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Biomethanation of Municipal Solid Waste

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Abstract

The application of anaerobic digestion of municipal solid waste, though well established in many European and other developed countries, the full scale anaerobic digestion of MSW is still in its infancy in India. The Biogas generation potential and the bio methane potential of three major Indian cities namely Delhi, Mumbai and Hyderabad had been studied by installation of three anaerobic reactors of 10 L capacity.

The theoretical methane and biogas generation are compared to the experimentally derived results. The MSW of Hyderabad city has the potential to generate 2.19 * 106 m3 methane per year. The Delhi MSW could generate around 3.87 * 106 m3 methane annually and the Mumbai MSW has a potential to produce around 5.30 * 106 m3 methane annually.

Also, the characterization of the MSW had been studied for the influent and effluent samples experimentally. It had been found that the concentration of ammonical nitrogen increases and the concentration of nitrate and total phosphorus in the samples decrease at the end of anaerobic digestion.

Keywords

Anaerobic digestion; Municipal solid waste; Methane; Biogas; Bio methane potential; Ammonical nitrogen; Nitrate; Total phosphorus.

Introduction

Cloud As per the definition by the United States Environmental protection agency, municipal solid waste, (MSW), commonly known as “trash” or “garbage” comprises of the waste from residential buildings, wastes from offices and from other goods sold to the public, and does not include industrial, hazardous and construction wastes. Examples of municipal solid wastes includes food and yard wastes, newspaper and plastic wastes, rubber, furniture glass and metal wastes. The handling and disposal of MSW is a growing concern as the population, standard of living and the volume of waste generation in India continues to rise [27].

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Anaerobic digestion is the process where the wastes are segregated and are added to a closed chamber inside which under anaerobic conditions, the organic fraction of the wastes undergo biodegradation producing biogas and sludge. The biogas produced is an energy source and replaces:

a) Petrol for refueling vehicles
b) Coal for heat and energy production
c) Natural gas for municipal gas supply

The effluent of this process, i.e. biomass/sludge after stabilization can be used as a soil conditioner. More over the anaerobic digestion process offers the possibility to recycle nutrients, reduce green house emissions, reduce odors and controlled waste disposal [2].

The treatment of municipal and industrial wastes by anaerobic digestion has some advantages over the aerobic biological treatment processes. Although the aerobic treatment has been widely practiced and are more developed then anaerobic processes, they requires high capital costs and larger number of skilled labour for operation and maintenance. This is due to the external source of oxygen which has to be supplied by the installation of aerators. The handling, treatment and disposal of the excess amount of sludge produced at the end of the process, adds to the drawbacks of aerobic processes. Anaerobic digestion technology, at the other end does not require any external source of energy or oxygen; moreover it produces energy in the form of biogas, which contains methane, which is a high source of energy. Also this process compared to the aerobic processes, produce several times lesser quantity of excess sludge.

Method and Methodology

Municipal solid waste collection, grinding and mixing

The raw materials consisting of bio-degradable fraction of MSW of different composition were collected and shredded to finer particles. The wastes were collected, segregated, shredded and weighed as per the different compositions. The shredded MSW samples were characterized for moisture content, total solids, volatile solids, total carbon, total nitrogen, C/N ratio and COD using the standard methods.

This substrate was mixed with the fresh anaerobic seeding sludge collected from the Sewage treatment plant in Saharanpur, Uttrakhand. The resultant mixture, called feedstock was used in the reactors for anaerobic digestion process. A portion of this feedstock was analyzed for its chemical composition.

Characterization of Sample

Moisture content: The moisture content for the waste samples and sludge was determined by weight loss of compost sample (105^{o}C for 24 hour) using the gravimetric method [1].

Moisture content (%) $= \frac{\text{mass of water}}{\text{mass of sample}} * 100$

Total solids and Total volatile solids: The total solids and total volatile solids were determined for all the influent and the effluent samples as per the standard method

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Total solids (%) = 100 – moisture content

Total volatile solids = Total solids - Fixed solids

pH: As pH is an important parameter for an efficient anaerobic digestion process, regular monitoring of pH has been done at an interval of every two days for the anaerobic reactors. The pH was measured using a pH meter with a glass electrode, previously calibrated and corrected for temperature. Sodium hydrogen carbonate ($NaHCO_3$) was added as to the reactors, as a buffer, for maintaining the pH in the desired range.

