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Production of biogas from municipal solid waste with domestic sewage

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Abstract

In this study, experiments were conducted to investigate the production of biogas from municipal solid waste (MSW) and domestic sewage by using anaerobic digestion process. The batch type of reactor was operated at room temperature varying from 26 to 36 °C with a fixed hydraulic retention time (HRT) of 25 days. The digester was operated at different organic feeding rates of 0.5, 1.0, 2.3, 2.9, 3.5 and 4.3 kg of volatile solids (VS)/m^3 of digester slurry per day. Biogas generation was enhanced by the addition of domestic sewage to MSW. The maximum biogas production of 0.36 m^3/kg of VS added per day occurred at the optimum organic feeding rate of 2.9 kg of VS/m^3/day. The maximum reduction of total solids (TS) (87.6%), VS (88.1%) and chemical oxygen demand (COD) (89.3%) occurred at the optimum organic loading rate of 2.9 kg of VS/m^3/day. The quality of biogas produced during anaerobic digestion process was 68–72%.

Keywords: Anaerobic digestion; Organic waste; Biogas; Organic feeding rate

1. Introduction

The anaerobic digestion of MSW is a process that has become a major focus of interest in waste management throughout the world. The untreated domestic sewage causes severe ecological harm to the area by polluting ground water and surface water, and it must be disposed safely. In India, the amounts of MSW generated in urban areas ranges from 350 to 600 g per capita/day [1]. The amounts of MSW generated in the Chennai Metropolitan city is around 3500 t/day, and contains more than 70% of organic wastes. The organic solid waste includes garbage, vegetable and food waste contains 52%, straw and wood contains 14%, clothes 3.1% and paper 3.5%. The present methods of disposal, like landfills are not suitable because in metropolitan cities like Chennai, where the space is a constraint, valuable land that can be used for diverse purposes is wasted. In other treatment methods, like incineration and pyrolysis, air pollution problems are predominant and initial investments are also usually too high. Anaerobic digestion has been demonstrated to be technically viable [2], and favorable temperature (26–36 °C) exists in Chennai for anaerobic processes [3]. Anaerobic digestion is a multi-stage process occurring in the absence of oxygen, where bacteria are the primary organisms involved [4].

The well-established digesters, pH of the fermenting mass are buffered between 6.8 and 7.4. Bacteria have limited range of temperature, in which they are active. Methanogens, in particular, are very sensitive to temperature changes. In this manner, the optimum temperature of anaerobic digestion ranges from 30 to 40 °C [5]. During fermentation of organic wastes, acetic acid is usually the main product. The excess production of volatile fatty acids (VFA) may result in an inhibitory effect on the fermentation of organic wastes [6]. The potential biochemical methane production yield from MSW and water can be as 0.2 m^3/kg of VS added [7].

The nitrogen and phosphorus contained in the MSW and domestic sewage are sufficient to satisfy the cell growth requirements during biogas production. The others elements, such as sodium, potassium, calcium, magnesium and iron are present in low concentrations. However, they may exhibit inhibitory effects at higher concentrations [8]. The experiment done with tomato waste processing showed that the influence of HRT depends on the organic loading rate and temperature. High yields of methane production (0.42 m^3/kg of VS) were obtained at the HRT of 24 days [9].

In our investigation domestic sewage was used in all anaerobic digestion experiments for diluting the feedstock to get the

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required concentration of TS. This prompts us to investigate the influence of domestic sewage on the biogas production from MSW.

Bioconversion of MSW is a non-polluting, environmentally feasible and cost effective process [10,11]. The main aim of this present study is to evaluate the effects of synergism and integrated use of biogas technology in order to dispose jointly MSW and domestic sewage, as well as to obtain biogas [12]. The effluent and digester residues are rich in nitrogen and phosphorus, which can be returned to the soil as a fertilizer [13].

