COMPUTATION OF METHANE GENERATED BY ANAEROBIC CO-DIGESTION OF FOOD WASTE AND SEWAGE SLUDGE

Kamat S. S.* and Kambete K. A.

Department of Civil Engineering, S. V. National Institute of Technology, Surat (INDIA)

Received April 20, 2016 Accepted August 11, 2016

ABSTRACT

Municipal Solid Waste (MSW) has always been a rising concern, with the advancement of technology and urban civilization. Moreover, the depleting resources of fossil fuels and the consequent growth of pollution is also an important aspect to be considered for achieving the goals of environmental sustainability. The kitchen waste, comprising of the left-over food waste can serve as a tremendous source of bio-energy which can serve dual purposes. It has been found that the effective load of kitchen waste on MSW can be reduced to a large extent, as well the energy in the form of biogas, can be utilized for the domestic purposes. It has found by survey that organic fraction comprises of 40-60% of the MSW. However, it becomes largely inconvenient for the local bodies to actually manage and segregate this kitchen waste for a considerably large population. Moreover, the amount to biological sludge generated in the municipal wastewater treatment plants, is difficult to manage, As a result, it becomes fairly advantageous to opt for a compact system to carry out the anaerobic co-digestion of food waste and sewage sludge. Biogas is produced when the bacteria degrades the organic matter in the absence of air i.e. anaerobically. Anaerobic process is a biological process that occurs naturally with the classification of three main reactions viz. hydrolysis, acidogenesis and methanogenesis. In this study, the process monitoring has been given due importance because it is important to regularly monitor the pH and alkalinity requirements of the system. Moreover, any kind of increase in the inhibitory substances can affect the process. Based on the Chemical Oxygen Demand (COD) profile, certain conclusions were being made. It was found that after the 25th day, there was uniform reduction in COD, however it was a steep fall of curve which indicated that the reaction is proceeding in the methanogenesis phase. From the 57th day onwards, it was observed that there is gradual exponential reduction of the COD profile, which was a clear indication of the dominance of the methanogens. Based on the COD balance concept, the amount of methane generated was predicted.

Key Words: Co-digestion, COD, Methane, pH, Municipal Solid Waste

INTRODUCTION

One of the global challenges of 21st century is the rapidly growing energy demand wherein a high percentage of energy demand is supplied by the fossil fuels. Reports of International Energy Agency say that the energy demand by the end of this century will increase by a factor of two or three. Very common examples of renewable energy are solar, wind, geothermal, biomass and biogas. Hence, it becomes liable for the world to have a paradigm shift towards economically feasible and environmentally sustainable technologies. These technologies that combine waste treatment and energy production serves dual purposes. They protect the surrounding water resources and also enhance the energy availability.

In India, it is found that about 3 billion residents generate 1.2 kg/c/d of Municipal Solid Waste (MSW). As per the estimates, the year 2025 will see a rise up to 4.3 billion residents generating 1.42 kg/c/d of MSW. It is nationally as well as globally found that the major composition of MSW consists of the organic fraction which amounts to 40-60%. Due to the problems of growing population, solid waste management has become an
alarming problem because of its large environmental impact. Conventional methods such as landfilling and composting has its vast share of demerits that are an environmental as well as a social concern. Thus, it is important to understand that engineered biodegradation of the organic waste is a more responsible way to process. It serves dual purpose. Firstly, it reduces the effective load of municipal solid waste, because major portion of this organic waste comprises of the food waste in various forms. Secondly, the anaerobic digestion ensures that the production of biogas, which consists of 60-65% methane content, serves an efficient source of energy that can be used for domestic purposes. However, treating organics is not an easy task as anaerobic digestion plants face difficulties in obtaining a clean feedstock. Anaerobic digestion is a process comprising of two stages in which specific bacteria are being fed on certain organic materials, in the oxygen starving environment. It is one of the oldest processing technologies mankind has ever used.

