BIOGAS PRODCTION FROM KITCHEN WASTE BY USING METHANOGENIC REACTOR

Malathi S
Department of Civil Engineering, M.A.M College of Engineering
Trichy-Chennai Trunk Road,Siruganur, Trichy, Tamilnadu, India.
divyamalathi1007@gmail.com

Abstract: The staggering potential environmental problems linked to organic fraction of municipal solid waste which is mostly landfilled have fostered the need for a biological treatment using anaerobic digestion. This is an attractive technology for waste stabilization with potential mass and volume reduction and significantly the generation of valuable by-products such as biogas and compost material. This research work focused on the biogas production from kitchen waste generated on the KNUST campus. The experiment was carried out in a multi-stage anaerobic digestion system operated under mesophilic temperature. Various process parameters were measured including temperature, pH, conductivity, total solids, moisture content, BOD, percentage BOD removal, biogas production and biogas production rate. The waste degraded at a rate of 36.1±2.2% / day, with average biogas production of 8.9±3.15 litres per day. Maximum biogas production rate per kilogram of total solids (TS) was 4.5±1.6 L/kg TS of biogas per day.

INTRODUCTION

1.1 Background

Solid waste has been identified by most local governments and urban agencies as a major problem that has reached proportions requiring drastic measures (Visvanathan *et al*., 2004). The major problems which show certain key trend are observed as an increase in volume of waste generated by urban residents; change in the characteristics or make-up of waste generated and disposal methods of waste collected. In developing countries like Ghana, the problem is rooted in improper waste management practices, increasing population, inadequate facilities and lack of adequate technology required for waste management. Waste streams are shown to consist of entirely different proportions of the waste components (Fobil *et al*., 2005; Fei-Baffoe, 2006). In Kumasi Metropolis there is an average percentage composition of 55% organic or putrescible materials, 5% paper & cardboard, 7% plastic & rubber materials, 1% metal & cans, 1% glass, 1% wood, 1% fabric and 28% miscellaneous or other waste (Ketibuah *et al*, 2005)About 1,500 tonnes of Municipal Solid Waste (MSW) is generated in Kumasi Metropolis in the Ashanti Region of Ghana on a daily basis (http://www.modernghana.com). Out of this an average of 0.18 kilogram per capita per day of waste is generated in Kwame Nkrumah University of Science and Technology (KNUST) campus alone, the greater percentage of which is biodegradable (Boadi-Danquah, 2005). Waste generated on this campus keeps increasing due to increasing student population and increasing commercial activities which put pressure on existing waste facilities. Thus, disposal of waste remains a major challenge on the campus and a cause of concern. Generally, effective handling of waste generated in communities in developing countries like Ghana with increasing population is a major challenge. The KNUST community is not an exception. Municipal solid waste could be treated using mechanical operation, thermal treatment, biological transformation and physico-chemical conversion.Biological transformation is applicable to native organic matter in which case the organic waste is digested in bioreactors, fermented, rotted or composted (Boadi-Danquah, 2005; Fei-Baffoe, 2006). According to a report by Bouallagui *et al.* (2003), various studies have proved that anaerobic biological treatment of organic fraction of MSW is a process which has received an increased attention during the last few years. And according to Mata-Alvarez (2003), among biological treatments, anaerobic digestion (or known as biomethanization) is frequently the most cost-effective, owing to the high energy recovery linked to the process and its limited environmental impact. Anaerobic digestion of biomass waste is now an established and commercially proven approach for treatment and recycling (Vogt *et al;* 2002). Anaerobic digestion of MSW was the preferred approach and reliable technology for the provision of energy and reduction of greenhouse gas emissions when compared to combustion or incineration, aerobic composting, pyrolysis and landfilling or landfill gas recovery.Notwithstanding the numerous benefits of anaerobic digestion, the level of its industrial application as a waste treatment technology has been limited due to the technical expertise required to maintain industrial scale anaerobic digesters coupled with high capital costs and low process

efficiencies.The United Nations Development Programme (UNDP) has however, recognized the anaerobic digestion facilities as one of the most useful decentralized sources of energy supply, as they are less capital intensive than large power plants (UNDP, 1997). Thus, it can be a better option for the treatment of the biodegradable fraction of the enormous solid waste generated on the KNUST campus.