COD: The Chemical oxygen demand was determined for all the influent and effluent samples as per the standard test procedure. A spectrophotometer was used for COD determination [1].

Ammonical nitrogen (NH3-N) and Nitrate (NO3-N): 50 ml samples were prepared and the ammonical nitrogen and nitrate nitrogen were determined in a spectrophotometer [1].

Total phosphorus (TP): 100 ml samples were prepared for the determination of total phosphorus. Total phosphorus (TP) was analyzed using stannous chloride method [1].

Experimental Setup

Anaerobic reactor and samples used: Three laboratory scale anaerobic reactors of volume 10 L capacity were setup for studying the anaerobic degradation process and methane generating potential of three different municipal solid waste samples representing the waste compositions of Delhi, Mumbai and Hyderabad cities. The physical composition of Delhi, Mumbai and Hyderabad waste as taken is shown on the table below.

Table 1: Municipal solid waste compositions for anaerobic reactor samples [18]

Sample No.	Name of city	Paper	Textile	Leather	Plastic	Metals	Glass	Compo-stable Matter	Inert Material
1	Hyderabad	7.0	1.7	-	1.3	-	-	40	50
2	Delhi	6.6	4.0	0.6	1.5	2.5	1.2	31.78	51.5
3	Mumbai	10	3.6	0.2	2.0	-	0.2	45	39.2

Three 10 L capacity vessels were purchased and each vessel was provided with suitable inflow and outflow valves manually and was made air tight for the perfect working conditions of an anaerobic reactor. An opening was provided at the top of the reactor for the gas collection facility and another opening was given at the side bottom of the reactor for the collection of the samples at desired time and for regular monitoring of the pH and characterization of the samples. The gas collection facility for the reactors was provided by means of a water displacement system. This system comprises of two glass cylinder

bottles of 1 L capacity in which the first cylinder was connected to the anaerobic reactor in which the waste samples was filled. This cylinder is filled with an acidic solution of pH < 3 so that the CO_2 from the biogas while coming to this cylinder should not be dissolved into the solution. The biogas coming to this cylinder will displace the water to the second cylinder connected to this cylinder and the water displaced will be collected in this graduated cylinder. Thus the amount of biogas collected daily was monitored manually every 24 hours. A constant pH between 5 and 7 was maintained throughout the retention time of the reactor by adding 0.16% of buffer into the waste samples for the efficient functioning and biogas production. The buffer used here was sodium hydrogen carbonate (NaHCO3). This process of gas collection and monitoring of data was continued till the end of the whole process.

Figure 1: Anaerobic reactor for Hyderabad (R1), Delhi (R2) and Mumbai (R3) cities

Sample preparation: The raw materials consisting of the paper, textile, leather, glass, metal and inert material such as gravel, sand etc. are collected weighed and mixed according to the waste composition given in the table. The biodegradable fraction of the waste comprises of food waste, green waste, vegetable and fruit wastes. All the raw materials are collected and shredded into finer particles and mixed thoroughly to prepare the substrate of desired composition.

This substrate was mixed with the fresh anaerobic sludge collected from the Sewage treatment plant in Saharanpur, Uttrakhand for seeding purpose. The sample was prepared with a biodegradable waste to anaerobic sludge ratio of 1:1. This mixture was again mixed with tap water to make slurry having 30% solids composition. This resultant mixture was used as the samples in the reactors for anaerobic digestion process.

The municipal solid waste sample in the slurry form was mixed thoroughly and transferred into the anaerobic reactors and was purged with N2 and CO2 in the ratio 70:30 to remove the oxygen present inside the reactor. The reactors are then sealed tightly to preserve the anaerobic growth inside the reactors. The openings on the top of the reactors were connected to the gas displacement system by means of silicon pipes for the collection of biogas from the anaerobic reactors. The biogas produced was recorded every 24 hours.

Sample characterization: The samples used for the experiment has been characterized and studied before and after the anaerobic digestion process. The proximate analysis has been done which includes the moisture content, volatile solids, ash and carbon content determination. Also the ultimate analysis of the sample raw materials such as food waste, paper, and plastic was also determined. The ultimate analysis is the determination of the percentage of carbon, hydrogen, nitrogen, sulphur and Carbon to Nitrogen ratio of the samples and was determined by keeping 3-5 mg of the samples in a CHNS analyzer as per the standard procedures (APHA, 2005).

