Methane Generation from Kitchen Waste under Solid Phase Anaerobic Digestion

S. Jayalakshmi

[#]Assistant Professor, Institute of Remote Sensing, Anna University, Chennai – 25, India

Abstract: *The present study is aimed at extraction of energy in terms of methane from the kitchen waste through high solids anaerobic digestion. Laboratory studies were conducted by varying the total solids concentration from 20% to 30% under controlled ($28^oC \pm 5^oC$) and ambient (37^oC) mesophilic condition. Maximum methane yield of 296.7 mL CH_4 / $g_{VS\ added}$ and VS degradation of 62% was obtained at 20% TS concentration. The methane concentration in the biogas with 20% TS concentration was 38 ± 17 % under ambient mesophilic condition and 44 ± 17 % under controlled mesophilic condition*.

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Keywords *Methane, Solid Phase Anaerobic Digestion, and Kitchen Waste.*

I. INTRODUCTION

Anaerobic digestion (AD) is the breakdown of complex organic materials by microorganisms in the absence of oxygen (Jewell et al 1997). The end product of anaerobic digestion includes biogas that comprises of methane, carbon dioxide and some trace gases; and stabilized organic matter (Funchigami et al 2001). Anaerobic digestion of organic fraction of municipal solid waste (OFMSW) has the potential for generating medium BTU gas with an energy content ranging from 4800-5800 kCal/m^3 (Brummeler et al 1992). At present one million tonnes of organic waste per year are digested worldwide (Bolzonella et al 2003). According to Baere (2000) the full scale application of anaerobic digestion process was around 30,000 tons per year during the period of 1990-1995, while the rate of increase averaged 150,000 ton per year for the period 1996-2000. Between 1990 and 1993, more wet digestion plants (<10% TS) were constructed and since then dry digestion (>20% TS) has prevailed (Kayhanian 1995). So far, no clear trends have been observed for these two processes and they are both successfully being used in the new plants. Though the conventional low solid anaerobic digestion is a proven technology for methane generation from municipal solid waste (MSW) the technology for High Solid Anaerobic Digestion (HSAD) system has not yet proved properly. This paper addresses the possibility of extracting biogas from kitchen waste through HSAD.

II. MATERIALS AND METHODS

2.1 Characterisation of Kitchen Waste

The kitchen waste used as the feedstock was collected from kitchen of a hostel with around 1000 inhabitants. The composition of the kitchen waste was studied by manual segregation. The kitchen waste was analysed for moisture content, pH, carbon, nitrogen, total solids and volatile solids as per standard methods (APHA 1998).

2.2 Experimental Setup

The Laboratory scale studies were conducted using 500 mL serum bottles as per biochemical methane potential test. One 500 mL serum bottle was used as digestion bottle and another 500 mL serum bottle was used as gas collection bottle. The mouth of the digestion bottle was closed using rubber cork. Both the digestion and gas collection bottles were connected by flexible rubber tube. The gas collection bottle was kept in an inverted position. The headspace of the reactor was purged initially with nitrogen gas for ensuring the anaerobic condition. The experimental setup of laboratory scale study under ambient mesophilic and controlled mesophilic condition is depicted in Figure 1. The duration of the study varied from 30 to 35 days depending upon the gas generation rate.

2.3 Solid Phase Anaerobic Digestion for Methane Generation

The TS concentration was varied in the laboratory scale study for methane generation from kitchen waste (20%, 22%, 24%, 26%, 28% and 30%). The TS of the kitchen wasted was adjusted by oven drying. The laboratory scale reactors were fed with 100 g of kitchen waste as substrate and 10 g of anaerobically digested biogas plant slurry as *inoculum.*

(a) Ambient mesophilic condition

(b) Controlled mesophilic condition

Figure 1 Laboratory scale reactor setup

The reactors were fed in triplicate to find the repeatability. The experiments were conducted both in the ambient mesophilic ($28^oC \pm 5^oC$) as well as controlled mesophilic condition (37^oC). The experiment under controlled mesophilic condition was conducted with the help of water bath (Figure 1 a).