1.2 Justification

Questions related to the final disposal and treatment of MSW constitutes one of the most serious problems of contemporary societies. The volume of waste has increased very quickly. The need for processes in the field of conservation of resources has become more than clear in recent years. More waste is generated at source and less of this waste is effectively handled in terms of recycling, treatment and disposal and thus waste generated is mainly landfilled without sorting. This is neither economical nor environmentally friendly and moreover there is the problem of land acquisition (Fei-Baffoe, 2006). Not only is the enormous generation of the quantities of waste a great concern but also improper management of this solid waste has both long and short term environmental effects. Incineration which is the quickest way of disposal is expensive due to high fuel demand and associated environmental problems due to emission of flue gases. Land filling is expensive, requires space and can have negative environmental impact if not well managed due to the production of leachate, methane, carbon dioxide and other nuisances like flies, odour, and vermins like birds and rodents. Leachate could pollute underground water and soil. Methane and carbon dioxide released in landfill sites are green house gases which can lead to global warming.Apart from these general challenges, as stated earlier, the increasing student population in KNUST with its corresponding increase in waste generation tends to put pressure on existing waste facilities (Boadi-Danquah, 2005; Fei-Baffoe, 2009). A large fraction of this waste is biodegradable material and can be efficiently converted to biogas. Nevertheless, less than half of this waste is properly managed as they are directly transferred into concrete skips and finally land-filled. A working framework for the solid waste management must therefore be developed by approaching the challenges from social, economic, technological, political and administrative dimensions.There is the need for more prudent measures to manage the enormous waste generated to reap economic benefits whilst protecting the environment. In such an endeavour an establishment of sustainable waste management practices which are effective, affordable, promote health and safety benefits to the public, prevents soil, air and water contamination, conserve natural resources, provide renewable sources of energy and generally environmentally friendly must be the priority (Fei-Baffoe, 2010).

1.3 Objectives of the Study

The main objective of this research project work is to determine the biogas production potential of kitchen waste generated on the KNUST campus. The specific objectives of the research include;

To design an appropriate anaerobic digester for the kitchen waste

To determine the chemical and physical characteristics of kitchen waste used

To determine the extent of waste degradation on biogas production

To determine the amount of biogas that can be produced per unit kilogram of kitchen waste used

2.LITERATURE REVIEW

Bruus et al., 1993). Rasmussen et al. The digestion process plays an important role in the solids handling system of a wastewater treatment process. Waste sludge is digested for destruction of organic matter and reduction of pathogens. Digestion may occur either in the presence or obsence of molecular oxygen. Historically, a majority of the work on digestion focused on process performance and volatile solids reduction, and not on the change in flocs and the impact this has on sludge dewatering properties. The objective of the study was to examine the digestion process from the perspective of floc structure, biopolymer and cation release from the floc, and the resulting impact on sludge dewatering properities.

(Metcalf and Eddy, 1991). Both aerobic and anaerobic digestions were studied using activated sludge from two different sources. The primary data wsa obtained at a temperature of 20°C. While this temperature is lower than that normally used for anaerobic digestion, it allowed for direct comparisons to be made between aerobic and anaerobic digestions from a mechanistic perspective. However, anaerobic anaerobic storage at 20°C has been studied extensively. Activated sludge is often stored prior to dewatering in full scale systems (Bruus et al., 1993). Rasmussen et al. (1994) also researched the implications of dewaterability, and the physical / chemical changes of anaerobically stored sludge in a nutrient removal plant. Overview of the anaerobic and aerobic digestion process. The breakdown of extracellular material (biopolymer) originating from biological and lytic activity of cells can be considered one of the predominate functions in digestion. This extracellular material can be generally uantified as higher molecular weight compounds (Mw > 10,000) produced by microorganisms under various environmental conditions (Morgan, 1990). The anaerobic digestion process can be divided into three main categories. The first step, hydrolysis, converts