Also the percentage of phosphate, nitrate and ammonia nitrogen in the samples before and after the experiment has been calculated.

Biogas collection and analysis: The biogas produced from the anaerobic digesters is recorded by means of a gas displacement system as mentioned above. The amount of water displaced daily equaled the amount of biogas produced per day. Thus this recording was continued for all the three reactors till the end of biogas production. The theoretical amount of biogas that could be generated is calculated and compared with the experimental results. Finally the biogas generation potential for the three reactors has been calculated in $m^3/kg\ VSS_{added}$. This data is again used for the calculation of methane that could be generated for these major cities annually.

Results and Discussion

Proximate Analysis

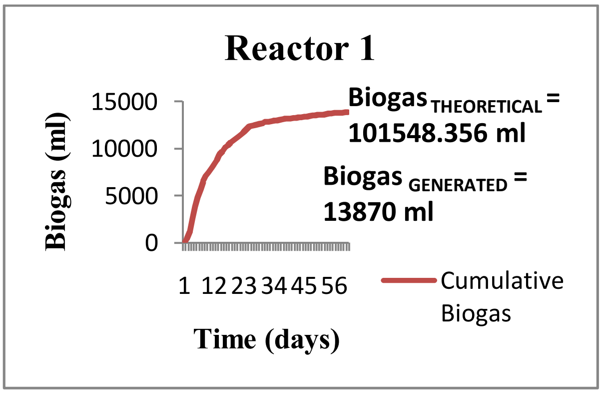
Table 2: Proximate analysis result for anaerobic reactors

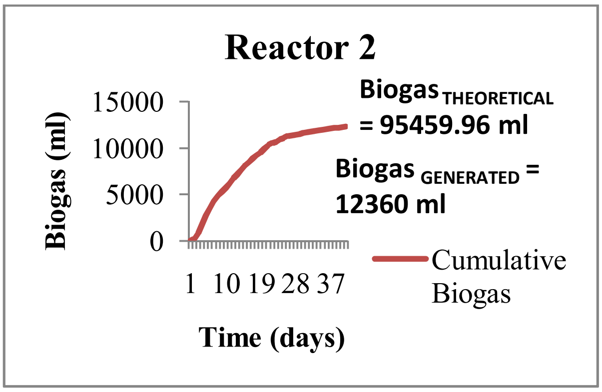
Sample No.	Reactor		Moisture content (%)	T.S.S (%)	V.S.S (%)	Ash content (%)
1.	R1	Initial	35.10	68.50	61.20	6.12
		Final	29.24	30.00	8.54	0.85
2.	R2	Initial	37.40	74.60	66.00	0.66
		Final	38.04	56.80	48.00	0.48
3.	R3	Initial	41.80	70.43	71.21	0.71
		Final	34.46	58.20	44.00	0.44

The anaerobic reactors R1, R2 and R3 represent the municipal solid waste compositions of the cities of Hyderabad, Delhi and Mumbai respectively. From the result above it is clear that the volatile solids breakdown was high for R1 compared to the other two cities.

The gas collection was measured by water displacement system and has been recorded daily and tabulated. The graphs showing the cumulative biogas generation has been plotted from the data for the three reactors and are shown below. The biogas generation of each samples was later calculated in per kg COD_{added} and also in per kg VSS_{added}.

Finally the biogas generation and methane generation potential for all the three states are calculated and the potential of municipal solid wastes of these cities to generate energy are studied. The graphs showing the cumulative biogas for the three reactors R1, R2 and R3 are shown below. The graphs also compares the theoretical biogas generation potential and to its experimental value.





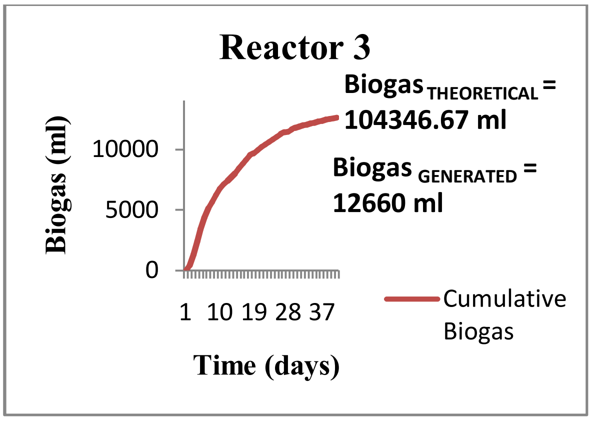


Figure 2: Cumulative generation for anaerobic reactors R1, R2 and R3

Characterization of the sample

The characterization of the anaerobic reactor samples was done before and after the experiment and is tabulated below.

