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Biogas Production from Biodegradable Kitchen Waste Generated on University of Science and Technology Campus, Ghana

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Abstract
The alarming potential environmental problems (low investment, operation cost, technical requirements, air, water and land pollutions, improper waste management practices) linked to organic fraction of municipal solid waste which is mostly landfilled in many parts of the world 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 Kwame Nkrumah University of Science and Technology campus, Ghana. 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.

Keywords: Biogas production; biodegradable waste; kitchen waste; methanogenic reactor; hydrolysis reactor; buffer system; KNUST; Ritter TG05/5 Drum-type Gas Meter; gas analyser, MSW
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1. Introduction

Large tons (> 8,000) of biodegradable fraction of municipal solid waste (MSW) are generated on daily basis in various residences and households in Ghana and are poorly managed despite their high bioenergy potential (Miezah, Obiri-Danso, Kádár, Fei-Baffoe, & Mensah, 2015). The immense challenges associated with proper management of MSW in many developing and middle-income countries cannot be over emphasized (Fei-Baffoe, Nyankson, & Gorkeh-Miah, 2014; Hoornweg & Bhada-Tata, 2012). Although MSW could be treated using mechanical operation (land-filling), thermal treatment (incineration), biological transformation (anaerobic digestion, composting) and physico-chemical conversion; landfilling is extensively used as final disposal in many parts of the world (Hu, Du, & Long, 2017) and Ghana is not an exception (Fei-Baffoe et al., 2014; Mensah & Larbi, 2005). Landfilling option is indicated to be uneconomical since the waste are not segregated before dumping (Fei-Baffoe et al., 2014); their leachate indicated to pollute groundwater and other waterbodies and emit unpleasant odours (Lucermoni, et al., 2017); and release greenhouse gases which threatens the sanity of the ozone layer (Kormi, Ali, Abichou, & Green, 2017; Lucernoni, Capelli, & Sironi, 2017; Myhre et al., 2013; Youcai & Ziyang, 2016). Anaerobic digestion for biodegradable waste is the most cost-effective, owing to the high energy recovery (biogas production) and its limited environmental impact (Fei-Baffoe & Busch, 2010; Parawira, Read, Mattiasson, & Bjornsson, 2008).

1.1 Research Objectives

This research work focused on the biogas production potential from kitchen waste generated on the KNUST campus. The specific objectives for the study were to: design an appropriate anaerobic digester for the kitchen waste; determine the chemical and physical characteristics of kitchen waste used; determine the extent of waste degradation on biogas production and determine the amount of biogas that could be produced per unit kilogram of kitchen waste used. The experiment was carried out in a multi-stage anaerobic digestion system operated under mesophilic temperature.

2. Materials and Method

The following is a discourse of how the research was conducted.

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2.1 Study Area
The project was undertaken on the KNUST campus. The biodigesters were set up at the Department of Theoretical and Applied Biology's in a controlled room where the temperature and other operation parameters could be controlled and monitored.

2.2 Source of Waste and collection
The kitchen waste used as substrate for the study were collected from some randomly selected restaurants and canteens at the various halls of residence and faculties within the KNUST campus every 10 days over a period of five months.

2.3 Waste Composition
The kitchen waste collected for the experiment was composed mainly of carbohydrate food substances which varied widely ranging from fried rice, cooked plane rice, 'waakye', kenkey, ripe plantain, and 'gari', bread. Other food substances present included fruits and vegetables residue such as tomatoes, spinach, onions, apples, banana peels, beans, meat, fish, bones. There were tissue papers, disposable plastic containers, cups and disposable cutlery which were sorted out.

