Influence of Nitrogen for Anaerobic Digestion of Municipal Solid Waste in a Laboratory Scale Reactor

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Abstract

The recent trends of increasing awareness of economic and environmental cost of conventional landfilling are being developed in accelerating pace for the degradation of the organic fraction of municipal solid waste (MSW). The anaerobic digestion (AD) is viewed as an attractive method for waste stabilization prior to landfills as a pre-treatment processing to reduce the significant fraction of organic pollutant as well as to generate methane as a fuel gas.

Batch studies were carried out in aspirator bottles of different capacities to select critical factors influencing the single stage high solid (SSHS) approach development with an emphasis on C/N ratio. At first the maximum total solid concentration was optimized for maximum biogas yield. At the optimum solid concentration, further experiments were processed for varying C/N ratios to examine the influences of nitrogen content in the waste for biomethanation.

The paper describes the performance of AD system of MSW in a laboratory-scale reactor for varying C: N ratio inputs. An optimum C: N ratio of 43.5 has been evaluated for maximum biogas yield.

1.0 Introduction

Unmanaged pollutants from organic farm waste, industrial and MSW degrades the environment and methane emitted from their decomposition contributes to global climatic change (Fricke *et al.*, 2005). Under modern environmental regulations in general and MSW (Management and Handling) Rules, 2000 promulgated by Ministry of Environment and Forests (MoEF), Govt. of India, New Delhi in particular, these wastes are becoming difficult to dispose off employing traditional methods.

There are various technologies for MSW processing and disposal at Global level. However, in India, open dumping is commonly being practiced. The huge quantity of MSW generated is mostly disposed off on land without adopting any precautionary measures. This results in contamination of air and water environments as well as influences the health of the society (Cecchi *et al.,* 1986; 1993). Though landfill sites are the sources of methane, the landfill gas needs to be purified to increase the methane concentration. Moreover, methane can be recovered for a limited period of time depending upon the life of the landfill site, the quantity of waste dumped at a particular site, and the methane potential of the dumped waste (Estimates of US Biomass Energy Consumption, 1994). Thus, the sanitation problem contributed by MSW is alarming and needs immediate attention on priority basis. Lands are also becoming scarce for disposal of waste, which pressurizes to look for integrated approach for MSW management. Also, due to an increasing awareness of economic and environmental cost of conventional landfilling, recent interest is to develop the technologies that accelerate the degradation of the organic fraction of MSW. An option is to digest the organic fraction prior to landfilling, or to preserve landfill space by accelerating the decomposition of the organic fraction within the landfill. Vermicomposting, as an alternative, is being used in many of the municipalities in India. But, inferior quality of compost and high cost has resulted in low-market demand. Hence biomethanation of MSW has drawn special attention of the researchers, stakeholders and policy makers. The Government of India has announced a national policy to promote and provide financial support to waste based power projects (Proceedings of 1st Workshop on National Master Plan, 2000). The advantage of biomethanation is that after extracting energy from waste, the digestible residue can further be bioprocessed to composting. The primary level of stabilization of organic matter in biomethanation process when coupled with composting gets maximum stabilization suitable for agriculture/land application. The inert in MSW in a condition of high level of stabilization by composting is easier to separate for landfilling. Apart from yield of biogas, AD creates solid and liquid byproducts, which can have value as a fertilizer or soil amendment (Cecchi *et al.*, 1991; 1992). The amount, quality and nature of the products will depend upon the quality of MSW feedstock, method of digestion (wet or dry) and the extent of the post-treatment refining processes. The C/N ratio of the organic matter as 25:1 is the optimum ratio for maximum microbial activity (Rao *et al.*, 2000). One of the major problem most frequently found during biological processing of the organic fraction of MSW is the high C/N ratio of the residues (Gomez *et al.*, 2005).

AD has been up to now essentially applied to wastewater management (Nopharatana *et al.*, 1996;

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Laclos *et al.*, 1997). However, anaerobic processing of organic solid waste fits in well with the new requirements for waste management. In connection with the utilization of renewable energies and the rising relevancy of climate protection, it can be affirmed that AD for the treatment of MSW has a high potential for future development. AD for wastewater is being practiced since long back when AD was mainly aimed as a treatment alternative. For MSW, it is processing option and it is better to considered as biomethanation.