2.4 Characteristics of Digested Slurry

The slurry was characterized for pH, Total Solids (TS), Volatile Solids (VS), Total Organic Carbon (TOC) and Total Kjeladal Nitrogen (TKN) as per standard methods (APHA 1998). The Total Volatile Fatty Acid (TVFA) concentration was analysed once in three days. The quantity of biogas generated was measured using gas displacement method and the composition of the biogas was analysed for methane and CO_2 daily using Chemito 1000 model gas chromatograph fitted with a thermal conductivity detector and a 1.83 m × 3.18 mm ID stainless-steel column packed with molecular sieve 5A. The operational temperatures of injector, detector and column were kept at 80^oC, 90^oC and 50^oC respectively. Nitrogen was used as a carrier gas at a flow rate of 50 mL/min.

III. RESULTS AND DISCUSSION

3.1 Characteristics of Kitchen Waste

The average composition and characteristics of kitchen waste used for this study is depicted in Table 1 and Table 2 respectively. The waste consisted of about 96 % of biodegradable organics, which were suitable for anaerobic digestion system (Lin and Lay 2004). The food waste was around 66% of the total waste. Vegetable waste was around 27% of the total waste. The eggshell, packing material and ash content were around 1.1%, 1.4% and 3.6% of the total waste respectively.

The optimal pH reported in literature for anaerobic methane generation was essentially within the range of 5.5 – 6.7 (Hawkes et al 2002, Fang and Liu 2002). pH of the waste was 5.51 ± 0.021; moisture content was 83.81 ± 0.2 % wet wt. Total solids and Volatile solid were 16.20 ± 0.2 % wet. wt. and 86.13 ± 0.44 % dry wt. respectively. TOC and TK was 47.58 ± 1.04 % dry wt. and 2.26 ± 0.12 % dry wt. respectively. The C/N ratio was around 20:1 to 23:1, which showed the suitability of the kitchen waste for anaerobic digestion.

Table 1 Composition of the kitchen waste used for the Methane Generation

Sl. No	Component	Weight (kg/day)	Weight (%)	Standard Deviation
1	Food Waste	51.40	66.02	1.86
2	Vegetable Waste	20.10	26.96	2.80
3	Tea Waste	0.75	0.96	0.20
4	Egg Shell	0.85	1.09	0.24
5	Packing Materials	1.10	1.36	0.32
6	Ash	2.80	3.61	0.33
Total		77.90	100.00	3.37

Table 2 Characteristics of kitchen waste

Sl. No.	Parameter	Average	Standard Deviation
1	pH	5.51	0.002
2	Moisture Content (% wet wt.)	83.81	0.200
3	Total Solids (% wet wt.)	16.20	0.200
4	Volatile Solids (% dry wt.)	86.13	0.440
5	Total Kjeladal Nitrogen (% dry wt.)	2.26	0.115
6	Organic Carbon (% dry wt.)	47.58	1.038
7	C/N	21:1	-

3.2 Methane Generation

The biogas generation from kitchen waste by solid phase anaerobic digestion under controlled (37ºC) and ambient mesophilic temperature (28 ºC ± 5 ºC) condition is depicted in Figures 2 and 3 respectively. The reactor operated with 20% TS concentration of kitchen waste generated 4293 mL of biogas under controlled and 3868 mL under ambient mesophilic conditions. The higher concentrations of TS such as 26% to 30% showed very low biogas generation. Vavilin et al (2007) have also reported similar results and attributed this to the inhibition of volatile fatty acids. The maximum biogas generation in the reactors with 20% TS concentration was observed on the 10th day whereas the reactor with 22% was on the 15th day of the reactor operation. The reactors with 24% TS and 26% TS did not show a steady biogas generation. The reactors with 28% TS and 30% TS were very less. This might be due to the overloading of the reactor (higher TS concentration) (Chynoweth and Ronisarson 1987).

The yield of methane is presented in Figure 4. A Maximum methane yield of 296.7 mL CH_4 /g $_{VS\ added}$ and 254.1 mL CH_4/g$_{VSadded}$ was observed in the reactor operated with 20% TS concentration in the controlled and ambient mesophilic temperature conditions respectively. The reactor operated with 22% TS in the controlled and ambient mesophilic conditions showed 254 mL CH_4/g $_{VS\ added}$ and 219 mL CH_4 /g $_{VS\ added}$ respectively. 126 mL CH_4/ g $_{VS\ added}$ and 91 mL CH_4 / g $_{VS\ added}$ were observed in the reactors operated with 24% TS under controlled and ambient mesophilic conditions respectively. The reactors operated with 26%, 28% and 30% TS showed almost equal rate (30 ± 7 mL CH_4 /g $_{VS\ added}$) of biogas generation. The reactor with 20% TS concentration showed 19% higher efficiency than the reactors operated with 22% TS concentration. The reactor operated with 24% TS showed around 50% lesser yield than the reactor operated with 20% TS concentration. The reactors operated with 26% to 30% TS showed around 85% lesser biogas generation than the reactors operated with 20% TS concentration.