large molecules into smaller units including converting particulate organic matter into dissolved organic matter. Dissloved organic matter is the broken down into volatile fatty acids, a process commonly reffered to as acido genesis. The final step, methogenesis, converts intermediate acid compounds (primarily acidic acid and hydrogen) into methane and carbon dioxide. Methano genesis is the rate limiting step in aerobic digestion due to the slow growth rates of methanogens most digest failures are due to methanogenic upset (Metcalf and Eddy, 1991). Aerobic digestion is another alternative method for the stabilization of waste sludge. Waste activated sludge, primary and waste activated sludge, trickling filter secondary sludge, are commonly treated by applications for aerobic digestion (Reynolds and Richards, 1996). Most of the microorganisms involved in aerobic digestion are facultative with the exception of nitrifies, which are obligate aerobes. Nitrification is frequently occurring process in aerobic digestion (Reynolds and Richards, 1996). As available substrates are depleted, microorganisms respire endogenously, whereby cells consume protoplasm and other internal parts to maintain cell function. The end products consist of carbon dioxide, ammonia, and water (Metcalf and Eddy, 1991). Advantages of aerobic digestion are fewer problems, lower capital costs, less laboratory control and daily maintenance, and much lower biological oxygen demand present in the supernatant. Disadvantages are high energy requirements due to mixing and aeration no useable byproduct generated, and lower solids content. Therefore, the volume of sludge bed watered in aerobic digestion is larger (Renolds and Richards, 5 1996) . Characterization of activated and digested sludge material. There is much debate as to the quantity and type of extracellular polynmers associated with activated sludge flocs.

Nielsen et al. (1996) found a decrease in the protein biopolymer fraction over a six day anaerobic storage time and a minor reduction in the carbohydrate content. However specific enzymatic activities were not measured, nor were correlations made to specified watering properties. Nielsen et al.'s (1996) data shoe that some protein degradation does occur; high-performance size exclusion chromatography indicated that observed changes in biopolymer content were due to degradation of existing compounds and not to the production of new EPS compounds.

Sarada and Joseph (1993) performed aninteresting study using batch and semi continuous processes to evaluate enzymatic activities of tomato processing waste. Glycosidase and neutral protease activites were measured. The optimum pH for glycosidase acitivity was between 4.4 and 5.2; the protease did not show any pH optimum. In the batch process, glycosidase activity remained fairly constant at very low levels and it starts to peak toward to the end of the process (70-80 days). However, in the authors' study the Ph of the batch reactors fell from 6.8 to 4.0. Thus glycosidase activity comparison should be misconstrued if Ph differences existed between studies

Comte et al (1997) says that, studied the effect of hydrodynamic operating conditions (column diameter, gas sparger, initial weight of particles introduced into the reactor) of an inverse gas-liquid-solid turbulent bed and proposed model to predict the values of specific gas velocity.

Sivasubramanian&velan (2004) says that, velocity and predicted correlations for minimum liquid fluidization velocity for Newtonian and non Newtonian fluids.

Beneyal&Tanyolac (1998) says that, used differential ATAD reactor to evaluate external mass transfer. The ATAD was operated under fixed hydrodynamic conditions to study the effects of biofilm thickness and density on mass transfer. The mass transfer coefficient was calculated with the analytical solution of effectiveness factor using density dependent effective diffuse coefficient. The results revealed that tha mass transfer coefficient increased with biofilm thickness at decreasing biofilm density values due to increasing porosity and roughness of the biofilm surface.

Farhana Tisa, Abdul Aziz Abdul Raman, and MohdAshri Wan Daud says that, ATAD is widely applied in many industries for various applications recently. It has been found promising to use considered as an improvement over the traditional water treatment methods.