The performance study of MSW and the effect of C: N ratio in AD of MSW has been presented in this paper.

2.0 Objectives of the Study

The study has been carried out with the following objectives,

- To identify the optimum total solid concentration, which gives maximum biogas production;
- To study the influence of pH on biogas production in high solids digester.
- To study the influence of C/N ratio in anaerobic degradation;
- To find out the optimum C/N ratio, which corresponds to maximum biogas yield.

3.0 Materials and Methods

The solid waste sample was collected from Laxminagar zone of Nagpur Municipal Corporation, India. About 50 kg of MSW samples were grabbed from five wards in the above area. These were mixed thoroughly. Sample for the present experiment was drawn on the basis of quartering technique. The physical characterization of MSW was done by separating one quarter. After that, inerts such as plastics, metals and glass items were isolated manually. No further preprocessing of MSW was done. This constitutes the base material for drawing samples for chemical characterization as well as for conducting various experiments. The physical and chemical characteristics of the wastes are presented in **Tables 1** and **2**. Laboratory-scale unit consists of glass aspirator bottle of suitable capacity (such as 2 litre or 5 litre) as reactor, another glass aspirator bottle of suitable size (such as 1.5 litre or 3 litre) for biogas filled with acidified brine solution along with a conical flask of suitable capacity to collect displaced brine solution. Suitable arrangement for pH electrode was provided with each set. The schematic of a series of single-phase experimental set-up is shown in **Figure 1**. A laboratory scale single-phase anaerobic reactor is shown in **Figure 2**.

Initially, batch studies were carried out in aspirator bottles of different capacity to select essential factors influencing the single stage approach for the development emphasizing on total solid concentration, C/N ratio, and temperature.

Effects of C/N Ratio

The experimental set for 50% total solid concentration, which gives maximum biogas yield during the experiment period, was selected for further study with varying C/N ratio. The experiments were conducted by selecting appropriate C/N ratios (between 20-60) in 2 liter reagent bottles.

This run pertains to the effect of different C/N ratios. In the first set, for the adjustment of C/N ratio of 20, 500 g of MSW was mixed with 28.30 g KNO_3 dissolved in 500 ml tap water. For preparing C/N ratio of 30, 500 g of MSW was mixed with 10.9 g of KNO_3 dissolved in 500 ml of tap water. In the third set, 500 g of MSW was mixed with 500 ml of tap water maintaining the C/N ratio of 43.5. In the fourth set,

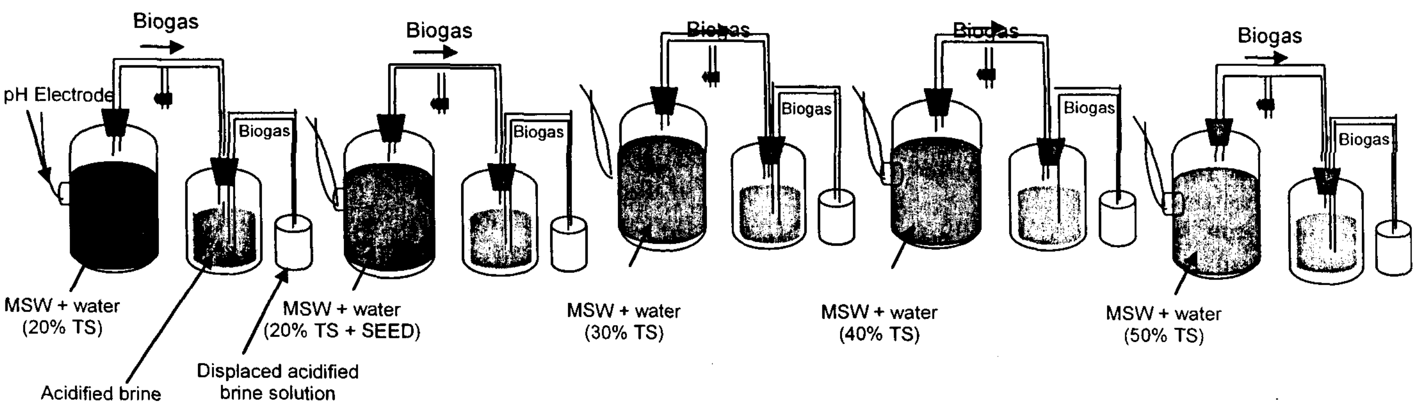

Figure 1: Experimental Set-up of a Series of Single Phase Anaerobic Reactor.