2. Experimental

2.1. Feed stock

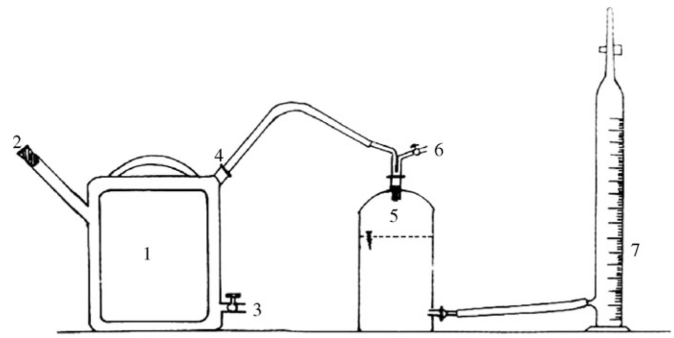
The MSW is collected from the Perungudi yard at the Chennai metropolitan city. The yard has an area of approximately 10 km^2. The population of the Chennai metropolitan city is 6.5 million [14]. Trucks transport the MSW collected from the point sources. The hand sorting method is applied. The Organic wastes used in digestion experiments are collected separately, dried by natural methods, shredded to a maximum particle size of 2–4 mm and stored in a plastic container at room temperature prior to characterization. Table 1 shows the composition of the MSW.

Domestic sewage is collected from a college campus before disposal to the treatment plant. It is used in all digestion experiments for diluting the feedstock to achieve the required total concentration of TS. Sludge obtained from the septic tank of a college campus is used for seeding the digester.

The domestic sewage is added to MSW, which is in the form of dry and shredded waste. Here both the wastes are mixed so that it forms slurry. The sewage contains organic solids and methanogenic bacteria, which can be easily feed into the digester, which increase the concentration of the substrate. This mixed culture is developed outside the digester. Once the culture enters the digester directly the decomposition process starts and the gas production rate simultaneously increases.

2.2. Anaerobic digester

Experiments are carried out in a 5 L batch-type reactor operated in semi-continuous mode with daily feeding. The digester is operated at a room temperature varying from 26 to 36 °C throughout the experiment with a constant HRT of 25 days with different organic feeding rates of 0.5, 1.0, 2.3, 2.9, 3.5 and 4.3 kg of VS/m^3 of digester slurry per day. Fig. 1 illustrates the experimental set-up.



1. Digester (V=5 L) capacity
2. Feed inlet and effluent outlet
3. Sludge outlet
4. Gas opening
5. Water displacement jar
6. Gas outlet
7. Measuring jar

Fig. 1. The experimental set-up.

The digester is equipped with two parts at the top, one for feeding and effluent discharge, and another for biogas line, which is connected to the calibrated measuring cylinders with water displacement arrangements to measure the volume of gas, collected.

The digester is started by charging with 2.75 L of feed stocks (2% TS) along with 2 lit of feed sludge. The digester is maintained anaerobically and it is allowed to stabilize for 2 weeks. During this stabilization period, first 1-week digester temperature of 26–36 °C is monitored and pH is maintained in the range of 6.5–7.5 by adding sodium hydroxide and COD also monitored. Second week TS and VS reduction and biogas generation was monitored. Increasing the VS concentration in the feed whose concentration can be changed by adding MSW and domestic sewage varies the organic loading rate. HRT of 25 days is maintained by feeding 180 mL of substrate and removing 180 mL of effluent daily. Steady-state condition is identified when the COD value of the effluent and daily biogas production is measured to be the same for two or three consecutive days.

2.3. Analytical methods

The influent and effluent parameters, such as COD, TS, and VS are measured once a week. VFA concentrations in the digester at different organic loading rates are also measured.

Table 1
The characteristic of MSW

Component	% wet weight
Plastics	1
Stones	5.2
Clothes	3.1
Paper	3.5
Organics fraction (garbage, vegetables, etc.)	52
Straw & Wood	14
Rubbish Straw & Wood	18
Glass	2.5

Table 2
The chemical characteristic of MSW

Parameters	Percentage (wet basis)
Moisture content	54.7
Total solids (TS)	45
Volatile solids (VS) (% of TS)	50
Ash	14
pH[a]	6.8

[a] Not applicable to unit.

Table 3
The chemical characteristic of domestic sewage

Parameters	Ranges (mg/L)
pH[a]	6.5–7.3
Total solids (TS)	320–800
Alkalinity	190–240
BOD	200–300
COD	400–600
Chlorides	180–220
Sulphates	300–550
Volatile solids (VS)	250–380
Dissolved oxygen (DO)	<1

[a] Not applicable to unit.