3.METHODOLOGY

Developing the methodology involved the following steps:

1. Define the system boundary

2. Identify and describe the sub-processes and which energy flow was part of which sub-process

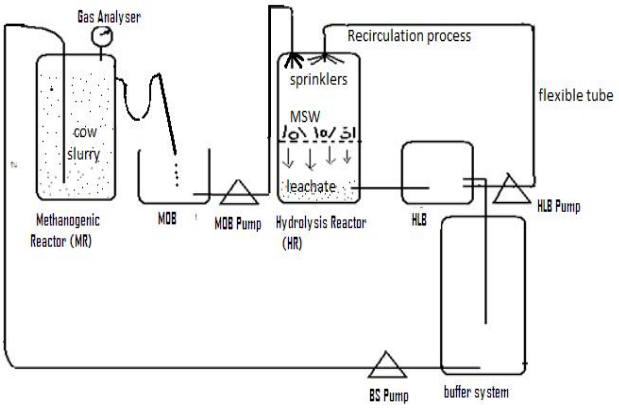
3. Identify and describe unit processes (divided into production processes and support processes)

4. Validate the methodology by applying it to two biogas plants

5. Evaluate the methodology

4. Reactor Design

The experiment was carried out in a double stage reactor system - Hydrolysis and Methanogenic reactors which is presented in the schematic diagram below in Fig.3.1. Also shown in plate 2 below is the actual set up of the experiment.



Schematic Diagram of Reactor Design

4.Experimental Procedure

A daily monitoring of the reactors and system performance were conducted by undertaking various laboratory analyses: pH, Conductivity, Temperature, Biological Oxygen Demand, Hydraulic Retention Time, and Volume of gas produced per day. The moisture content and total solids of the kitchen waste were determined before and after the 10 days degradation period after which the percentage degradation was calculated. The following parameters were held constant for all the different dilutions: the type of waste (kitchen waste), mass of waste used (10 kg), degradation period (10 days) and number of times the experiment was repeated (2 x). A summary of the experimental run and conditions to which the kitchen waste was subjected to is presented in table 3.1.

4.1pH Determination

The pH meter was calibrated, using two buffer solutions, of which one was the buffer with neutral pH (7.0) and the other in the range value of the pH of the sample. The pH was measured with a PC cyberscan Waterproof Handheld pH meter. 100 ml each of the hydrolysis leachate in HLB, buffered hydrolytic leachate in BS and Methanogenic overflown slurry in MOB were collected and put into labeled sample containers on a daily basis and sent to the Laboratory to measure their pH. Each sample in the sample container was well shaken to allow a homogenous mixture and poured into 100 ml beakers. The probe was then inserted and the pH value digitally read and recorded.

4.2Conductivity Measureme

The conductivity of the various samples taken to the laboratory on a daily basis was measured using a PC 300 cyberscan Waterproof Handheld Conductivity meter. The conductivity probe was calibrated with a conductivity standard solution of 12.88 µS. The conductivity probe was inserted into 100 ml of each sample from the HLB, BS and MOB; the conductivity values were digitally read and recorded. The probe was rinsed with distilled water after each insertion and recalibrated after taking several measurements to ensure accurate measurement.

4.3Temperature Measurement

A 30 cm long mercury-in-glass thermometer was used to measure the temperature of the content of HR, HLB, BS, MR and MOB. This measurement was done at specific times of the day on regular basis by inserting the thermometer into its content and leaving it for some few minutes. The MR temperature was measured by inserting the thermometer into the slurry overflowing from the U-tube connected to the MR.

4.4Biochemical Oxygen Demand (BOD_5) Determination

The biochemical oxygen demand (BOD) determination is an empirical test in which standardized laboratory procedures are used to determine amount of oxygen consumed by bacteria and other microorganisms while they decompose organic matter under aerobic conditions at a specified temperature. It is computed from the initial and final dissolved oxygen (DO) of a sample after incubating at 20 °C for five days. In determining BOD_5 of the samples collected, 100 ml of the sample was poured into a 300 ml BOD bottle and diluted with water to the 300 ml mark and then corked. Another standard 300 ml BOD bottle was filled with dilution water to represent the blank. The initial dissolved oxygen concentrations of the blank and diluted sample were determined using a DO meter. Both bottles were stored at 20 °C in the incubator for five days. The BOD was measured by taking composite samples of 50 ml a day. Several serial dilutions were conducted on the samples to obtain the best results. After 5 days the amount of dissolved oxygen remaining in the samples were measured with a DO meter. The 5-day BOD was computed using the equation below:

$$BOD_5, \, {}^{mg}/_{L} = \frac{D_1 - D_2}{P}$$

D_1 = DO of diluted sample immediately after preparation, mg/L,

D_2 = DO of diluted sample after 5 day incubation at 20 °C, mg/L,

P = decimal volumetric fraction of sample used

The 'P' was calculated by dividing the volume of sample taken (i.e. the 100 ml poured into the BOD bottle) by the total volume of the diluted sample in the BOD bottle).