Table 1: Physical Composition of MSW Sample

Sl. No.	Constituent	Percent by mass
1	Coarse Organics	48.00
2	Paper	7.17
3	Plastics*	4.50
4	Coconut	1.93
5	Rubber/Leather	4.20
6	Metals*	1.95
7	Glass*	1.86
8	Rags (textile)	6.89
9	Fine Organics, Earth and Ash	20.00
10	Stones, Bricks, *etc.*	3.50

*Components removed for laboratory experiments

Table 2: Chemical Composition of MSW

Sl. No.	Parameters	Values
1	Moisture Content	35.0%
2	pH	6.5
3	Loss on Ignition	64.70%
4	Carbon	37.53%
5	Nitrogen	1.10%
6	Phosphorous	0.60%
7	Potassium	0.75%
8	C/N Ratio	34.12
9	Calorific Value	800 kcal/kg
10	Fermentable Organic Substance	27%

* All values except moisture content are on dry weight basis.

500 g of MSW was mixed with 123.5 g of cardboard and 500 ml of tap water adjusting the C/N ratio of 50. In the last set, 377 g of MSW was mixed with 123.5 g of cardboard and 2.18 g of KNO_3 dissolved in 500 ml water with the adjustment of C/N ratio of 60. The biogas yield was observed by displacement of acidified saturated brine solution. The experiments were carried out under controlled conditions at a temperature of 30 ± 31°C. Another set was also repeated at various C/N ratios under ambient room temperature. Preparation of feed at different C/N ratio is presented in **Table 3.**

The experiments were conducted at room temperature and the parameters checked daily were the biogas volume and pH of the feed inside the digester. The results of gas volume/ Kg of MSW and pH variations are described in **Table 4.**

To maintain control conditions of temperature, digital hot air oven is used the temperature is maintained between 30-33°C. pH was monitored everyday using glass electrode and pH meter.

Table 3: Preparation of Feed at Different C/N Ratio (with TS 50 %)

C/N ratio	Wt. Of MSW	Vol. of water (ml)	Wt. Of Cardboard (g)	Wt. of KNO_3 (g)
20	500	500	Nil	28.30
30	500	500	Nil	10.90
43.5	500	500	Nil	Nil
50	500	500	123.50	Nil
60	377	500	123.50	2.18

