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EVALUATION OF BIOGAS PRODUCTION FROM THE DIGESTION AND CO-DIGESTION OF ANIMAL WASTE, FOOD WASTE AND FRUIT WASTE

[1]Otun T.F., [2]Ojo O.M., [3]Ajibade F.O. and [4]Babatola, J. O

[1,2,3,4]Department of Civil and Environmental Engineering
Federal University of Technology, Akure

ABSTRACT: *The increased use of fossil fuels for energy consumption has causes environmental problems both locally and globally. The study investigates the anaerobic digestion in the production of biogas a renewable energy from the digestion and co-digestion of three different types of biodegradable wastes (cow dung, fruit waste and food waste) as an alternative for fossil fuels for energy consumption. This was carried out using a 25 Litres capacity plastic keg prototype biogas plant, constructed to investigate the anaerobic digestion in generating biogas. The experiment was batch operated and daily gas yield from the plant was monitored for 30 days. The slurry temperature and pH were also monitored and presented. The digester was charged with these wastes in the ratio of 1:1, of waste to water respectively. The mesophilic temperatures range attained within the testing period were 25℃ - 28.4℃ and a slurry temperature range of 24.4℃ - 28.4℃. The result obtained from the biogas production showed that the co-digestion of cow dung and food waste produced the highest biogas of 164.8%, followed by the co-digestion of the three waste (cow dung, fruit waste and food waste) which has a percentage of 91.0%, co-digestion of cow dung and fruit waste (83.9%), cow dung of 79.8%, food waste of 77.4% and fruit waste of 76.4% within this retention period. During the digestion period, the volume of biogas production and the changes in pH indicate that the pH decreases as the retention period increases. These results showed that co-digestion wastes produce more biogas than when the wastes are ordinarily used for biogas production. The study recommends that biogas is not just a renewable energy source but also an appropriate way of managing waste, having potential to replace fossil fuel.*

KEYWORDS: biogas, renewable energy, anaerobic digestion, biodegradable wastes, fossil fuel.

INTRODUCTION

In evaluating national development and the standard of living of any nation, the supply and consumption of energy are very important. The overdependence on fossil fuels as primary energy source has led to global climate change, environmental pollution and degradation, thus leading to human health problems. According to current research and future predictions, the crude oil will run out within 40 to 70 years, and natural gas will be finished within 50 years (Courtney and Dorman, 2003). Global average temperature is predicted to increase 1.4 to 5.8 °C by year 2100 and continue to rise long after that (Dow and Downing, 2006). Several investigations point out that this will inevitably lead to drought, flooding, increases in hurricanes and tornadoes and possibly widespread crop failures (Sen, 2009; Mills, 2009). It is now widely accepted that it is caused by the rapidly increasing concentrations of greenhouse gas (CO_2 and others) in the atmosphere, which is emitted mainly by the combustion of fossil fuels containing carbon like coal, oil, and natural gas (Jaynes, 2010). The rising greenhouse gas emissions, decreasing fossil fuel supplies and energy security have led to the introduction of renewable energy targets at national level (Smyth *et al.*, 2011).

Renewable energy has remained one of the best alternatives for sustainable energy development. The energy carrier in focus, in this paper, is biogas, which is among the alternatives to fossil fuels. One of the most efficient energy sources is the biogas produced from green energy crops and organic waste matters. Biogas is distinct from other renewable energies because of its characteristics of using, controlling and collecting organic wastes and at the same time producing fertilizer and water for use in agricultural irrigation. Biogas does not have any geographical limitations nor does it require advanced technology for producing energy, also it is very simple to use and apply. It has a very positive impact on the environment, since less CO_2 is formed during its combustion than used for photosynthesis by the plants from which it is produced (Navickas, 2007; Weiland, 2003; Chynoweth, 2004; Ploj *et al*., 2006).

MATERIALS AND METHOD

Materials

In this study, plastic bio-digester is the equipment used in the production of biogas which has a 25 liters keg, $1\frac{1}{2}$ inches pipe, $\frac{1}{2}$ Inches pipe, 1 inches pipe, 90^0 angle elbows, hose, dollop slippers and measuring cylinder. Other materials used during the construction and biogas production are steel rod of different sizes ($\frac{1}{2}$ Inch, $1\frac{1}{2}$ inches and 1 inch), electric cooker, thermometer, pH meter, toilet papers, gum, paper tape, hand gloves and noise cover. The major raw materials used for the production of the biogas in the bio-digester are cow dung, food waste, fruit waste and distilled water

Methodology

The methods used in the construction of bio-digester, feeding of bio-digester and mode of biogas collection are as discussed as follows;

