied. The biogas yield increased with increase in quantity of substrate. Beyond a particular amount of substrate, the yield after 24 hours decreased. The biogas production increased from 2560 ml at a proportion of 10:1:1 to 6140 ml at 10:1:2.5. Increase in the proportion after 10:1:2.5 decreased the production. This is because when solids increase, it causes the immobility of the methanogens, thus gradually decreasing the production. Hence, 10:1:2.5 was selected for the study. For a 5L reactor, 3000 ml water, 300 ml inoculum and 750g substrate was added to achieve the proportion 10:1:2.5. Different substrates are used in different proportion for different studies. In a study conducted by Zhanga et al (2013), Kitchen Garbage waste and Municipal Waste Water sludge were mixed in the ratio of 5:1. It increased the production after 20 days. The biogas production was 26.56 L/g VS fed in conventional system and it increased to 46.38 L/g of VS fed on Co-digestion system.In a feed composed of 25% olive pomace and 75% whey, biogas production of 13L/L dasy was obtained, which corresponds to 0.013L biogas/ g TS (Battista et.al 2013).

Parameter analysis of scale up study

Total Solids

Total solid of the reactor was studied for 96 hours and the data obtained are shown in Table3. Some previous studies have stated the importance of TS. Methane production will decrease due to the immobility of methanogens, caused by excess solids(Kossmann et.al 1999). Production will be maximum at a solid range of 6 to 10% and will decrease when TS exceeds 12% (Desai et.al 1994). In a study conducted by Filis et.al, maximum production was obtained ataTS of 4%.

Table 3: Variation of Total solids with time

Time (Hrs)	TS
0	7.58±0.01
24	3.31±0.01
48	2.74±0.02
72	1.58±0.01
96	3.17±0.01

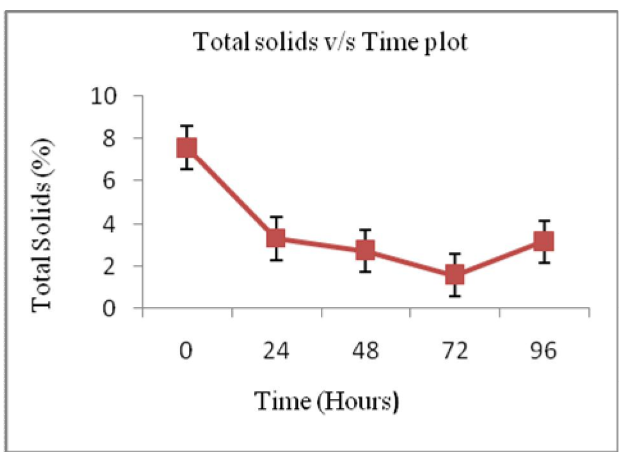

Fig 10: Total solids v/s Time plot

In this study, total solids at the 0^{th} hour was 7.58% and it decreased to 1.58% on 72th hour. After 72 hours, the TS value increased to 3.17%. The decrease in TS till 72 hour was due to the breaking down of organic matter by microorganisms. During decomposition, the organic solids will be utilised by microbes for their growth and will convert it into simpler forms.Maximum biogas production was obtained for a TS content of 2.74%. The increase in the last 24 hrs is attributed to the accumulation of microbial biomass in the reactor.

Total Volatile Solids (TVS)

Total Volatile Solids of the 5L reactor was studied for 96 hours and the results are shown in Table 4. Sample solids lost upon ignition at firing temperature of 550°C (±25°C) are Volatile Solids.Volatile solids represent the organic solids. More the TVS stronger will be the sample. There is an inverse relationship TVS degradation and methane production.

Table 4: Variation of Total Volatile Solids with time

Hrs	0	24	48	72	96
TVS (%)	83.58 ±0.04	78.6 ±0.01	76.68 ±0.03	72.5 ±0.01	64.5 ±0.02