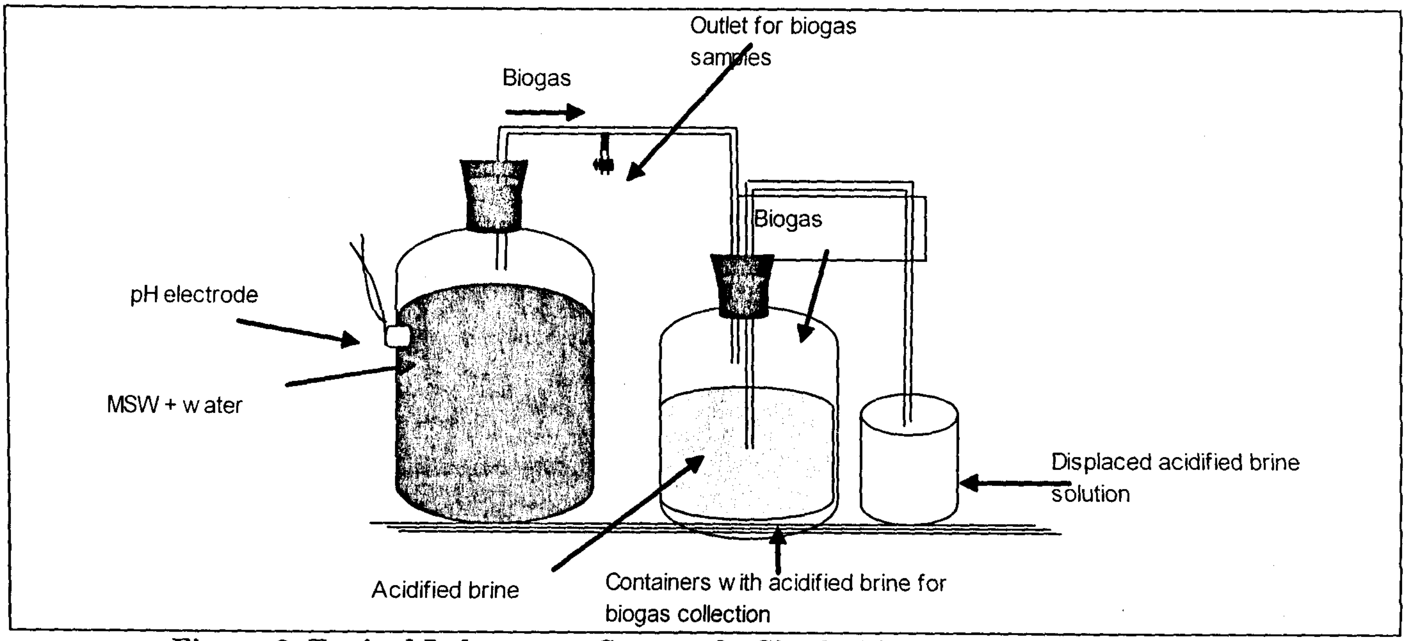

Figure 2: Typical Laboratory Set-up of a Single Phase Anaerobic Reactor.

Table 4: Feed Preparation of Different Total Solid Concentrations

Total Solids	Wt. of MSW (g)	Vol. of water (ml)
40%	1600	2400
50%	2000	2000
60%	2400	1600

5.0 RESULTS AND DISCUSSION

Investigations on the effect of C/N ratio

The trials were done with varying C/N ratios as 20, 30, 43.5, 50& 60 respectively. The original C/N ratio of the waste was 43.5 and the rest were adjusted by using KNO_3 and cardboard. Total Solid concentration was adjusted as 50%. These trials are done at high solid AD. The daily monitored parameters were pH of the digester content and biogas volume. The detention time allowed to the digester was 60 days. The pH variation is presented in **Figure 3.**

The pH variations in all the digesters were in between 6 to 8. This is in accordance with the conclusion obtained from the earlier studies (Lay *et al*, 1997). But the set up with C/N ratio 50 showed some deviation. From 45th day of the experiment, the pH of the digester decreased to 5.69 and achieved a lowest value *i.e.*, 5.66 and again started increasing and reached a value of 6.09 after one week.

Even though all the digesters exhibit the optimum pH range (6.6-7.8) and acceptable range (6.1-8.3), the biogas production was observed only in digesters with C/N ratios 20 & 43.5. The biogas production data is presented in **Figure 4.** In Digester with C/N ratio 20, pH variations was between 6.77-7.03 for maximum gas production and that for C/N ratio 43.5, it was between 6.51-6.85.

At higher C/N ratios, the nutrient availability will be less. Nitrogen is regarded as a nutrient for anaerobic conditions and the buffering effect caused by ammonia will get decreased. Both phosphates and ammonia are regarded as nutrients (Barlaz *et al.*, 1992; Sterling *et al.*, 2001). A high C/N ratio is an indicator of rapid consumption of nitrogen by methanogens. This may be the reason why the digesters do not shown significant gas production with C/N ratios as 50 and 60. As unsorted wastes have been used, some potential inhibitor perhaps exists in the digester with C/N ratio 30. Cation concentrations are sometimes inhibitory to AD (Barlaz *et al.*, 1990). This can be attributed to the reduced performance of digester with C/N 20 (0.383L/Kg MSW). The trial with C/N ratio 43.5 showed maximum performance (5.33L/Kg MSW).