Design Consideration

The requirements for designing of a Bio digester are volume of digester ($vol_{digester}$), storage capacity of the gas, volume of gas holder (vol_{holder}), retention period and the amount and type of organic waste to be disposed in the digester. In order to determine the unit size of a biogas unit, equation 1 must be achieved:

Volume of digester (liters) = Daily feed-in (liters/day) × Retention time (day) (1)

Where the volume of digester is volume occupied by the fermented material and the volume of gas storage. The digesters were fed at once but the calculation was based on daily feeding with the design criteria of retention period of 30 days, daily feeding of 0.34 kg and 0.34 kg of water for feeding i.e. 1:1 of waste and water

Computation of the Biodigester

1 kg is equivalent to 1 liter; hence the total volume of digester's feed per day is given as:

$$vol_{total}\ of\ digester's\ feed/day = 0.34l\ of\ waste\ + 0.34l\ of\ water =\ 0.68l/day$$

From equation 1,

$$vol_{digester} = vol_{total}\ of\ digester's\ feed\ /day\ \times\ retention\ period\ (day)$$

$$= 0.68 \times 30\ = 20.4 \text{ liters}$$

Also the volume of the gas holder is given as one-fifth of the volume of the digester:

$$vol_{holder} = \frac{1}{5} \times 20.4 = 4.1 \text{ Liters}$$

Hence the total volume of digester is given as:

Total digester volume = volume of digester + volume of gas holder

= 20.4 + 4.1 = 24.5 ~ 25 liters

Collection of Waste

The three different waste (cow dung, food waste and fruit waste) used, was collected from their different waste generation. The cow dung used throughout this project was collected from the Federal University of Technology Akure Ondo state (FUTA) cow's corral while the food waste was collected from different restaurants within and around the university campus. The food waste comprised of rice, salad, fish, meat, vegetable soup and beans flour. The fruit waste was gotten from fruit selling areas around FUTA, it comprises of orange, banana, plantain and pineapple peels. In the course of the collection of the waste, necessary health precaution was taken by wearing hand gloves and nose cover.

Feeding of Digester

The mode of feeding used was a discontinued feeding (batch feeding). This simply means loading the digester at once and maintaining a closed environment throughout the retention period. Six different digesters were prepared down for loading. These six digesters are for the three wastes (cow dung, food waste and fruit waste) and the co-digestion of the three wastes (cow dung and food waste, cow dung and fruit waste including cow dung, food waste and fruit waste). The procedures taken during feeding of the digester are as follow;

1. 10 kg of each of the wastes (cow dung, food waste and fruit waste) was weighed and 10 liters of water was mixed thoroughly with each of the waste in the ratio of 1:1 (Table 1).
2. The mixture of each of the wastes were poured into three different digesters.

3. 5 kg of cow dung with 5 kg of food waste, 5 kg of cow dung with 5 kg of fruit waste including 3.3 kg of each waste were weighed and mixed thoroughly with 10 liters of water each for the co-digestion (Table 1)
4. The mixtures of the each of the co-digestion waste were poured into three different digesters as well.

Table 1. Ratio of Waste and Water Used

Waste used	Weight of waste	Liters of water used
Cow dung	10 kg	10 liters
Fruit waste	10 kg	10 liters
Food waste	10 kg	10 liters
Co-digestion		
Cow dung and food waste	5 kg each	10 liters
Cow dung and fruit waste	5 kg each	10 liters
Cow dung, fruit and food waste	3.3 kg each	10 liters

Mode of Biogas Production

The full setup for this study was the connection of the bio digester to the water displacement setup for the gas collection and then to another water displacement setup for the methane gas collection as shown in Plate 1. The water displacement method of gas collection is a method in which gas is allowed to replace water at equal volume of water displaced and this was used to determine the volume of gas produced daily.

Plate 1: Setup of Biogas Production

RESULTS AND DISCUSSION

Volume of Biogas Produced for Each Waste and Co-digestion waste

Figure 1 shows the volume biogas produced from cow dung, fruit waste and food waste within the retention period 30 days. For biogas produced in cow dung, biogas was not produced for the first 8 days because it takes more time for cow dung to decompose after which gas is being produced. This is predicted because biogas production rate in batch condition is directly equal to specific growth of methanogenic bacteria (Nopharatana *et al*., 2007). This can also be traced to the fact that most cows feed on fibrous materials and microorganisms require a longer time to degrade fibrous materials. This finding is in conformity to that, from the works of Babatola in Akure, and Ukpai and Nnabuchi in Abakaliki (Babatola, 2008; Ukpai and Nnabuchi, 2012). Production of gas from cow dung started on day 9 of the retention period by producing average biogas of 65 ml, thereafter increases to 197.5 ml on day 10 and reduces to 95 ml on day 12. At day 13, the biogas produced was 355 ml in which decreases back to 95 ml on the next day and increases thereafter until it reached the peak on day 22 with 675 ml biogas production after which it begins to reduce till the completion of the retention period which is similar to the work of Aremu and Agarry, 2012).