2.4 Reactor Design
The experiment was carried out in a Double stage reactor system - Hydrolysis and Methanogenic reactors which is presented in the schematic diagram in **Figure 1** below:

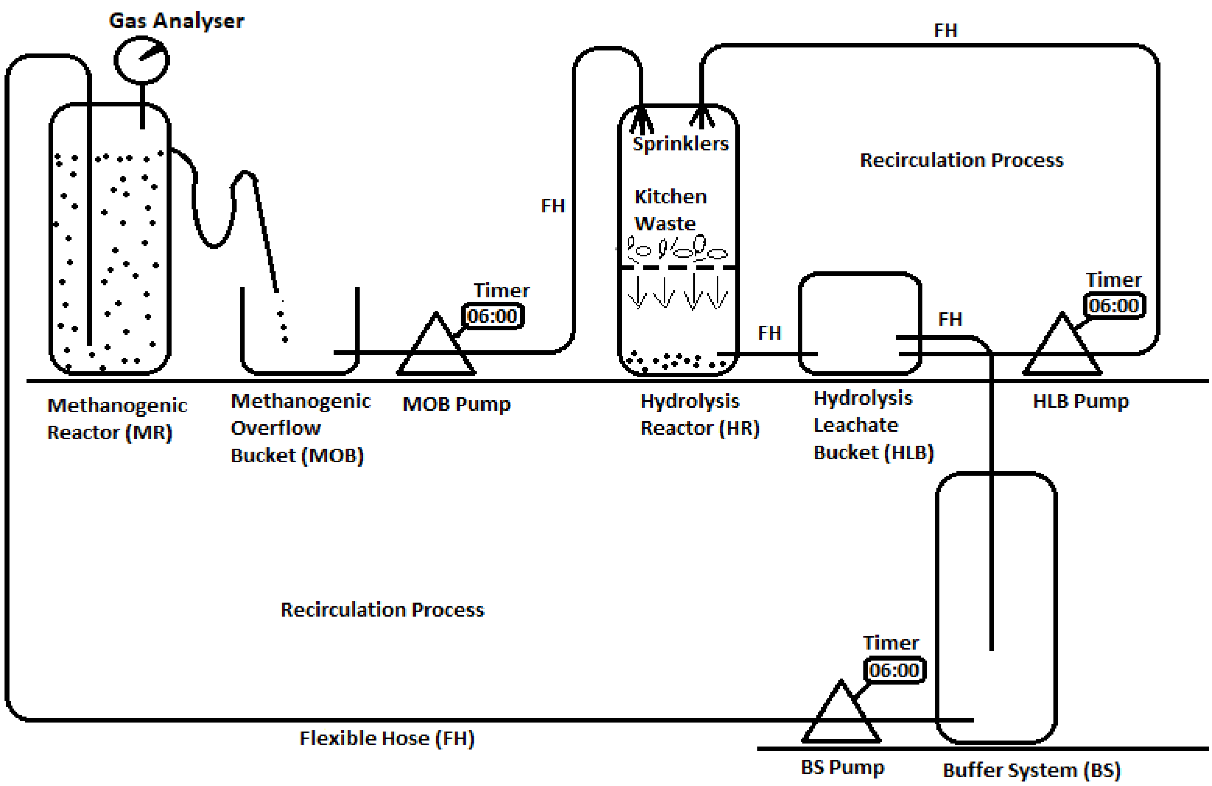

Figure 1: Design of Double-Stage Biodigesters

The set up was designed such that, leachate from the Hydrolysis Reactor (HR) was collected into a 12 litre plastic bucket labeled as Hydrolysis Leachate Bucket (HLB) and connected to a low horse powered pressure pump (labeled as Hydrolysis Leachate Bucket Pump – HLBP) with the help of flexible plastic pipe at about 3 cm from the base of the HLB. The HLBP recirculated the leachate in the HLB to the top of the HR with the help of a sprayer. The spout for the connection of the HLB to the HLBP was also at about 3 cm from the base of the HLB but directly opposite that of the HR. Another connection with a flexible tube of similar size and diameter was made at the same side just about 0.5 cm above the spout connection leading to the HLBP. This was made to drain any overflowing leachate in the HLB by gravity into another system, labelled as Buffer System (BS). These were programmed to recirculate their leachate to other reactors.