The anaerobic co-digestion of food waste and sewage sludge has more advantages and benefits as compared to the mono-digestion. There is a synergistic effect observed in the overall rate of the reaction process as well as the yield of methane in the composition of generated biogas. The suitability of small-scale biogas system as a decentralized treatment option for the organic fraction of market and household solid waste, is effective in terms of the reduction of waste volume and organic load. The reduction of COD is influenced by the composition of the food waste. Owing to this, the variation in the food wastes being added to the sewage sludge, will have a major role in the digestion process. The kitchen waste has less solid content and more volatile matter as compared to the cow dung, and hence the former is rapidly decomposed by the anaerobic microbes. With respect to the solid waste, kitchen waste has lesser fixed solid mass than the cow dung and hence the rate of decomposition of kitchen waste is more rapid. The decomposition of fibrous matter in the cow dung takes longer time for the micro-organisms. The content and distribution of lignin is responsible for the restricted enzymatic degradation, which ultimately makes hydrolysis as the rate limiting step in case of cow dung. Food waste is an attractive feed stock for anaerobic digestion due to its high methane potential. High concentration of lipids in the food waste is highly beneficial as it contains higher potential of generating biogas. The inhibition in the digestion of food waste always occur due to the imbalance of nutrients in the anaerobic digester. Moreover, the concentration of lipids in food waste is always higher than the limited concentration which leads to inhibition. Hence, in order to counteract this inhibition, co-digestion of food waste with equivalent organic substrates is suggested as it balances all the nutrients and provides a stable environment for anaerobic bacteria. In addition to this, co-digestion improves the buffer capacity and result in increased acceptable organic loading as compared to mono-digestion. In case of digestion of food waste, it is universally observed that the hydrolysis is not the rate limiting step but it is the transition from acidogenesis to methanogenesis which is a rate limiting step. The degradation of organic substances under fermentative condition is significantly enhanced with the addition of lime solution in the anaerobic digestion of food waste. The fermentative microorganisms easily hydrolyze and degrade the food waste. The last degradation step is the rate limiting step because methanogens grow more slowly than the acidogens. The VFAs (Volatile Fatty Acids) concentration accumulation results in the reduction of pH, thereby terminating the anaerobic process. Importantly, the point to be noted is that, the addition of lime solution can reduce the rate of pH reduction, thereby providing a favourable environment for the survival of methanogenic bacteria. The possible formation of bicarbonates improve the buffering effect of the system. The lime solution addition enhances the process stability and methane production and also improves the speed balance of producing acid and methane.

Anaerobic Digestion is a complex process, consisting of three basic stages viz. hydrolysis, acidogenesis and methanogenesis. A typical mechanism of anaerobic digestion process has

171
been shown in Fig. 1. Hydrolysis is a reaction in which the complex organic molecules break down into soluble organics. These simpler molecules then further undergo bacterial action. Acidogenesis is the stage in which the acid forming microorganisms transform the products of hydrolysis into simple organic acids. The compounds produced include volatile fatty acids (VFAs), alcohols, besides new bacterial cells. These organisms are commonly found in the digestive tracts that degrade the sugar and amino acids\textsuperscript{16}. Methanogenesis refers to that stage of anaerobic digestion in which the methanogenic microorganisms convert soluble matter into methane.

![Diagram of Anaerobic Digestion Process]

\textbf{Fig. 1:} Mechanism of anaerobic digestion process

The chemistry and microbiology of the anaerobic treatment are more complex as compared to the aerobic system. Owing to these, there are various advantages and disadvantages. When the wastes are most suitable for the anaerobic treatment, there are highly significant advantages viz. the low production of waste biological solids, low nutrient requirements, methane as useful end product and a net energy producer and the possibility of high organic loading. The disadvantages include the low growth rate of microorganisms, odour production, high buffer requirement for pH control and poor removal efficiency with higher wastes\textsuperscript{17}. Process monitoring of an anaerobic reactor is an important activity due to its concern with the stability of the anaerobic degradation process. The system develops its own unique process conditions, thereby, there is no single value based system for each process parameter that can be referenced for a reactor system\textsuperscript{18}. Initially, the reactor must have good anaerobic seed. Temperature is also an important criteria to ensure that the temperature is regularly monitored till the system becomes stabilized. The chemicals such
as sodium bicarbonate, as buffer material, are useful against the pH drop. The addition of small amount of organic waste is sufficient to let the organic acid content from fermentation, while keeping pH between 6.8 and 7.6.