Biogas production in fruit waste began on the second day of the retention period with 155 ml of gas produced. Subsequence biogas produced each day fluctuated between day 4 and day 16, thereafter increases to the maximum biogas of 450 ml produced on day 24, and between day 25 to 30, the biogas production reduces each day. Fluctuation of biogas production occurs in food waste, in which the maximum gas was produced on the last day (day 30), by producing 540 ml of biogas. Comparing these three wastes, cow dung has the highest biogas produce which occur at day 22 of the retention period.

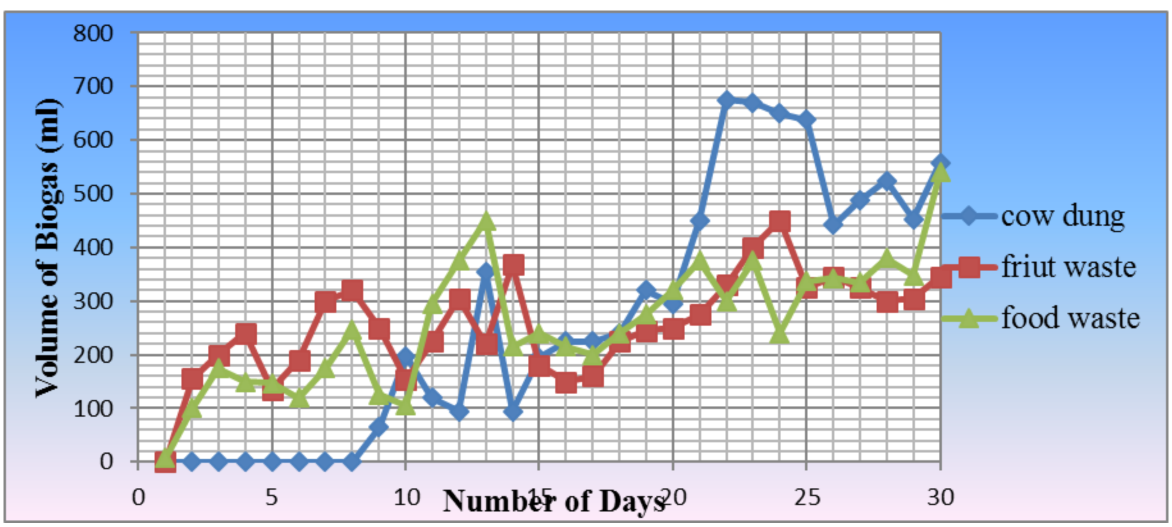

Figure 1. Volume of Biogas of Waste against Number of Days

Figure 2 shows the volume biogas produced from the co-digestion of cow dung fruit waste, cow dung food waste and cow dung food and fruit waste. With the co-digestion of cow dung and fruit waste, the production of biogas begins on day 3 by producing 7.5 ml and increases each day till day 6 and after which it production began to flunctuated. However on day 24, it produces the highest volume of biogas (660 ml) and began to decreases for each of the remaining days. Considering the biogas production in co-digestion of cow dung and food waste, the production begins on the day 5 with 225 ml gas produced and it increased gradually until it get to day 14 where it produces 1425 ml of biogas which was the highest biogas produced among the six experimented waste. Proceeding with the experiment on this co-digestion, after day 14, the biogas began to fluctuate and reduces each day for the remaining days of the production. The production of biogas for co-digestion of the three wastes begins right from the first day with production of 107.5 ml of biogas and reached its peak production on the day 19 with 655 ml of biogas, thereafter decreases gradually for the days left for the completion of the experiment. From the three mix groups, digester with the cow dung and food waste produced biogas much faster, followed by the co-digestion of cow dung and fruit and the co-digestion of the three waste, which is in line with the work of Aragaw *et al.*, 2013. This might be due to the attribution of the positive synergetic effect of the co-digestion of cow dung and food waste in providing more balanced nutrients, increased buffering capacity, and decreased effect of toxic compounds (Aragaw *et al.*, 2013).