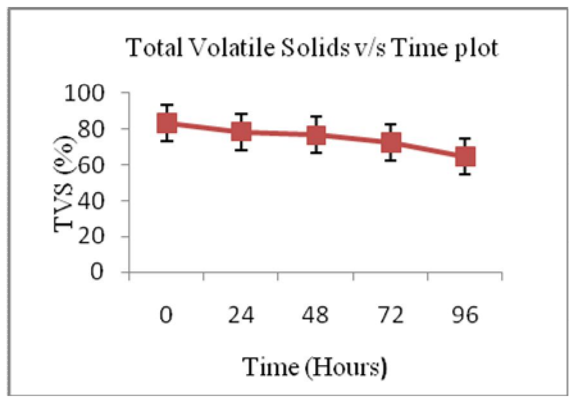

Fig11: Total Volatile Solids v/s Time Plot

In this study, total volatile solids was 83.58%, 78.6%, 76.68%,72.5% and 64.5% for 0,24,48,72 and 96 hrs. It was found that, TVS decreases from 83.58% at 0th hr to 64.5% at 96th hr. maximum production was obtained at a TVS of 76.68%.The decrease in TVS value is attributed to the progressive hydrolysis of the complex organic matter present in the feed. As decomposition progresses, organic solids decreases and thus TVS also decreases.

pH

pH of the 5L reactor was studied for 96 hrs and the values are shown in Table 5. pH is an indicator of acidity or alkalinity or neutral condition of a sample. Fermentative microorganisms can thrive in a pH range 4 to 8.5. pH values in this study was in the range of5.4 to 7.8 during the anaerobic decomposition (Filiz et.al 2016). The pH curve was of dropping nature as shown in Fig 12.

Table 5: Variation of pH withTime

Time (Hrs)	pH
0	7.8±0.15
24	6.5±0.01
48	5.9±0.05
72	5.9±0.05
96	5.4±0.015

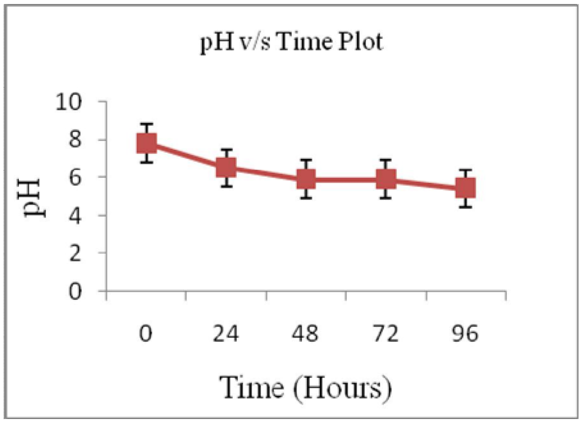

Fig 12: pH v/s Time Plot

pH value was found to decrease from 7.8 at 0th hour to 5.4 at 96th hour. During the first 48 hours, pH dropped with simultaneous increase in VFA production. Peak value of VFA was obtained in the 48 hours. Decrease in pH after 48 hours is attributed to the presence of CO2, produced as part of anaerobic decomposition, in the dissolved form.

Volume of gas production

Volume of biogas production of 5L reactor was studied for 96 hrs and the results are shown on Table 6. In a study conducted, using a mixture of fruit waste and vegetable waste, maximum biogas production of 3.2L/day was obtained at TS content of 8%(Bouallagui et.al 2003). In the present work, the biogas production was 6140ml, 6800ml, 2640ml and 1540 ml respectively for 24, 48, 72 and 96hrs.

Table 6: Variation of Volume of gas production with time

Time (Hrs)	Volume of gas production (ml)
24	6140 ±5
48	6800 ± 4
72	2640 ± 7
96	1540 ± 5

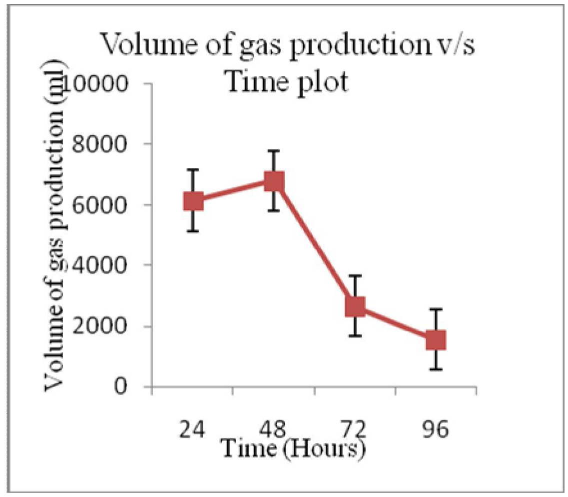

Fig 13: Volume of gas production v/s time

Maximum production was obtained after 48 hours and after that the production decreased.This decrease could be mainly due to a combination of high VFAs (especially propionic acid) and low pH, which decrease theactivity of methanogens.Limited availability of substrate also causes decreased production. in some cases, nutrients may be lacking in the reactor. The decline in production indicates that the time for next loading has occurred.