MATERIAL AND METHODS
The study was based on various literature reviews as well as certain important conclusions. Moreover, the system was designed in order to regularly monitor the process.

**Installation and initialization of the reactor**
The system was designed to its full proof to ensure that there is no scope for leakage of any evolved gases. The drum of 18 cm diameter and 50 cm height was used as the reactor system as shown in Fig. 2.

![Fig. 2 : Reactor system](image)

Initially, the reactor consisted of 10 L fresh sewage sludge from STP, food waste as initial substrate to the microorganisms and the miscellaneous composition consisted of domestic wastewater. Food waste was blended using a grinder. Fresh cow urine of 3 litres was added to the reactor, in order to add important nutrients. All these ingredients were rapidly mixed in order to ensure a uniform mixture. The initial pH of the system was adjusted to 8.2 using a lime solution.

**Process monitoring and sample collection**
Process monitoring is important in order to check the pH reduction due to acidogenesis phase. Thus, it is important to periodically add lime solution and soda ash as buffers, in order to stabilize the system till the methanogenesis stage is reached. From the 60th day onwards, when the system becomes completely stable, consistent feeding was done to the system, after every 6 days, to observe the behaviour of COD profile. The daily samples were collected by means of a faucet arrangement at the bottom.

**Experimental Analysis**
The pH of the collected samples were measured using a pocket-sized pH meter, whereas the temperature of the slurry and the
ambience were being measured using a simple thermometer. The moisture content and the volatile solids were initially measured using standard methods, in order to compute the effective mass involved in the anaerobic reaction. The Chemical Oxygen Demand (COD) was the main parameter governed in the entire course of the study. The COD parameter was being measured using the Open Reflux Method, due to the high strength of sample slurry.

**Prediction of methane**

COD Balance concept is accountable for the changes in the COD during the fermentation. The COD loss is accounted for the methane production\(^ {21}\). The COD of the methane is the amount of oxygen needed to oxidize methane to carbon dioxide and water. The reaction for oxidation of methane is given by the following reaction.

\[
\text{CH}_4 + 2\text{O}_2 \rightarrow \text{CO}_2 + 2\text{H}_2\text{O}
\]

The COD per mole of methane is \(2 \times (32 \text{ g O}_2 /\text{mole}) = 64 \text{ g O}_2 /\text{mole CH}_4\). The volume of methane. The volume of methane per mole at standard conditions (0 °C and 1 atm) is 22.414L. Therefore, the \(\text{CH}_4\) equivalent of COD converted under anaerobic conditions is \(22.414/64 = 0.35 \text{ L CH}_4 / \text{g COD}\)\(^ {22}\). The COD Balance equation is given as follows. Influent COD converted to methane = (Influent COD) – (Portion of Influent COD in Effluent) – (Influent COD converted to cell tissue)

1. Observed COD must be expressed in g by considering the fixed volume of 50 litre mixture in the reactor system
2. COD per day, in grams, must be computed
3. Using ideal gas equation, \(PV = nRT\), volume of methane occupied by 1 mole of methane, must be computed for a particular reactor temperature in Kelvin (Assumption: \(P= 1 \text{ atm, R=0.082057 atm L/ mole K}\))
4. Volume of methane per gram of COD, must be computed considering that 1 mole of methane is equivalent to 64 g of COD, as per the stoichiometry
5. Compute the cumulative methane production

The system was connected to the bottle containing 2% potassium hydroxide solution, and the observed methane was measured using displacement method\(^ {23}\). The least count of the measurement bottle was fixed to 25 mL. The observed values of methane were noted for the graphical plots. The Fig. 3 shows that the displacement of 200 mL is the observed value of methane in millilitres.
RESULTS AND DISCUSSION

The outcome of the study was the tangible as well as intangible, sufficed by the practice of monitoring the reactor process on a regular basis. In all the preliminary tests on food waste, the moisture content was found to be in the range of 75-85 %, whereas that of Volatile Solids (VS) were found to be in the range of 90-95 %. The pH, temperature and the COD were the parameters mainly focused on daily basis.