The BS was also connected at about 3 cm from its base to another low horse powered pressure pump labeled as Buffer System Pump (BSP) to pump programmed calibrated amount of buffered leachate in the BS into a

Methanogenic Reactor (MR) containing the cow slurry as an inoculum. The MR was connected to a gas analyzer at its top with an air tight gas tube. A u-tube with its top slashed in a slanted manner was positioned 50 cm from the base of the MR such that any overflow beyond this level flowed into another 12 L plastic bucket labeled as Methanogenic Overflow Bucket (MOB). Another low horse powered pump labeled as Methanogenic Overflow Bucket Pump (MOBP) was connected at about 3 cm from the base of the MOB with flexible pipes to pump programmed amount of the overflown effluent slurry to the top of the HR. The reactor barrels were lagged and labeled accordingly. Each of the reactors including the BS had an internal diameter of 36 cm, a height of 59 cm and a total volume capacity of 70.5 litres. Each operating pump had timers to control their flow per period.

2.5 Reactors and System Operation

The HR was filled manually with 10 kg of kitchen waste collected from the restaurants and canteens on KNUST campus. The mass of the kitchen waste was measured with a digital balance. The kitchen waste was mixed with very large-sized wood shavings obtained from carpentry shops on campus and thoroughly mixed to reduce turbidity and provide a good structure for water percolation when put into the HR. See plate 1. Varying amounts of water dilutions of 8, 10, 12, 15 and 20 litres were used in the operation of the HR. The kitchen waste and their varying water dilutions were each detained for 10 days and each dilution repeated. The MR was filled with 10 kg cow slurry obtained from the Kumasi Abattoir which was variously diluted with water and sieved to remove the fibrous matter in it and thereafter diluted to the 50 L mark of the MR where the u-tube was fixed.

The cow slurry served as the source of inoculum that is the methane bacteria which were fed periodically with the buffered hydrolytic leachate collected into the BS to allow the bacteria to grow and perform biological activity. The HLBP had a flow rate of 0.1 L/min and was programmed with the help of timers to supply calibrated amounts of leachate to the various reactors. Specifically, the leachate was recirculated four times at 6-hour intervals within the 24 hours for all the different dilutions. The number of minutes for each time of pumping only varied with respect to the number of litres of leachate expected to be supplied to the various reactors at various dilutions. For example, in the 10 litre dilution, the pump with the flow rate of 0.1 L/min was programmed to pump for 25 minutes per period for four times every six hours. The reactors were maintained at an ambient temperature of 28^{o}C. The gas produced per day was measured with a Ritter TG05/5 Drum-type Gas Meter and the daily readings were recorded. The gas spout was connected to a Bunsen burner and lighted with a spark, however, since there were no means of storage the rest of the gas was allowed to escape.

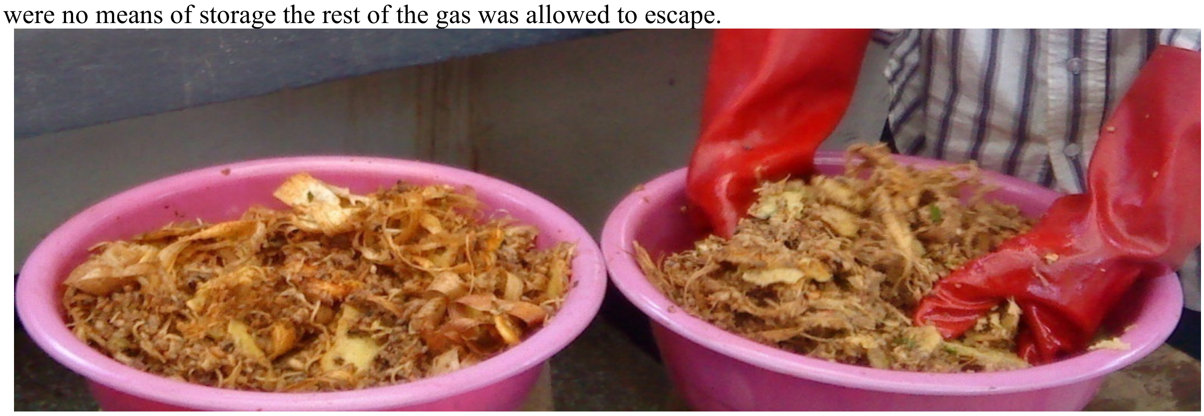

Plate 1: Sample Kitchen Waste Mixed with Wood-shavings

2.5.1 Process Parameters Measured

Various process parameters were measured including temperature, pH, conductivity, total solids, moisture content, BOD, percentage BOD removal, biogas production and biogas production rate.