BOD

BOD of 5L reactor for 24 hrswas studied and the results are shown in Table 7.

Table7: Variation of BOD with time

Hours	BOD (mg/l)
0	7600 ± 2.51
24	10400 ± 2

Initial BOD of the sample was 7600 and it increased to 10400 on the 24th hour. BOD is the amount of oxygen required to cause the decomposition of organic matter. The increase in demand indicates the presence of excess amount of organic matter yet to be decomposed. As BOD increases, the production also increases.

COD

COD of the 5L reactor was studied for 96 hrs and the results are shown in Table 8.COD values first rose and then decreased as shown in Fig 14. Peak value was obtained after 48 hours. During this first 48 hours, the substrate was largely utilised by the anaerobes, which caused the increase of COD.

Table 8: Variation of COD with time

Time (Hrs)	COD (mg/l)
0	32±1.5
24	128±1
48	164±1.05
72	140±2
96	120±1.2

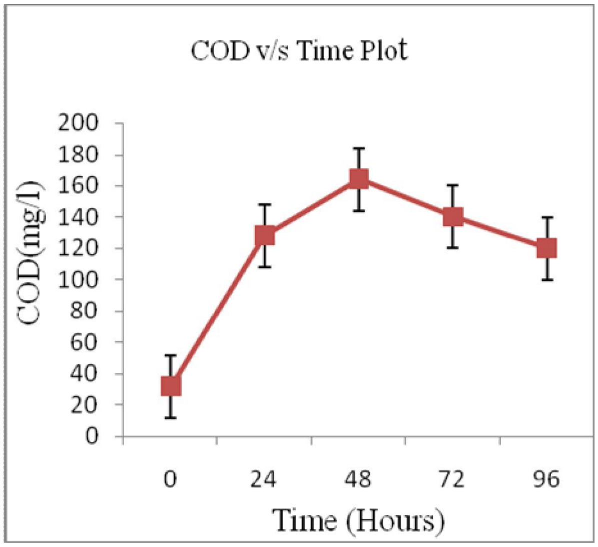

Fig14: COD v/s Time Plot

COD values were found to increase from 32mg/l in the 0th hour to 164mg/l in the 48th hour. After 48 hrs, values were found to decrease with time. COD value of the 96th hour was 120mg/l.Biogas production decreased after 48 hours, which means that there is decrease in organic matter. The decrease in organic matter caused decrease in oxygen demand.

Dissolved Oxygen

DO of 5L reactor was studied for 96 hours and the results are shown in Table 9. Even though dissolved oxygen acts as a toxic or inhibitory agent, it also helps in improved hydrolysis rate. Hydrolysis is often considered to be the rate limiting step, hence, improved hydrolysis rate can improve the overall efficiency of the process(Deshai et.al 2011).

Table 9: Variation of DO with Time

Time (Hrs)	COD (mg/l)
0	7±2.08
24	9.8±1.2
48	9.6±1.05
72	6.2±1
96	5±1.08

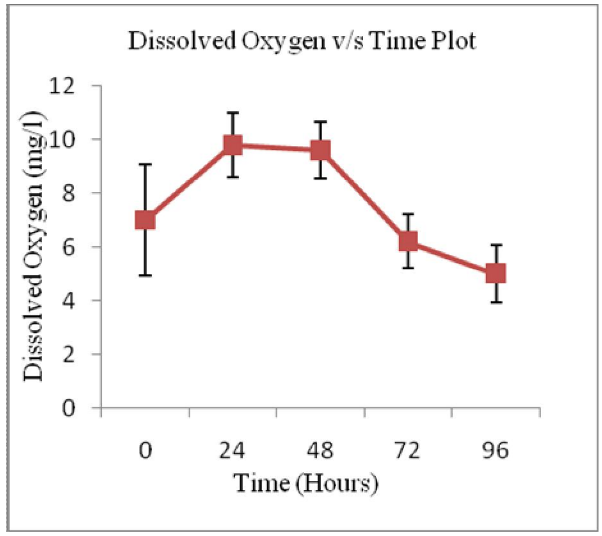

Fig 15: D.O v/s Time Plot

Dissolved oxygen was found to increase from 7mg/l in the 0th hour to 9.8 mg/l in the 24th hour. After 24th hour, D.O level decreased from 9.8 mg/l to 5mg/l in the 96th hour. The increase in oxygen in the first 24 hour may be due to the presence of the oxygen that had entered while mixing and feeding. Some amount of oxygen is also formed during anaerobic decomposition process. The decrease in oxygen after 24 hrs is due to the rapid consumption of oxygen by facultative anaerobic bacteria.