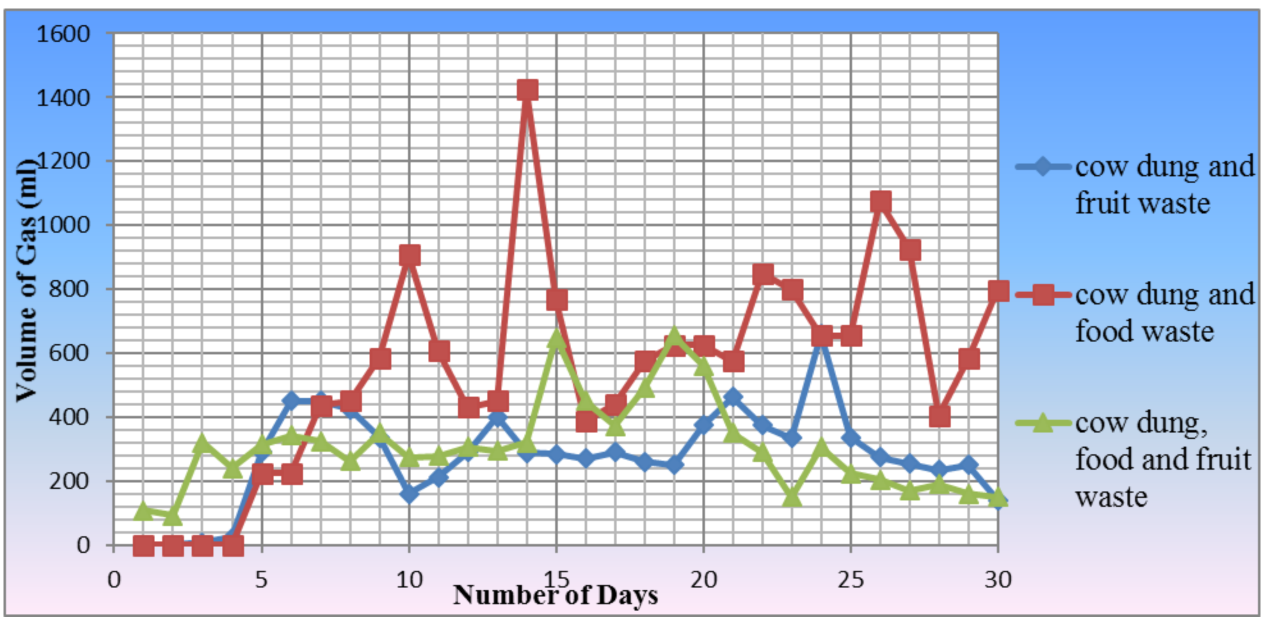

Figure 2. Volume of Biogas of Co-digestion Waste against Number of Days

Temperature of Slurry for Each Waste and Co-digestion waste

Figure 3 shows the temperature of cow dung, fruit waste and food waste within the 30 days retention period. The temperature varies from 25.1℃ - 28.4℃ for cow dung, 24.4℃ – 27.4℃ for fruit waste and 25℃ – 27.7℃ for food waste. These temperature ranges signifies a mesophilic thermal stage of biogas production (25℃ - 45℃). In this stage, the reaction of rate are slow because of the effect of the environmental temperature. The maximum biogas produced for each waste (cow dung, fruit waste and food waste) was attained at day 22, day 24 and day 30 in which the temperature for these days was 27.7℃, 26.9℃ and 27.1℃ respectively