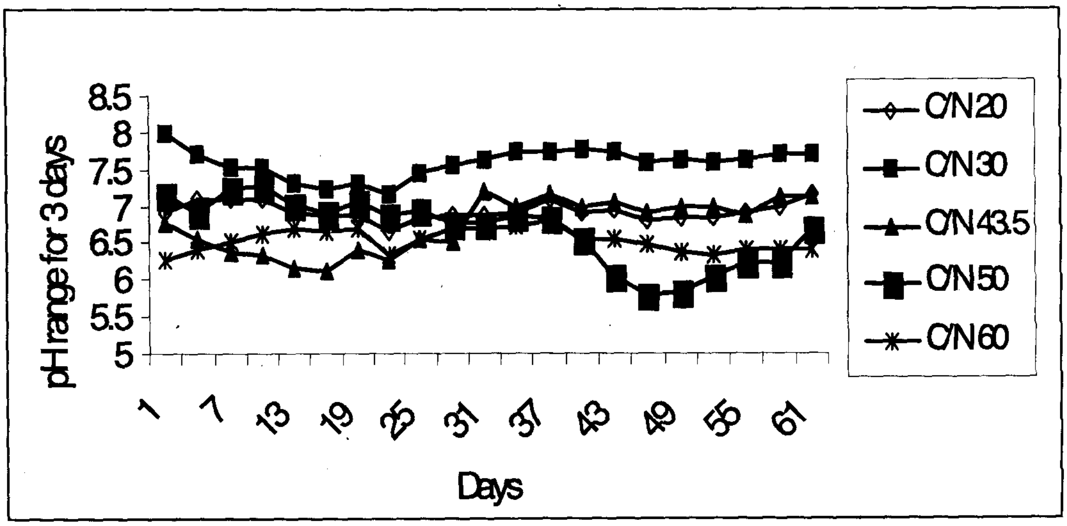

Figure 3: pH Variations during AD at Different C/N Ratios (TS 50%)

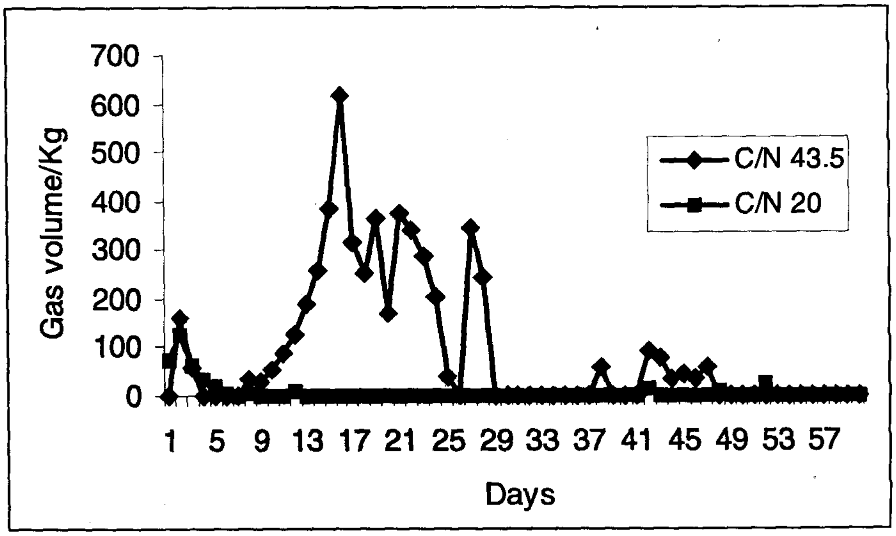

Figure 4: Gas Production for Different C/N Ratios

Investigations with High Solid Concentrations (Controlled temperature conditions)

The temperature was kept in between 30-33°C. The room temperature was in between 20-30°C. The experiments were done with total solid concentrations 40, 50 and 60%. The results for pH variations are shown in **Figure 5.**

In the digester with 40% concentration, pH range was 5.5-6.81 and in the digester with 60% concentration, it was 6.33-6.77. But in the case of digester with 50% TS, pH lowered to 4.43 and reaching maximum at pH 6.35.

The production of biogas in the digesters is plotted in **Figure 6.** A biogas yield of 18.979L/Kg of MSW was observed in the digester with TS 40%. For 60% TS, yield was reduced to 1.667L/Kg of MSW.