The pH, Conductivity and Temperature were measured with pH meter, conductivity meter and mercury-in-glass thermometer respectively.

For the Biochemical Oxygen Demand, BOD, a 5-day BOD was computed using the equation below:

$$BOD_5,\ mg/L = (D_1 - D_2)/P$$

Where, 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 percentage (%) Moisture Content was determined by the oven drying method at 105^{o}C

Total Solids Content was determined using the formula:

$$\text{Total solids (kg)} = \frac{\text{(percentage moisture content)}}{\text{Mass of food waste (kg)}} \times 100$$

Percentage Degradation was calculated using the formula below:

$$\% \text{ Degradation} = \frac{\text{TS before (kg)} - \text{TS after (kg)}}{\text{TS before (kg)}} \times 100$$

Hydraulic Retention Time, HRT was calculated using the formula below:

$$\text{HRT} = \frac{\text{Reactor Volume, V(m}^3)}{\text{Flow rate, Q(m}^3/\text{day)}}.$$

Biogas Production Rate (L/kg TS) was calculated using the formula:

$$\text{Biogas production rate} = \frac{\text{Biogas production/ (L/day)}}{\text{Total Solid /(kg)}}$$

Percentage BOD Removal in MR was determined using the formula:

$$BOD_5 \text{ Removal in MR} = \frac{(BOD_5 \text{ in BS}) - (BOD_5 \text{ in MO})}{BOD_5 \text{ in BS}} \times 100\%$$

2.6 Statistical Analysis

One-way ANOVA was used to analyze the various treatments at 95% confidence level and 5% probability level.

2.7 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. A summary of the experimental run and conditions to which the kitchen waste was subjected to is presented in table 1.

Table 1 Summary of Experimental Run Performed on Kitchen Waste

Parameter/Dilution	8L/day	10 L/day	12L/day	15 L/day	20 L/day
Type of waste	Kitchen waste	Kitchen waste	Kitchen waste	Kitchen waste	Kitchen waste
Mass of waste used/(kg)	10	10	10	10	10
Ambient Temperature /(ºC)	28.22 ±1.68	28.29±1.62	28.11± 1.82	28.24±1.54	28.32±1.47
Degradation period/(days)	10	10	10	10	10
Number of repetitions	2	2	2	2	2
Hydraulic Retention Time, (L/day)	1.5±0	1.2±0	1.0±0	0.8±0	0.6±0

3. Results

The tables presented show the results obtained from the monitoring of parameters measured during the anaerobic digestion process.

3.1 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.

3.2 Degradation in the Hydrolytic Reactor

The degradation in the hydrolytic reactor at various dilutions is presented in table 2. 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.

Table 2 Particulate Matter Degradation in the Hydrolytic Reactor

Parameter/Dilution	8L/day	10 L/day	12L/day	15 L/day	20 L/day
Degradation/(%)	10.45±1.2	26.65±0.9	30.79±2.8	29.30±1.6	36.13±2.2

3.3 Characteristics 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 3. below.

Table 3 Characteristics of Leachate Produced in the Hydrolytic Reactor

Parameter/Dilution	8 L/day	10 L/day	12 L/day	15 L/day	20 L/day
pH	3.2 ± 0.07	3.61± 0.08	3.39 ± 0.11	3.59 ± 0.13	3.93 ± 0.20
Conductivity, µS/cm	4.55 ± 0.48	4.99 ± 0.29	6.37 ± 1.02	5.69 ± 0.42	6.03 ± 0.21
BOD_5 of Buffered Hydrolytic Leachate /(mg/L)	10880 ± 2516	8614 ± 3786	15861 ±2882	17347 ±5253	22212 ±8034

3.3.1 BOD Removal in the Methanogenic Reactor

Presented in Table 4 are the results of percentage BOD removal from the MR. The Table compares the percentage BOD removal with their gas production rate.