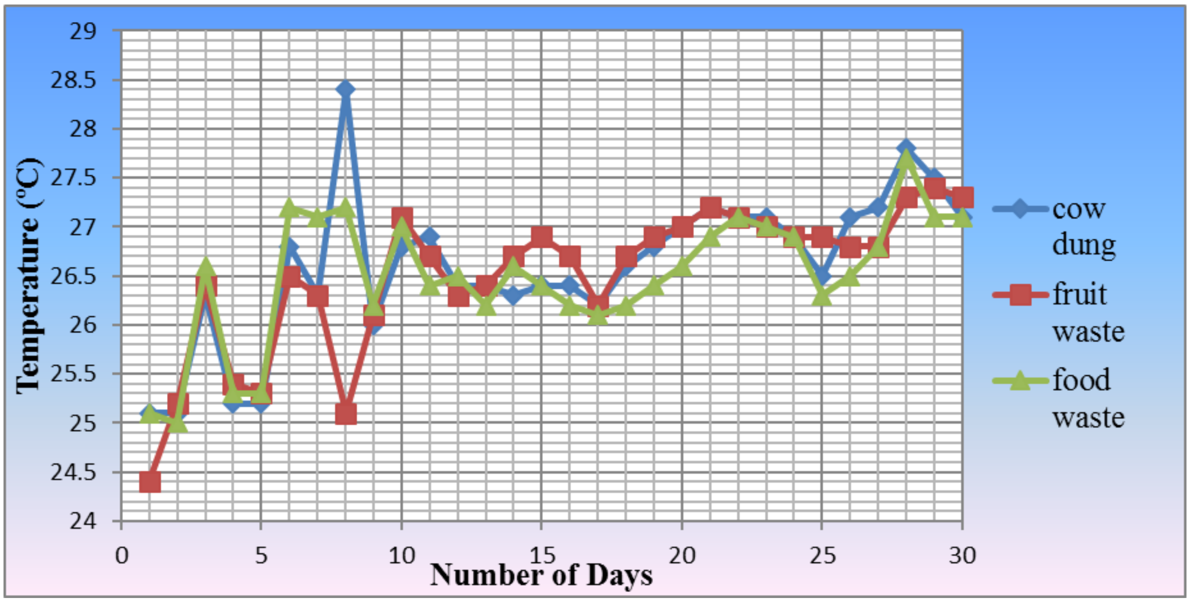

Figure 3. Temperature of Slurry for Waste against Number of Days

Figure 4 indicates the temperature of the co-digestion of cow dung fruit waste, cow dung food waste and cow dung food and fruit waste. The temperature varies from 25.1℃ - 27.4℃ for cow dung and fruit waste, 25.2℃ – 27.8℃ and remained stable on day 15 to day 17 with a temperature of 26.3℃ for cow dung and food waste and 25.4℃ – 27.8℃ for cow dung fruit and food waste. These temperature ranges also signifies a mesophilic thermal stage of biogas production (25℃ - 45℃). The maximum biogas produced for each co-digestion (cow dung fruit waste, cow dung food waste and cow dung food and fruit waste) was attained at day 24, day 14 and day 19 in which the temperature for these days was 27.1℃, 26.4℃ and 26.9℃ respectively. Temperature has been observed by most biogas researchers to be quite critical for anaerobic digestion, since methane – producing bacteria operate most efficiently at temperatures 30.0 – 40.0℃ or 50.0 – 60.0℃ (Ilori *et al.*, 2007). For this study, the six digesters operated under a mesophilic which is similar to the temperature of the work of Ukpai, and Nnabuchi, 2012. The temperature of below 30℃ in which this experiment was operated, could have contributed to the slow development of methanogens and consequently low methane production. This is similar to the report of (Ilori *et al.*, 2007) that the recovery time for biogas production as well as the quality and quantity of biogas produced from agricultural materials are a function of the nature, and composition of the digester feedstock.