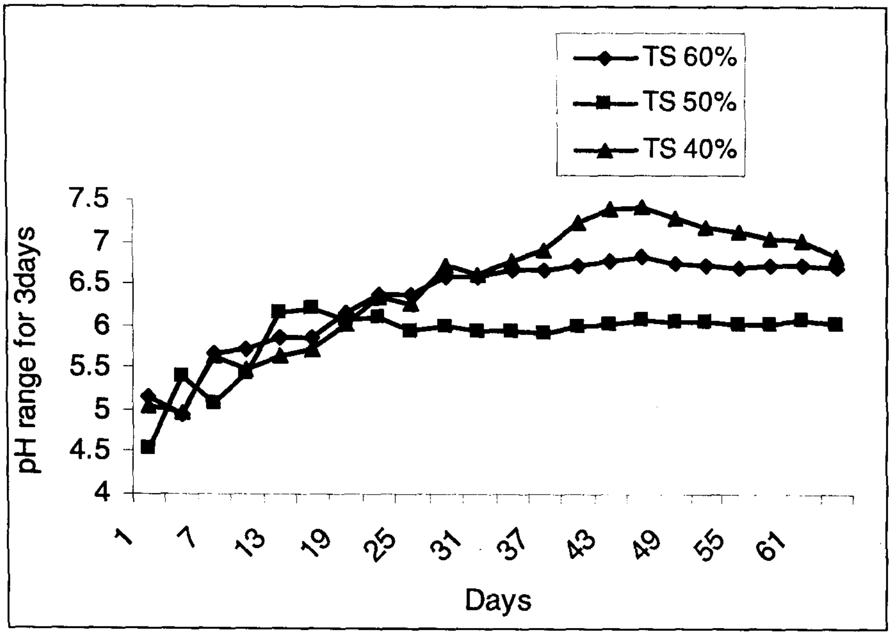

Figure 5: pH Variations at Different Total Solid Concentrations (C/N: 43.5)

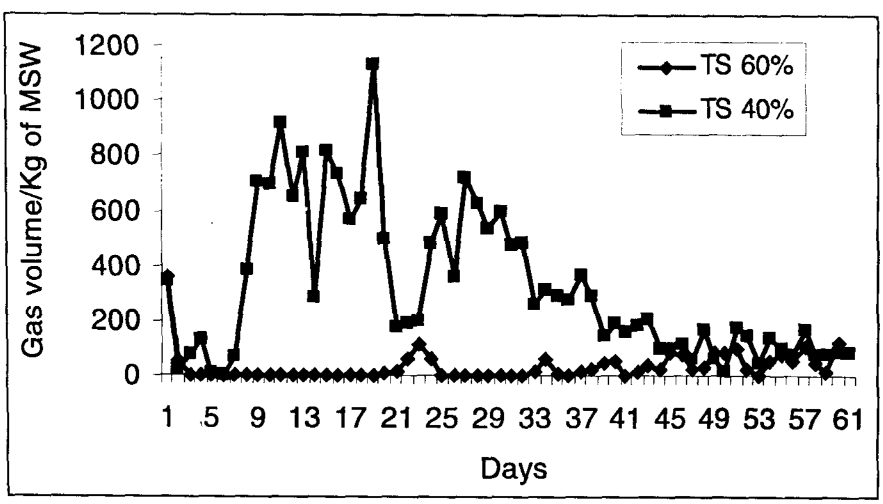

Figure 6: Gas Production for Different Total Solids (C/N 43.5)

6.0 CONCLUSION

The preliminary experiments were done with different C/N ratios ranging from 20-60. The most suitable C/N for maximum gas production was found to be 43.5 *i.e.,* without chemical adjustment. The addition of foreign substances to the natural environment reduced their performance. During the experiments, all the digesters were maintained at a total solid concentration of 50%. The pH variations (6.51-6.85) inside the digester were found to fall in the optimum level. The experiment was carried out under room temperature. The gas yield for C/N 43.5 was1.598L/Kg of MSW.

All the trials were designed at high rate digestion. The further experiment was performed with different total solid concentrations ranging from 40-60%. The C/N ratio was 43.5 in all the digesters. This experiment was performed under controlled conditions of temperature (30-33°C). The maximum biogas production was observed in the digester with 40% TS. The pH variations were found to be in slight acidic range (5.5-6.81). Yield of biogas was 18.22L/Kg of MSW. However, the gas production in the digester with 60% TS was negligible.

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