Table 4 BOD Removal in Methanogenic Reactor and Biogas Production Rate

Parameter/Dilution	8 L/day	10 L/day	12 L/day	15 L/day	20 L/day
Percentage BOD_5 Removal /(%)	2.28 ± 0.16	5.22 ± 0.39	9.90 ± 0.28	5.60 ± 0.01	4.06 ±0.07
Biogas Production Rate/(L/kg TS)	0.21±0.09	0.28±0.10	0.52±0.14	2.96±0.63	4.5±1.59

In Table 4 above, the highest BOD removal of 9.90±0.28% occurred at a dilution of 12 L and the lowest BOD removal of 2.28±0.16% occurred at a dilution of 8 L. And though the 12 L dilution achieved the highest percentage BOD removal, it nevertheless, recorded a biogas production rate of 0.52±0.14 L/kg TS which was smaller than that of the 15 L and 20 L.

3.3.2 Biogas Production in the Methanogenic Reactor

Presented in table 5 are the means of the daily biogas production and the corresponding BOD_5 of the various dilutions.

Table 5 Biogas Production in the Methanogenic Reactor

Parameter/Dilution	8 L/day	10 L/day	12 L/day	15 L/day	20 L/day
BOD_5/(mg/L) of Methanogenic effluent	10633 ±2124	8164 ±2327	14290 ± 3980	16375 ± 5205	21311 ± 7486
Biogas production/(L/day)	0.65±1.36	0.73±0.26	1.36 ±0.3	7.42 ±1.58	8.91±3.15

In the Table 5 above, the 20 L dilution recorded the highest BOD_5 of 21311±7486 mg/L and also recorded the highest biogas production of 8.91±3.15 L/day while the 8 L dilution which recorded the lowest BOD_5 of 10633±2124 mg/L also recorded the lowest biogas production of 0.65±1.36 L/day. The 10, 12 and 15 L showed a similar trend that is, biogas production increased with increasing dilutions.

4. Discussion

This section presents a discussion on the composition of waste; degradation in the hydrolytic reactor; characteristics of leachate produced in the hydrolytic reactor; BOD removal in the methanogenic reactor and biogas production in the methanogenic reactor.

4.1 Composition of Waste

The greater proportion of the kitchen waste was carbohydrate food substances which constituted about 80% of the waste. Carbohydrate foods seems to be the most consumed food on the KNUST campus probably because it is an energy giving food and needed in higher quantities. Proportion of protein foods in the kitchen waste was about 10% probably because not much protein foods were consumed on the campus and rarely was a kitchen waste collected which contained big chunk of meat or fish (except bony, cartilaginous and internal structures) unconsumed. Most kitchen waste collected contained some amounts of vegetables and fruits salad, which constituted about 5% of the overall waste. Most foods were served with some amount of vegetable and or fruit salads because of the belief that it promotes the health of consumers. Foods from most restaurants and canteens on the campus are served in disposable plastic containers with disposable cutlery wrapped in tissue paper. These disposable plastics and tissue were normally discarded directly with the unconsumed food and drinks. Generally, proportions of different food components consumed by people vary with age, sex, occupation, environment and knowledge of what a balanced diet is to different categories of people (Fei-Baffoe, Osei, Agyapong, & Nyankson, 2016; Miezah et al., 2015).

4.2 Characteristics of Waste

The waste generally had high moisture content and high total solids.

4.2.1 Moisture content

The waste used for the research contained an average of 65% moisture. The moisture content after degradation for each of the dilutions increased generally due to the fact that some amount of water was added to the waste at the start of the experiment and the leachate produced was recirculated. The wetter the feedstock the more suitable it is to handle with standard pumps and the more volume and area it takes up relative to the levels of biogas that are produced (Kratky & Jirout, 2011; Mata-Alvarez et al., 2014).

4.2.2 Total solids

The waste fed into the HR recorded an average of 35% total solids. According to (Mata-Alvarez et al., 2014), high solids AD processes range from 22% to 40%, thus, the kitchen waste fed into the HR had high solid content. However, this percentage decreased with increasing dilutions as the addition of water and leachate recirculation enhanced to some extent the hydrolysis of the feedstock and consequently its degradation.