4.5 Moisture Content Determination

Principally, the moisture contents of cooked food vary widely and give an indication of its shelf-life and nutritive value. Low moisture content is a requirement for a long storage life. In practice, the guiding principle for moisture determination has been to prefer the method that gives the highest moisture values, provided decomposition of organic components and volatilization of compounds other than water are negligible. The following materials were used to determine the moisture content by drying method: analytical balance, dessicator, thermostatically controlled oven and glass dishes. Moisture content determination was determined before and after degradation of the kitchen waste. The determinations were conducted immediately after the kitchen waste was put into the HR and just after removing the degraded food waste from the HR to the reduce any loss or gain of moisture. In determining the moisture content using the drying (air-oven) method, a known mass of the kitchen waste sample was transferred to previously dried and weighed dish. The dish (with waste) was then placed in an oven and thermostatically controlled at 105 ^{o}C for 5 hours. The dish was afterwards removed and placed in a dessicator to cool at room temperature and weighed. It was dried again for 30 minutes, cooled down and re-weighed. The drying, cooling and weighing were repeated until a constant weight was obtained. The determination was repeated and the average determined where necessary. The moisture content was expressed in percent weight by measuring the loss of weight after drying the sample using the formula below:

Percentage moisture = (wet weight- dry weight)/wet weight

4.5 **Total Solids Content Determination**

The total solids content is known to be a measure of the amount of material remaining after all the moisture has been evaporated. Percentage total solids was calculated using the formulae below:

Total solids (%) = (100 - *% Moisture content*).

5 RESULTS AND DISSCTION

The tables and figures presented below represent the results obtained from the monitoring of parameters measured during the anaerobic digestion process.

5.1 Composition of Waste

The kitchen waste collected was shown to consist of entirely different proportions of the waste components, with an average percentage composition of about 80% carbohydrate foods, 10% bones and other animal protein; 5% vegetables and fruit remains; 3% plant protein; 0.5% oils; 2.5% tissue paper & plastic disposable cups. The kitchen waste contained an average of 65±2.06% and 35±0.5% moisture content and total solids respectively.

5.2 Degradation in the Hydrolytic Reactor

The degradation in the hydrolytic reactor at various dilutions is presented in table 4.1. From the Table, the highest degradation of 36.13±2.2% was achieved at a dilution rate of 20 L/day while the lowest degradation of 10.45±1.2% was achieved at a dilution rate of 8 L/day. The 10, 12 and 15 L dilutions recorded a degradation of 26.65±0.9%, 30.79±2.8% and 29.30±1.6% respectively.

5.3Characteristics of Leachate Produced in the Hydrolytic Reactor

Leachate produced in the hydrolytic reactor recorded very low pH values and relatively high conductivity values. The 20 L dilution recorded the highest pH of 3.93±0.20 while the 8 L dilution recorded the lowest pH of 3.2±0.07. The 10, 12 and 15 L dilutions recorded pH of 3.61±0.08, 3.39±0.11 and 3.59±0.13 respectively. The highest conductivity of 6.37±1.02 µS/cm was recorded by the 12 L dilution and the lowest conductivity of 4.55±0.48 µS/cm was recorded by the 8 L dilution. The 10, 15 and 20 L recorded 4.99±0.29 µS/cm, 5.69±0.42 µS/cm and 6.03±0.21 µS/cm respectively. The 20 L recorded the highest BOD of 22212±8034 mg/L while the 8 L recorded the lowest BOD of 10880±2516 mg/L. The BOD of the 10, 12 and 15 L dilutions were 8614±3786 mg/L, 15861±2882 mg/L and 17347±5253 mg/L respectively as shown in Table 4.2. below.