All parameters summarized in Tables 2 and 3 are as measured using methods described in "Standard methods for the examination of water and wastewater", published jointly by APHA, AWWA, WEF [15]. The biogas composition was confirmed by gas chromotograph. The available methane 68–72%, carbon di oxide 18–20% and hydrogen sulphide 8% was present.

3. Results and discussion

Production of biogas during anaerobic process at different organic loading rates is presented in Fig. 2. The biogas production increases from 0.13 to 0.36 m^3/kg of VS added as organic feeding rates are increased from 0.5 to 2.9 kg of VS/m^3/day. Further increase of the organic feeding rate as 3.5 kg of VS/m^3/day results in decreased biogas production rates. The increased degree of biogas production is due to the addition of domestic sewage, without dissolved oxygen (DO) present but with some readily available facultative and methanogenic microorganisms, which could utilize the substrate and accelerate the biogas production rate.

Fig. 3 shows the evolution of the TS reduction versus the organic loading rate. The reduction of TS is measured for the concentration of both MSW and domestic sewage of high concentration effluent. The maximum reduction degree occurs at the organic feeding rate of 2.9 kg of VS m^3/day, which corresponds to high purification effluent of TS reduction 11256 mg/L. This may be due to the stable degradation of the substrate, as well as the addition of domestic sewage at subsequent stages to stabilize the anaerobic degradation.

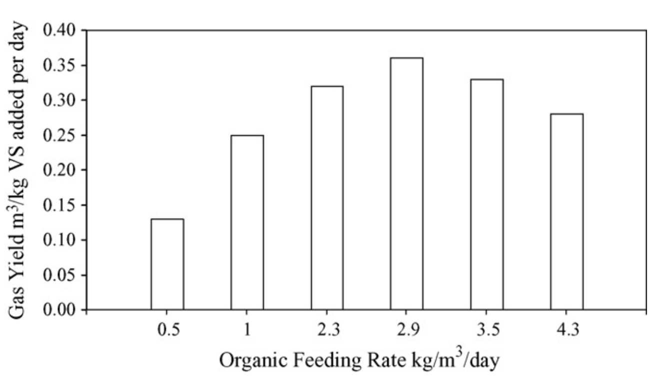


Fig. 2. Organic feeding rate vs. biogas production yield.

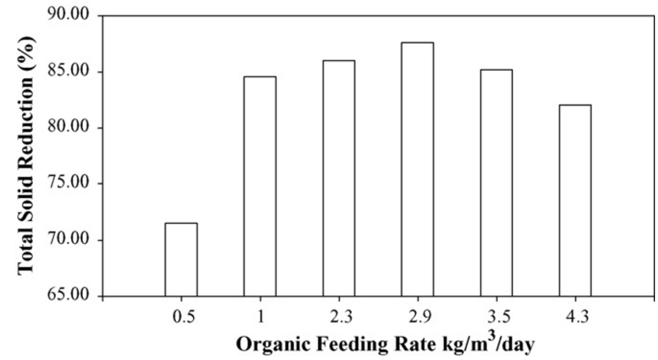


Fig. 3. Organic feeding rate vs. reduction of TS.

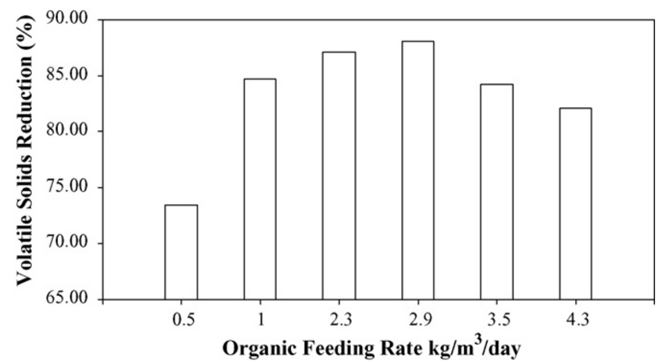


Fig. 4. Organic feeding rate vs. reduction of VS.