4.3 Degradation in the Hydrolytic Reactor

The 20 L dilution recorded the highest percentage degradation of 36.13% and the 8 L dilution recorded the lowest percentage degradation of 10.45%. It was expected that the percentage degradation would have shown a certain trend with respect to their dilution rates, however this was not the case as the 12 L dilution rather had a slightly higher degradation than the 15 L dilution. Perhaps the proportion of wood-shavings used to improve the structure of the feedstock during the 15 L dilutions was a little higher and might have hindered degradation due to the presence of lignin material which is not degradable or most likely the proportion of lipids in the waste was high.

And according to Astals et al. (2013) and Hidalgo, Sastre, Gómez, and Nieto (2012), the highest degradation rate could be obtained with starch, protein and cabbage but lipids seem to degrade very slowly. Degradability generally is enhanced when feedstock is putrescible and through the addition of water and leachate recirculation. The feedstock used contained a greater proportion of carbohydrate which is putrescible. From the chemical point of view, as indicated by Astals et al. (2013), hydrolysis is the breakdown of long-chain biomolecules by the reaction with water. In this sense, water is essential for the enhancement of the process. Biologically, hydrolysis works through the influence of enzymes. For solid substrate, hydrolysis is often the slowest and limiting-step in anaerobic degradation process. The waste characteristics can be altered by simple dilution. Water reduces the concentration of certain constituents such as nitrogen and sulfur that produce products (ammonia and hydrogen sulfide) that are inhibitory to the anaerobic digestion process. High solids digestion creates high concentrations of end products that inhibit anaerobic decomposition. Therefore, some dilution can have positive effects (Zupančič & Grilc, 2012).

According to Shahriari, Warith, Hamoda, and Kennedy (2012), leachate recirculation provides moisture to the waste where moisture is responsible for simulating the degradation of the organic waste. Furthermore, this process facilitates the provision of nutrients and bacteria necessary for the process. Although, digesters typically can accept any biodegradable material, if biogas production is the aim according to Fei-Baffoe and Busch (2010) and Fei-Baffoe et al. (2014) , the level of putrescibility is the key factor in its successful application.

4.4 Characteristics 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.

4.4.1 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.

Mata-Alvarez et al. (2014), 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. Zhai et al. (2015) indicate that low pH does not enhance degradation and that the initial stage of anaerobic degradation is inhibited by low pH and a pH of around 6 can promote degradation. In this view, pH must be meticulously observed and adjusted if necessary. Consequently, hydrolysis of particulate kitchen waste could improve significantly with increase in pH. Thus, for an enhanced hydrolysis rate, a neutral pH is recommended.

In the experiment conducted in this research, the 20 L dilution recorded relatively the highest level of degradation and comparatively recorded highest average pH among the pH values recorded whereas that of the 8 L with the comparatively lowest pH recorded the lowest degradation. During digestion, the two processes of acidification and methanogenesis require different pH levels for optimal process control. The retention time of digestate affects the pH value and in a batch reactor system acetogenesis occurs at a rapid pace. Acetogenesis can lead to accumulation of large amounts of organic acids resulting in pH below 5. Rapid rate of acetogenesis is believed to have also accounted for the low pH observed in the various dilutions during this experiment. The growth of anaerobic microorganisms like methanogens could have been inhibited by acidic condition because of sensitive to acid concentration (Mata-Alvarez et al., 2014; Zhai et al., 2015).

The acidic conditions observed in this experiment might have also affected the amount of biogas generated. According to Astals et al. (2013), the degradation of protein through the release of ammonia has a buffering capacity. As digestion reaches the methanogenesis stage, the concentration of ammonia increases, and the pH value can increase to above 8.

Once the methane production is stabilized, the pH stays between 7.2 and 8.2. In the experiment conducted, the waste composition showed very low protein proportion, and this could have also accounted for the low pH recorded.

4.4.2 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. Tsapekos, Kougias, and Angelidaki (2015) and Pastor, Ruiz, Pascual, and Ruiz (2013) demonstrates that the purer the liquid, the lower the conductivity.