5.4Characteristics of Leachate Produced in the Hydrolytic Reactor

In this section the pH and conductivity of the hydrolytic leachate produced as well as the HRT are discussed.

5.4.1 Ph

Average pH of all the samples taken ranged between 3.20 and 3.93 meaning that the waste had a high acid content. The different dilutions with respect to their average pH varied very marginal although it showed a little trend that as dilution increased pH increased with the exception of the 10 L dilution that had a pH of 3.61 which was higher than the averages of both the 12 L and 15 L dilution. Water was used as the sole buffer to help increase the pH to an optimum level for the process in this research work. However, this did not make any significant changes. The waste used for the experiment was characteristically acidic as stated earlier. Veeken *et al.* (2000), demonstrated that the digestion of organic compounds is affected by the fermentation constraints such as the biodegradability of substance, the degrading capability of microorganism and the environmental conditions like pH. Moreover, pH is considered as the primary process variable in controlling the hydrolysis rate of anaerobic digestion of solid state fermentation. It seems that pH control even during pre-stage is imperative.

5.4.2 Conductivity

A conductivity of 6.37 µS/cm of the 12 L dilution was the highest average with the 8 L dilution recording the lowest conductivity of 4.55 µS/cm. Conductivity with respect to the various dilutions did not show any specific trend but varied widely. Generally, however, there was high conductivity in all the dilutions resulting probably from the different ionic compositions or amount of salts used in preparation of some of the feedstock. Moreover it could have also resulted from the contamination from varying impurities in waste containers and salts from detergent normally used in washing eating bowls or even the pipe borne water used. Thus the hydrolytic leachate was neither salt-free, ion-free, or impurity-free because according to Michaud (1991), the purer the liquid, the lower the conductivity.

5.4.3 HRT

In the experiment conducted, the HRT decreased with increasing dilution. The 8 L dilution recorded the highest HRT of 1.5±0 and the 20 L dilution recorded the lowest HRT of 0.6±0. Probably the lower the HRT the lower the biogas production rate as the 20 L dilution recorded the highest biogas whereas the 8 L recorded the lowest biogas production.

5.4.4BOD Removal in the Methanogenic Reactor

The average BOD increased as the dilutions increased probably because the dilutions enhanced solubilization and consequently degradation. Microbial degradation increased as the unstable organic components were available to the microbes. BOD of the hydrolytic leachate was generally higher than that of the buffered hydrolytic leachate. The average BOD of the methanogenic effluent was relatively lower because the methanogens extracted the unstable organic component delivered into the methanogenic reactor at higher rates. As the microbes fed on the biodegradable material, biogas was released as a result. In general, the assertions that may be made include the fact that a high BOD indicates a high content of easily degradable, organic material in the sample and a low BOD indicates a low volume of organic materials, substances which are difficult to break down or other measuring problems (Perley *et al.,* 1992).

5.4.5 Biogas Production in the Methanogenic Reactor

An increasing biogas production was realised with increasing dilutions and increasing percentage degradation. The highest biogas production of 8.91±3.15 L/day was achieved at the 20 L dilution and the lowest biogas production of 0.65±1.36 L/day was recorded by the 8 L dilution.

The 20 L dilution achieved the highest biogas production rate of 4.5±1.59 L of biogas per kilogram of TS whereas the 8 L dilution recorded a biogas production rate of 0.21±0.09 L of biogas per kilogram TS. The high biogas production potential of the 20 L dilutions is probably the result of its corresponding higher biodegradability and higher BOD removal efficiency which was efficiently converted to biogas.

6 CONCLUSION

The 20 L dilution recorded the highest percentage degradation recorded the lowest percentage degradation. Percentage waste increased with increasing dilution.

Biogas production increased with increasing percentage degradation.

The highest biogas production of 8.91±3.15 L/day was achieved at the 20 L dilution and the lowest biogas production of 0.65±1.36 L/day was recorded by the 8 L dilution.

The 20 litres dilution recorded the highest average biogas production rate of 4.5±1.59 litres of biogas per kilogram of total solids whereas the 8 litres dilution recorded the lowest of 0.2±0.09 litres of biogas per kilogram of total solids.

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