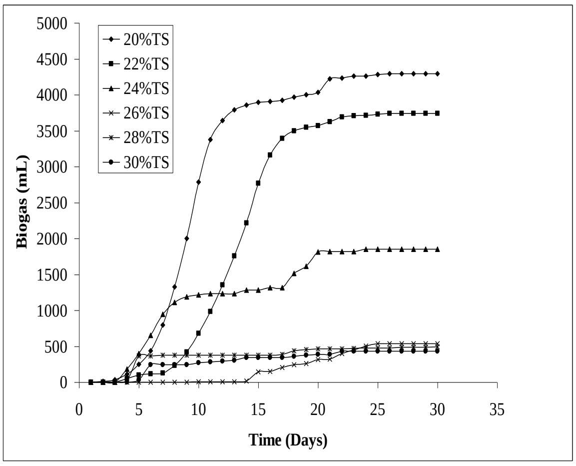

Figure 2 Cumulative generation of biogas under CMT

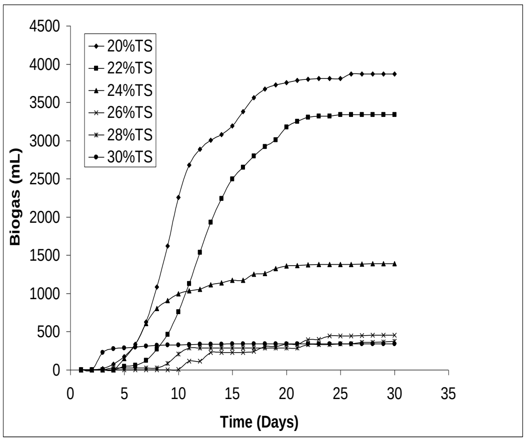

Figure 3 Cumulative generation of biogas under AMT

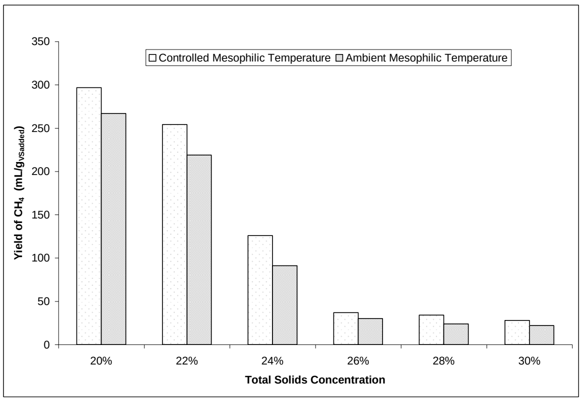

Figure 4 Yield of methane under solid phase anaerobic digestion

The possible reason for this could be the lower pH in the reactor in the initial acidogenic stage (Ranade 1988) as pH less than 6.5 is not favourable for methanogens. The accumulation of ammonia in the latter stage increases the reactor pH (Themelis 2002), which in turn induces the methanogenic activity and hence the observed increase in methane concentration in the latter days of reactor operation. The methane concentration was stabilized from the 25^{th} day onwards.