Fig. 4 shows the VS reduction versus the organic loading rate. VS is an important parameter for measuring biodegradation, which directly indicates the metabolic status of some of the most delicate microbial groups in the anaerobic system. The VS reduction is measured for the continuous addition of both MSW and domestic sewage of high strength effluent. The initial range of VS reduction is 73% only. After the continuous feeding of substrate, the VS 87% reduces gradually. The activities of microorganisms increase with the increase of temperature, reflecting stable degradation of the substrate. The reduction of VS denotes the process stabilization. Addition of domestic sewage at subsequent stages stabilizes the anaerobic degradation, which gives the stable reduction of VS without inhibition.

Fig. 5 presents the COD reduction versus the organic loading rate. After the first three feedings of MSW and domestic sewage

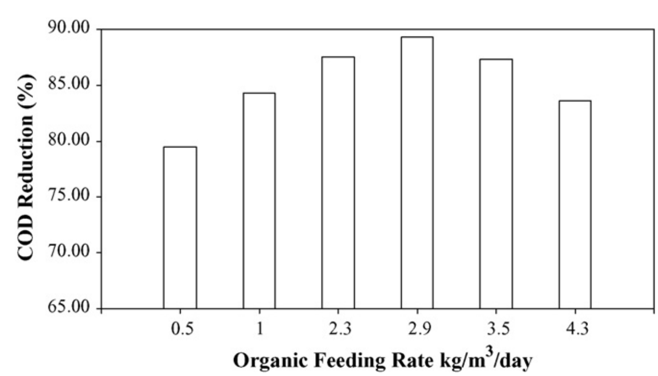


Fig. 5. Organic feeding rate vs. COD reduction.

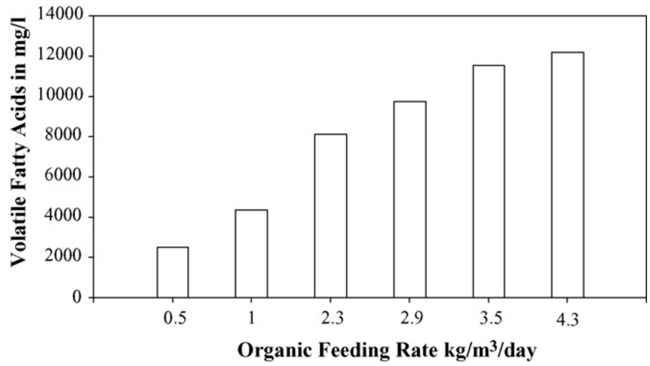


Fig. 6. Organic feeding rate vs. reduction of VFA.

in the experiment, the COD reduction is the maximum at 85%. After this adaptation period, the reactor stabilizes and the COD of the effluent is further reduced to 89%, which corresponds to high purification efficiency of COD removal 6400 mg/L.

Fig. 6 shows that the VFA concentrations increase from 2515 to 12210 mg/L as organic feeding rates are increased from 0.5 to 4.3 kg of VS/m^3/day, which is significantly influenced by the addition of MSW and domestic sewage. After 35 days (stationary phase) the methanogenic bacteria are not capable to utilize the substrate, because most of the bacteria changes to death phase. Finally the remaining waste material in the digester changes to acidic stage ultimately the generation of biogas is reduced [16]. The acidogenic and methanogenic phases are unbalanced in the final stage process and VFA is accumulated. Further increase of organic feeding rates of 3.5 kg of VS/m^3/day results in an increase of concentration of VFA and inhibits the methanogenic bacteria, which in turn causes the reduction of the biogas production yield. It is found that the maximum reduction of TS (87.6%), VS (88.1%) and COD (89.3%) occur at the optimum organic feeding rate of 2.9 kg of VS/m^3/day.

4. Conclusions

The favorable environment created by the addition of MSW and domestic sewage can explain this enhancement. The addition of domestic sewage to MSW has an inhibitory effect on methane gas production from the mixed anaerobic cultures in slurry form in the reactor. While MSW is increases the microorganism's population, domestic sewage addition increases the concentration of available soluble substrate required by the microorganisms. The maximum amount of methane production is 0.36 m^3/kg of VS added per day. The effluent contains high nutrient content i.e. N, P, K, of 60%, 73% and 70%, of sludge, respectively. These nutrients can be used as natural fertilizers in the agriculture. Successful implementation of anaerobic digestion as the method of waste treatment leads to the regional utilization of renewable energy resources with site-specific application depending upon local resources, energy requirements and costs. The disposal problem of MSW and domestic sewage can also be solved substantially.

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