Table 3: Characterization of anaerobic reactor samples

Sample No.	Reactor		pH	COD (mg/L)	Nitrate nitrogen (mg/L)	Ammonical nitrogen (mg/L)	Total Phosphorus (mg/L)
1.	R1	Initial	7.43	18433.24	288	156	2.8
		Final	5.80	4527	193.5	270.5	1.8
2.	R2	Initial	7.26	17328	302	172	4.7
		Final	5.12	6810.44	236	234.0	3.0
3.	R3	Initial	7.01	18941.09	298.5	187.1	4.4
		Final	5.18	6171.49	238	235.5	3.4

From the above table, it is clear that the COD values for the municipal solid waste samples are highly varying. At the end of the process, all the three reactor samples showed a high decrease in their COD values. This COD breakdown in the samples are a clear proof of the anaerobic activity inside the reactors. The sample representing Hyderabad city shown a COD removal of 75.44 %, followed by Mumbai (67.4%) and Delhi (60.7%).

The characterization results of the samples clearly show the increase in the concentration of ammonical nitrogen in the effluent samples and decrease in case of nitrate and phosphorus concentrations.

The anaerobic reactor signifying the MSW composition of Hyderabad produced a total of 13,870ml of biogas during a course of 60 days and its methane generated has been calculated to be 0.75 $m^3/kg\ COD_{added}$. The sample for Delhi MSW generated 12,360 ml and the Mumbai MSW sample generated 12,660 ml. The methane generated for these cities was found to be 0.713 $m^3/kg\ COD_{added}$ and 0.668 $m^3/kg\ COD_{added}$ respectively.

The theoretical values for methane generation for the anaerobic reactors are calculated as R1 = 45696.76 ml, R2 = 42956.98 and R3 = 46956 ml. The annual waste generation of Hyderabad city is around 730,000 tonnes (2000 TPD) Taking into account that the biogas comprises of 45-50% methane, the city of Hyderabad could produce around 2.19 * 106 m3 methane per year. Similarly, the Delhi MSW generation annually is 14,60,000 tonnes (4000 TPD) (Singh., 2010) and is capable of producing around 3.87 * 106 m3 methane per year. Also, the Mumbai city generates 19,54,575 tonnes of MSW annually (5355 TPD) (Singh., 2010) and has the potential to generate 5.30 * 106 m3 methane per year.

The results clearly infer that the municipal solid waste in India is a valuable raw material for the production of energy. Under controlled environmental conditions, anaerobic digestion can be used as an effective technology for waste treatment in India.

Conclusion

All the three anaerobic reactors, R1, R2 and R3 generated good amount of methane as discussed in the results above. More over COD breakdown efficiency was up to 80%. The MSW of Hyderabad city has the potential to generate 2.19 * 106 m3 methane per year. The Delhi MSW could generate around 3.87 * 106 m3 methane annually and the Mumbai MSW has a potential to produce around 5.30 * 106 m3 methane annually

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Ammonia nitrogen accumulates in the reactor during the course of anaerobic digestion as observed from the results. This accumulation is caused from the protein fraction of the organic fraction of the municipal solid waste (OFMSW). The OFMSW, which contains an average 4% of protein content (major source of nitrogen) is removed via ammonification process and is accumulated as ammonia-N [30].

Nitrate nitrogen (NO3-N) and phosphorus concentrations decreased in the characterization of the effluent samples of the reactors. This decrease in concentration is because, the nitrogen and phosphorus in the samples act as nutrients for the growth of anaerobic bacteria and are used up during the course of the process [30].

The study infers that the municipal solid wastes are rich in organic content and its potential for the generation of huge amount of biogas having methane in surplus quantity. This energy can be a viable option and can be replaced for other sources of energy such as petrol, coal and natural gas. Anaerobic digestion is a stable and is the prime option for waste treatment in many of the developed countries. Though there are some concerns regarding the failure of the process due to volatile fatty acids and ammonia nitrogen accumulation and lowering of the pH, this is one technology to look forward as these concerns would be overcome in the near future especially in developing countries including India.

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