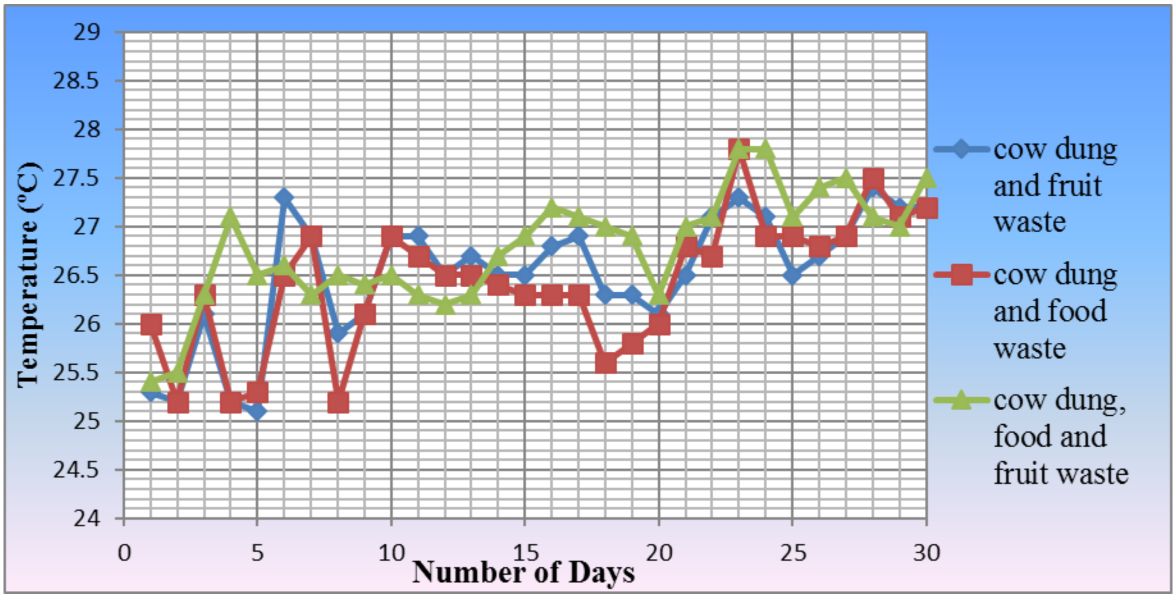

Figure 4. Temperature of Slurry for Co-digestion Waste against Number of Days

pH of Slurry for each Waste and Co-digestion Waste

Figure 5 illustrates the pH of cow dung, fruit waste and food waste within the 30 days retention period. The pH for cow dung fluctuate from the first day to the tenth day between 4.8 and 7.5, after which is begins to decrease gradually for the remaining days of the retention period. As it was observed in the first few days, the pH of cow dung decreases as also reported in the study of Baba *et al.*, 2012 this is due to high volatile fatty acid (VFA) formation (Rao *et al*., 2000). The gradually reduction explains the gradually change of stage of the production of biogas, from hydrolysis to acidogenesis in which the slurry become acidic and form substrate after which it produces biogas. Fruit waste naturally contain some content of acid in them, at the first day of retention period, the pH was 4.2 and it reduces to 3.9 on the third day, after which it began to fluctuate till on the tenth day having a pH of 4.9 and from this day, the pH reduced gradually for the whole retention period. The pH was within the range of 4.9 and 3.1 throughout the retention period. The pH range for food waste varies between 4.6 and 2.7, in which the decrease in pH also begins on the tenth day till the completion of the retention day. It was reported by Suyog 2011 that kitchen waste (food waste) pH decreases highly means reaction is fast, means hydrolysis and acidogenesis reaction is fast as organism utilize the waste more speedily than dung (Suyog, 2011).

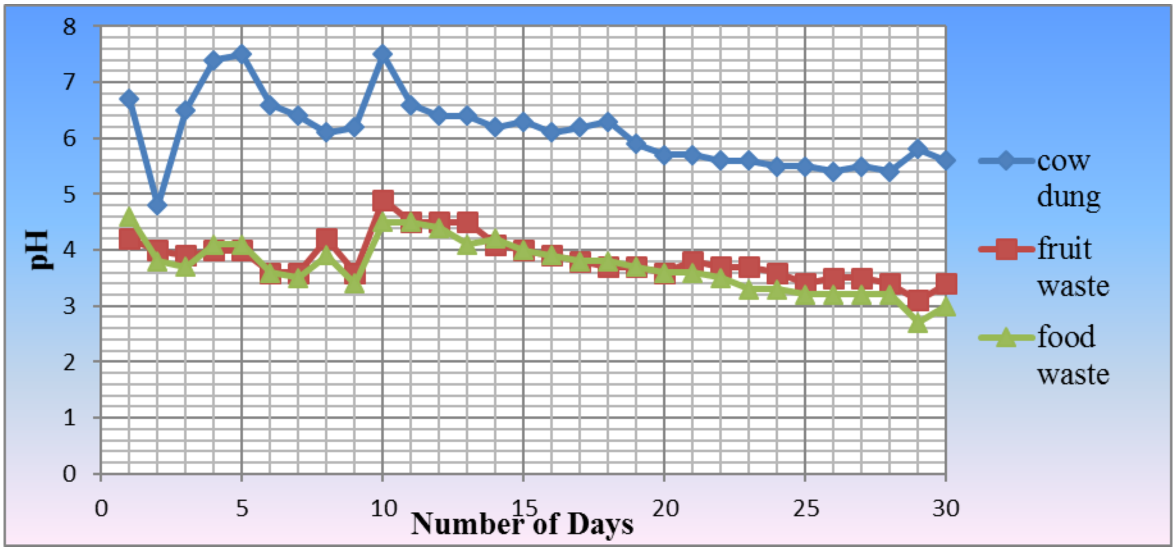

Figure 5. pH of Slurry for Waste against Number of Day

Figure 6 shows the pH of co-digestion of cow dung and fruit waste, cow dung and food waste, and cow dung food and fruit waste within the retention period of 30 days. Unlike the pH of the normal waste (cow dung, fruit waste and food waste), in which the pH began to reduce at day 10 in Figure 5, the pH for co-digestion fluctuate for a longer day before it starts decreasing. For the co-digestion of cow dung and fruit waste, the decrease in pH started on day 10. However, before this day, the pH fluctuates between 4.1 and 6.3, after which it reduces to 5.7 on day 11 and fluctuates to 5.5 at day 17, thereafter it began to reduce until the retention period was completed. The co-digestion of cow dung and food waste fluctuates in pH from the day 1 to day 14 between 3.8 and 5.9, after which it began to reduce for the remaining retention period until 4.3 on day 27 and maintained a pH of 4.5 for day 28, 29 and 30. For the co-digestion of the three wastes, the pH fluctuates to day 13 between 3 and 6.8, after which it deceases continuously throughout the remaining retention period to a pH of 3.2. It is important to maintain the pH of an anaerobic digester between 6 and 8; otherwise, methanogen growth would be seriously inhibited (Gerardi, 2003). In this study, some of the initial pH of cow dung, co-digestion of cow dung and fruit waste and the co-digestion of the three waste ranges between these standard pH to be maintained given by Gerardi 2003.