4.4.3 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. Shi et al. (2017) indicate that HRT affect the performances and stability in anaerobic digestion as it influences the biogas production potential, the pH, the VFAs, methane content and degradability of waste. Lower HRT showed lower stability compared and biogas production potential of the substrate used. Climenhaga and Banks (2008) posit that it challenging to predict the effect of HRT on anaerobic treatment systems, since it depends on reactor configuration, type of feed and characteristics, organic loading rate, type of biomass and method used to evaluate performance.

4.5 BOD 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. The greater the HRT, BOD5 removal increases (Botheju & Bakke, 2011; Mata-Alvarez et al., 2014).

The 12 L dilution recorded the highest percentage BOD removal of 9.90±0.28% and the 8 L dilution recorded the lowest percentage BOD removal of 2.28±0.16%. Although the 12 L dilution achieved the highest percentage BOD removal, it nevertheless, recorded a biogas production rate of 0.52±0.14 L/kg TS which was relatively smaller than that of the 15 L and 20 L. Meanwhile the 20 L dilution which recorded the highest biogas production rate of 4.5±1.59 L/kg TS recorded as low as 4.06±0.07% BOD removal. This is probably due to the fact that the BOD removed during the 20 L dilution was of highest quality in that it was highly degradable and had higher biogas potential Thanwised, Wirojanagud, and Reungsang (2012).

4.6 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. Lower biogas production could be the presence of spices in kitchen waste. Spices could decrease the number of methanogens and consequently the methane (biogas) yield. Spices contributes significantly to metals and bioactive compounds which influence biomethanization of the kitchen waste (Sahu et al., 2017).

Mata-Alvarez et al. (2014) point out that, biogas yield is directly proportional to the process efficiency. However, it is also important to note that a low biogas yield does not necessarily indicate a deficient performance, but it is simply due to a low biodegradability of the substrate used. Digestion of waste with high biodegradability like market waste may pose a problem due to the complex reaction involved in digestion especially that acidogenesis can produce more acids than methanogenesis can convert at higher temperature. The ultimate yield of biogas depends on the composition and biodegradability of the waste feedstock. But the rate of production will depend on the population of bacteria and archaea, their growth conditions and the temperature of the system.

5. Conclusion

Generally, 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. The 20 L and 8 L dilutions recorded the highest and lowest percentage degradations respectively. Percentage degradation 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.

This study recommends for further studies a comparison of the single stage reactor with the double stage digesters using the similar feed stock subjected to similar process parameters. A variation with wood shavings to determine the degradation rate. Incorporating more protein in feedstock to see the impact. Moreover, a comparison of various spices incorporated in the food could be experiment to check their impact on degradation especially with respect to the population of methanogens and their activities.

References

Astals, S., Esteban-Gutiérrez, M., Fernández-Arévalo, T., Aymerich, E., García-Heras, J., & Mata-Alvarez, J. (2013). Anaerobic digestion of seven different sewage sludges: a biodegradability and modelling study. *Water research, 47*(16), 6033-6043.

Botheju, D., & Bakke, R. (2011). Oxygen effects in anaerobic digestion-a review.

Climenhaga, M., & Banks, C. (2008). Anaerobic digestion of catering wastes: effect of micronutrients and retention time. *Water Science and Technology, 57*(5), 687-692.

Fei-Baffoe, B., & Busch, G. (2010). Hydrolysis of Unsorted Municipal Solid Waste Using a Percolating Reactor Mechanism. *The Journal of Solid Waste Technology and Management, 36*(4), 227-234.

Fei-Baffoe, B., Nyankson, E. A., & Gorkeh-Miah, J. (2014). Municipal Solid Waste Management in Sekondi-Takoradi Metropolis, Ghana. *Journal of Waste Management, 2014*.

Fei-Baffoe, B., Osei, K., Agyapong, E. A., & Nyankson, E. A. (2016). Co-composting of organic solid waste and sewage sludge–a waste management option for University Campus. *International Journal of Environment, 5*(1), 14-31.

Hidalgo, D., Sastre, E., Gómez, M., & Nieto, P. (2012). Evaluation of pre-treatment processes for increasing biodegradability of agro-food wastes. *Environmental technology, 33*(13), 1497-1503.

Hoornweg, D., & Bhada-Tata, P. (2012). *What a waste: a global review of solid waste management* (Vol. 15): World Bank, Washington, DC.