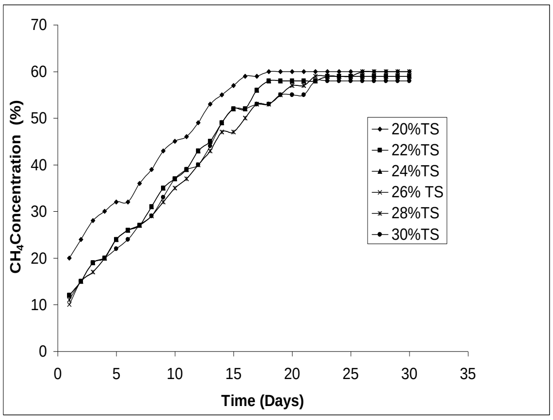

Figure 5 Methane concentration of biogas under CMT

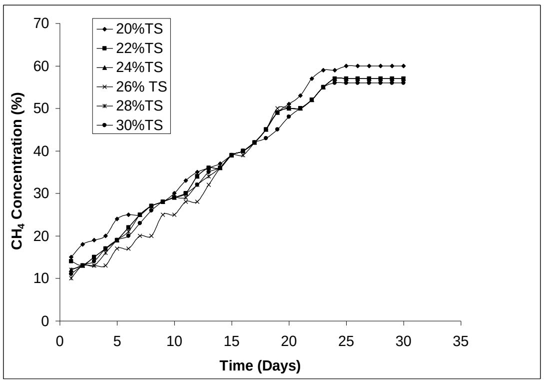

Figure 6 Methane concentration of biogas under AMT

3.2.1 Effect of VFA on Methane Generation

VFA is the most important intermediate generated during the anaerobic digestion (Buyukkamaci and Filibeli 2004). Variation of TVFA from kitchen waste under controlled and ambient mesophilic temperature is depicted in Figures 7 and 8 respectively. The maximum TVFA of 6135 mg/kg was observed in the reactors operated with 20% TS concentration. The minimum TVFA of 3427 mg/kg was generated in the reactor operated with 30% TS concentration. Around 67% of TVFA reduction was observed in the reactor operated with 20% TS and around 50% TVFA reduction was observed in the reactor operated with 22% TS. The remaining reactors showed around 20-30% TVFA reduction.

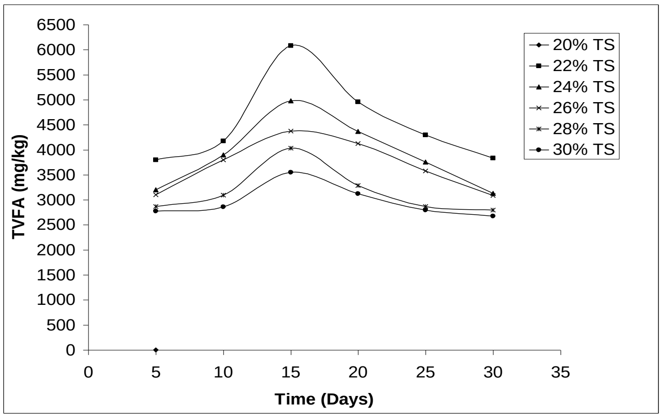

Figure 7 Variation of TVFA under CMT

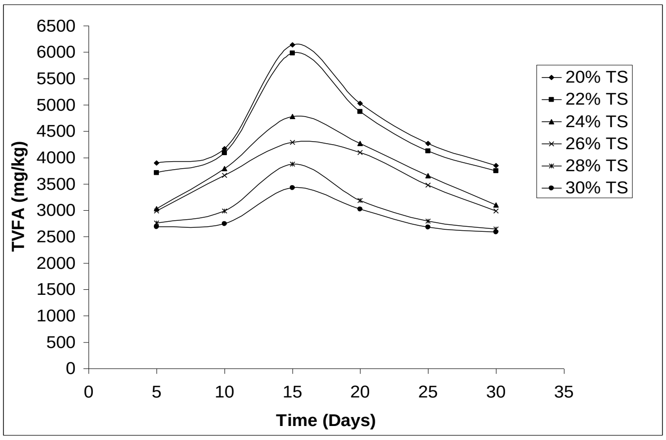

Figure 8 Variation of TVFA under AMT

Initially the TVFA concentration was less, then it increased gradually and the maximum concentration was observed on the 15^{th} day in all the reactors thereafter it started to decrease. The reduction in TVFA is due to their conversion into gaseous products. It is evidenced by biogas generation, the maximum generation was observed on the 15^{th} day of the reactor operation (Figure.2 and Figure 3). After 25 days (stationary phase) the methanogenic bacteria are not capable to utilise the substrate, because most of the bacteria go to death phase. The acetogenic and methanogenic phases are unbalanced in the final stage process and VFA is accumulated (Metcalf and Eddy 1996). The VFA accumulation inhibits the methanogens and the biogas generation gets reduced.

3.2.2 Effect of pH on Methane Generation

The pH variation of biogas generation from kitchen waste under solid phase anaerobic digestion is depicted in Figures 9 and 10 under controlled and ambient mesophilic temperatures respectively. Initially, the pH was at 5.5, which slowly increased to the neutral pH in all the reactors. In the initial days of the reactor operation the reactor pH was in the extreme acidic range due to the generation of volatile fatty acids in the initial acidogenic stage (Zinder et al 1984). In the later digestion stage due to the accumulation of ammonia the reactor pH reached to the neutral condition (Themelis 2002). Though the TVFA concentration increases (Figures 7 and 8) the pH increases continuously. This is due to the presence of uniionized dissociation equivalents of soluble ammonium (Koster and Koomen 1988).