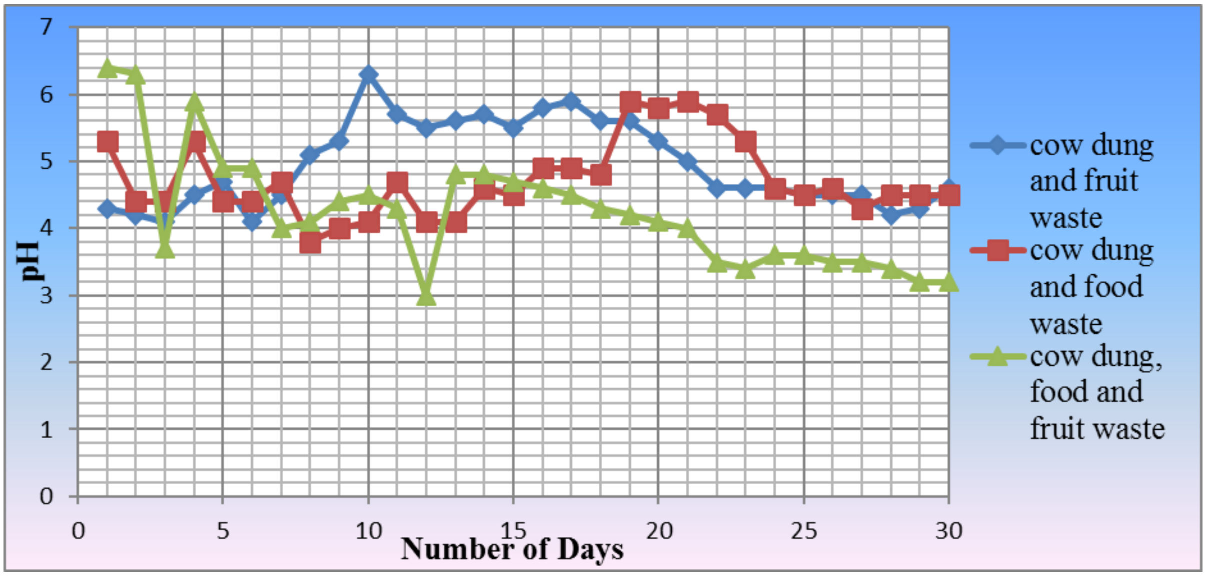

Figure 6. pH of Slurry for Co-digestion Waste against Number of Days

Cumulative Volume of Biogas Produced for Each Waste and Co-digestion waste

Figure 7 shows the cumulative of biogas produced from cow dung, fruit waste and food waste within the retention period 30 days. At the end of 30 days retention period the cumulative of 7975 ml, 7670 ml and 7742.5 ml biogas was produced from cow dung, fruit waste and food waste respectively with cow dung producing the highest biogas.

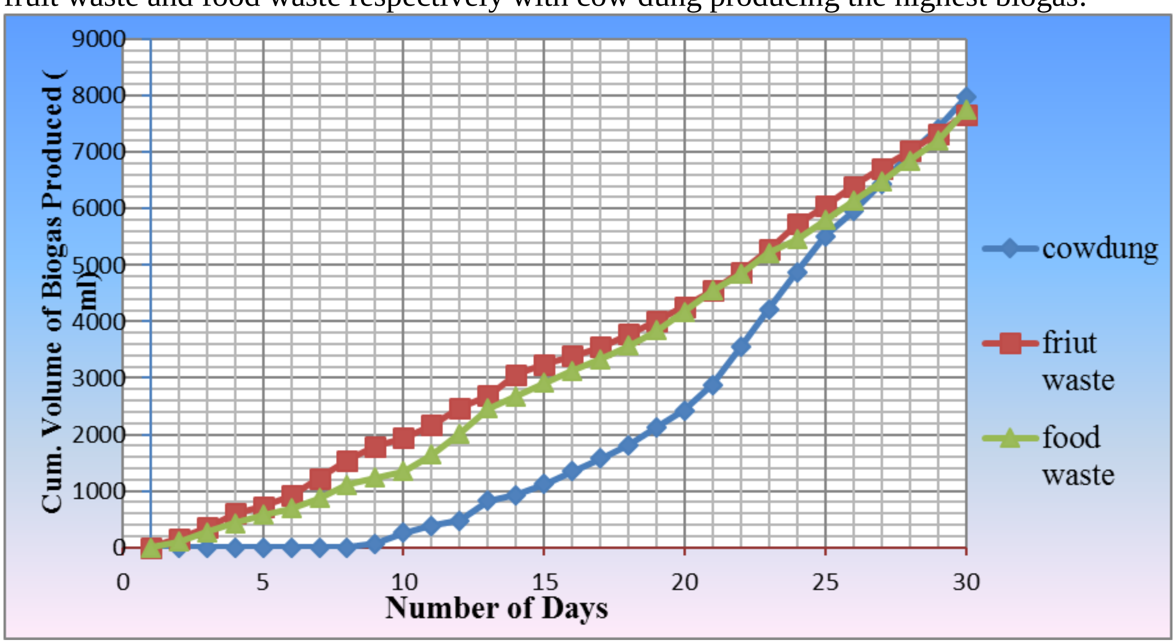

Figure 7. Cumulative Volume of Biogas of Waste against Number of Days

Figure 8 shows the cumulative of biogas produced from the co-digestion of cow dung and fruit waste, cow dung and food waste and cow dung food and fruit waste. At the end of

30 days retention period, the cumulative of 8390 ml, 16482.5 ml and 9096.5 ml biogas was produced from the co-digestion of cow dung and fruit waste, cow dung and food waste and cow dung food and fruit waste respectively with co- digestion of cow dung and food waste producing the highest biogas.