Hu, L., Du, Y., & Long, Y. (2017). Relationship between H2S emissions and the migration of sulfur-containing compounds in landfill sites. *Ecological Engineering, 106*, 17-23.

Kormi, T., Ali, N. B. H., Abichou, T., & Green, R. (2017). Estimation of landfill methane emissions using stochastic search methods. *Atmospheric Pollution Research, 8*(4), 597-605.

Kratky, L., & Jirout, T. (2011). Biomass size reduction machines for enhancing biogas production. *Chemical Engineering & Technology, 34*(3), 391-399.

Lucernoni, F., Capelli, L., & Sironi, S. (2017). Comparison of different approaches for the estimation of odour emissions from landfill surfaces. *Waste Management, 63*, 345-353.

Mata-Alvarez, J., Dosta, J., Romero-Güiza, M., Fonoll, X., Peces, M., & Astals, S. (2014). A critical review on anaerobic co-digestion achievements between 2010 and 2013. *Renewable and sustainable energy reviews, 36*, 412-427.

Mensah, A., & Larbi, E. (2005). Solid Waste Disposal in Ghana. WELL Factsheet November 2005.

Miezah, K., Obiri-Danso, K., Kádár, Z., Fei-Baffoe, B., & Mensah, M. Y. (2015). Municipal solid waste characterization and quantification as a measure towards effective waste management in Ghana. *Waste Management, 46*, 15-27.

Myhre, G., Shindell, D., Bréon, F.-M., Collins, W., Fuglestvedt, J., Huang, J., . . . Mendoza, B. (2013).

Anthropogenic and natural radiative forcing. *Climate change, 423*, 658-740.
Parawira, W., Read, J. S., Mattiasson, B., & Bjornsson, L. (2008). Energy Production from Agricultural Residues: high methane yields in pilot-scale two-stage anaerobic digestion. . *Biomass Bioenergy, 32*, 44-50.
Pastor, L., Ruiz, L., Pascual, A., & Ruiz, B. (2013). Co-digestion of used oils and urban landfill leachates with sewage sludge and the effect on the biogas production. *Applied energy, 107*, 438-445.
Sahu, N., Sharma, A., Mishra, P., Chandrashekhar, B., Sharma, G., Kapley, A., & Pandey, R. (2017). Evaluation of biogas production potential of kitchen waste in the presence of spices. *Waste Management, 70*, 236-246.
Shahriari, H., Warith, M., Hamoda, M., & Kennedy, K. J. (2012). Effect of leachate recirculation on mesophilic anaerobic digestion of food waste. *Waste Management, 32*(3), 400-403.
Shi, X.-S., Dong, J.-J., Yu, J.-H., Yin, H., Hu, S.-M., Huang, S.-X., & Yuan, X.-Z. (2017). Effect of hydraulic retention time on anaerobic digestion of wheat straw in the semicontinuous continuous stirred-tank reactors. *BioMed research international, 2017*.
Thanwised, P., Wirojanagud, W., & Reungsang, A. (2012). Effect of hydraulic retention time on hydrogen production and chemical oxygen demand removal from tapioca wastewater using anaerobic mixed cultures in anaerobic baffled reactor (ABR). *International Journal of Hydrogen Energy, 37*(20), 15503-15510.
Tsapekos, P., Kougias, P., & Angelidaki, I. (2015). Biogas production from ensiled meadow grass; effect of mechanical pretreatments and rapid determination of substrate biodegradability via physicochemical methods. *Bioresource technology, 182*, 329-335.
Youcai, Z., & Ziyang, L. (2016). *Pollution Control and Resource Recovery: Municipal Solid Wastes at Landfill*: Butterworth-Heinemann.
Zhai, N., Zhang, T., Yin, D., Yang, G., Wang, X., Ren, G., & Feng, Y. (2015). Effect of initial pH on anaerobic co-digestion of kitchen waste and cow manure. *Waste Management, 38*, 126-131.
Zupančič, G. D., & Grilc, V. (2012). Anaerobic treatment and biogas production from organic waste. *Management of organic waste, 3*, 1-28.