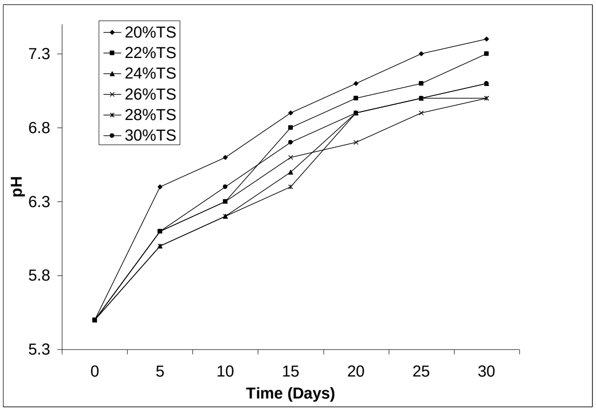

Figure 9 pH variation under CMT

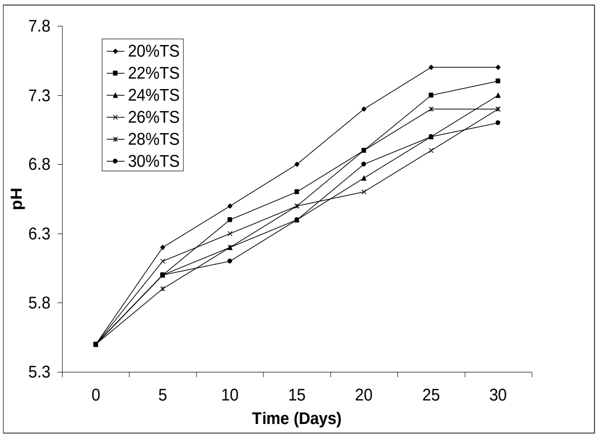

Figure 10 pH variation under AMT

3.3 Characteristics of Digested Slurry

The characteristics of the digested slurry are presented in Table 3 TS degradation of 43 % and VS degradation of 67 % was observed in the reactor operated with 20% TS concentration. The reactors operated with 22% TS concentration showed 42 % and 62% TS and VS degradation respectively. The reactors operated with 24%, 26%, 28% and 30% TS showed 15± 3 % and 36± 4 % TS and VS degradation respectively. The digestion of TS and VS obtained in the present study is lower than the results reported by other researchers (Lastella et al 2002; Gallert et al 2003), this is due to the higher TS concentration. Around 67% carbon degradation was observed in the reactor operated with 20% TS concentration. Around 47% carbon degradation was observed in the reactor operated with 22% TS concentration. The reactor operated with higher TS concentration showed only around 30% carbon degradation, this is due to the overloading of the reactor. Over loading may cause accumulation of inhibiting substances such as fatty acids in the digester slurry (Hori et al 2006).

The ammonia increased to a maximum of around 51% in the reactor operated with 20% TS concentration. Around 46% increase of ammonia was observed in the reactor operated with 22% TS concentration. The reactor with 24% TS showed 35% increase, the other reactors operated with TS 26%, TS 28% and TS 30% showed around 20% increase of ammonia. There is no degradation pathway for ammonia in anaerobic systems, it leads to the accumulation of ammonical nitrogen in anaerobic systems (Ehrig 1989; Burton and Waterson-Crail 1998; Onay and Pholand 1998; Price et al 2003).

IV Conclusion

The reactor operated with 20% TS concentration showed 19% higher yield than the reactors operated with 22% TS concentration. The reactor operated with 24% TS showed around 50% lesser yield than the reactor operated with 20% TS concentration. The reactors operated with 26% to 30% TS showed around 85% lesser yield than the reactors operated with 20% TS concentration. The methane concentration in the biogas with 20% TS concentration was 38 ± 17 % under ambient mesophilic condition and 44 ± 17 % under controlled mesophilic condition. TS degradation of 43 % and VS degradation of 67 % was observed in the reactors operated with 20% TS concentration. The reactors operated with 22% TS concentration showed 42 % and 62% TS and VS degradation respectively. The reactors operated with 24% to 30% Ts showed 15± 3 % and 36± 4 % TS and VS degradation respectively. From the findings it is evidenced that the solid phase anaerobic digestion at 20% TS concentration is suitable for methane generation form kitchen waste.

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