Volatile Fatty Acid

VFA of 5L reactor was studied for 96 hours and the results are shown in Table 10. VFAs are produced during acid ogenesis and then it gets converted into methane and carbon dioxide by acetogenesis and methanogenesis. Variation of VFA with time is shown in Fig 16.

Table 10: Variation of Volatile Fatty Acids with Time

Time (Hrs)	VFA
0	0.8±0.05
24	78.47±0.15
48	119.93±1
72	88.98±1.2
96	78.4±0.05

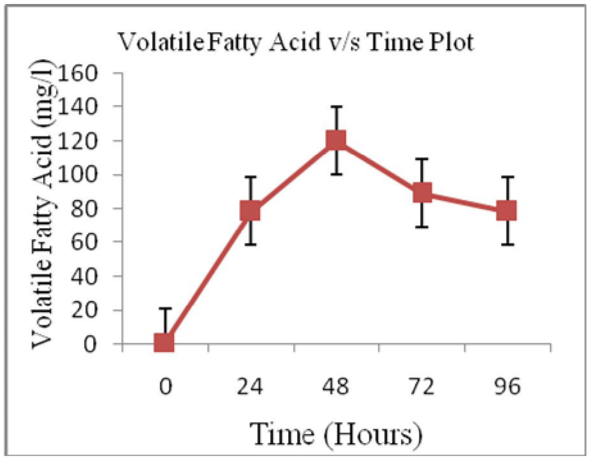

Fig 16: Volatile Fatty Acid v/s Time plot

VFA plot initially increases to a peak value due to the activity of acidogenic bacteria and then it decreases due to the action of methanogenic bacteria. In this study, the VFA varies between 0.8 and 78.40 mg/l. Peak value of 119.93 mg/l was obtained after 48 hours, which indicates that the initial stage of anaerobic digestion was much faster. Excess amount of VFA can inhibit the production process.

Biogas produced was confirmed for the presence of methane by flame test. The collected gas was allowed to flow to a burning candle. The gas burns with blue colour flame which indicates the presence of high concentration of methane. If the gas hinders the burning of candle, it indicates the high concentration of carbon dioxide than methane. The parameters were also analysed in pilot scale study for 0 and 24 hours, similar results were obtained. Flame test gave a blue coloured flame.

IV. CONCLUSION

The gas productions were 6140, 6800, 2640 and 1540 ml for 24, 48, 72 and 96 hrs. Maximum production was obtained in the 48thhr, after that the production decreased. pH was found to decrease with time, which is attributed to the acid production during the anaerobic decomposition and also the dissolved CO2 in the reactor. Total solids was found to decrease till the 72th hour, after that there was a slight increase in total solids which is attributed to the accumulation of microbial biomass. BOD of 24thhr was more than that for 0th hour, which indicates active decomposition. COD values were found to increase till 48th hour, after that it decreased since the biogas production decreased after 48 hours. D.O values were found to increase initially, and then it decreased. Increase in oxygen level may be due to the trace amount of oxygen produced during the anaerobic decomposition and also the oxygen entered while feeding and mixing. The decrease in oxygen level is attributed to the rapid consumption of oxygen by facultative anaerobes. TVS was found to decrease with time, which is attributed to the conversion of organic matter while decomposition. Biogas produced was confirmed for the presence of methane by flame test. The collected gas was allowed to flow to a burning candle. The gas burns with blue colour flame which indicates the high concentration of carbon dioxide than methane.

Fruit waste has shown a greater potential for biogas production. A maximum production of about 6800 ml was obtained from fruit waste after 48 hours. The highly organic fruit waste can be treated and converted to usable forms by anaerobic reactors. The gas produced serves as an energy source and digested slurry can be used as a fertiliser, as it is rich in nutrients.

V. CONCLUSION

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