The pH profile, as shown in Fig. 4, infers that initially the pH reduces considerably, which is a clear indication of the acidogenesis phase. The phase prior to acidogenesis is the hydrolysis phase, which is generally a rate-limiting step. However, in this case, hydrolysis is not a rate limiting step\textsuperscript{24}. Therefore, one can infer from this behaviour that food waste is easily biodegradable to form organic acids, which needs to be regularly monitored in the initial stages of the process. Addition of lime solution on the 10\textsuperscript{th} day was important to ensure sufficient alkalinity is present in the system so as to arrest the accumulation of Volatile Fatty Acids (VFAs) and lead to the stabilization of the system. Addition of cow urine was an additional supply of important nutrients in order to increase the rate of the process towards stabilization. From the 25\textsuperscript{th} day, the pH values were obtained in a stable range between 7.1 and 8.1, which was a clear indication that the system has almost reached a point where acidogenesis is in a controllable stage.

The temperature profile, as shown in Fig. 5, shows that the average ambient temperature is considerably below the optimum mesophilic temperature of 35 °C, which may also be one of the factors for the slow-reaction reaction process. In this dissertation study, temperature was not a controllable factor. However, during the winter months of January and February, it was ensured during the night time, that the reactors were fully covered with thick tarpaulin sheet to minimize the effect of low temperature during the night time.

The COD profile, as in Fig. 6, shows the variation of the chemical oxygen demand w.r.t. time. It was observed that the COD was consistently reducing from 25\textsuperscript{th} day onwards. This was also the period when the pH was fluctuating in a considerably stable range of values. However, the steep reduction of COD was just an indication of high rate of biodegradability and was an indication that the methanogenesis phase would be dominant in the following course of time. From 60\textsuperscript{th} day onwards, it was observed that the COD is reducing very gradually in an exponential profile, which was an indication of methanogenic growth\textsuperscript{25}.

![Fig. 4 : pH vs Time](image-url)
The COD profile from the 57th day onwards reduced very gradually, in an exponential form, which was a clear indication that the population of the methanogens is dominating in the system. The methanogenesis phase governs that certain amount of COD in the system is getting utilized for the conversion into methane. The profiles of cumulative methane for observed and predicted cases, as shown in Fig. 7 and Fig. 8, infer that the observed production is consistently lower as compared to the predicted values. One of the major reasons that can discussed on this, is that the pressure generated in the reactor is quite low, due to which the displacement of the liquid is lesser than the theoretically predicted values.
CONCLUSION

Solid waste is a growing problem and India’s energy problems have made the need to turn towards waste-to-energy technologies extremely important, especially because landfills in India’s urban centres are fast nearing the limits of their capacity. It was observed that the entire anaerobic process is highly sensitive to the pH. This makes it important that the system needs regular monitoring in the initial period, in order to ensure that the accumulation of VFAs is controlled. On the 25th day, when the COD started reducing at a faster rate, the pH value of 7.0 was noted. The initial phases of hydrolysis and acidogenesis, the complex reactions that take place are a clear indication of the negligible population of methanogens. After the 25th day onwards, it was observed that there is a faster reduction in the COD, which signifies that the
reaction is proceeding to enter into the methanogenesis stage. After 60th day onwards, a stable exponential curve is obtained which precisely signifies the dominance of methanogenic population. It was observed that the co-digestion of food waste and sewage sludge serves dual purpose. From the economical point of view, it serves as a great source of energy recovery in the form of methane. Moreover, from the environmental point of view, the compact system can be useful to manage the food waste, which is of biodegradable form, at the source itself. This will ensure that the application of this system on a large scale would reduce the load on the municipal landfills.

ACKNOWLEDGEMENT

The experiments were carried out at the Environmental Engineering Laboratories at S. V. National Institute of Technology, Surat, India. Our humble thanks to the entire faculty.

REFERENCES

21. Tchobanoglous G., Burton F. L. and Stensel H. D., Wastewater Engineering-