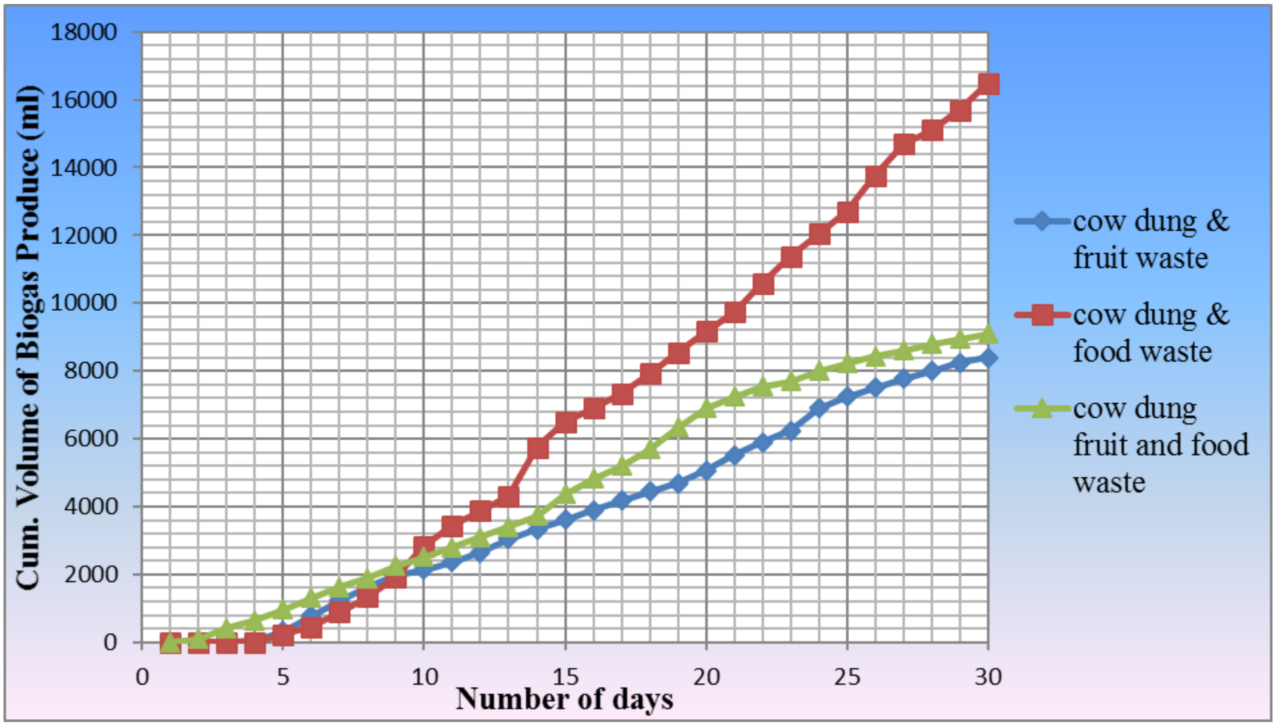

Figure 8. Cumulative Volume of Biogas of Co-digestion Waste against Number of Days

Figure 9 shows the percentage of biogas produced from each of the waste (cow dung, fruit waste and food waste) and from each of the co-digestion as well (cow dung and fruit waste, cow dung and food waste including cow dung, fruit and food waste). The highest percentage was found in the co-digestion of cow dung and food waste (164.8%), followed by the co-digestion of the three waste (cow dung, fruit waste and food waste) which has a percentage of 91.0%, co-digestion of cow dung and fruit waste (83.9%), cow dung of 79.8%, food waste of 77.4% and fruit waste of 76.4%. As compared to the single anaerobic digestion of the three wastes, the co-digestions higher volume of biogas, in which the cow dung and food waste as the highest percentage and this was also recorded in the study of Aragaw *et al.*, 2013. This might be due to mixing of cattle manure with organic kitchen waste (food waste) provided balanced nutrients, buffering capacity, appropriate and sufficient anaerobic microorganisms. (Aragaw *et al.*, 2013).

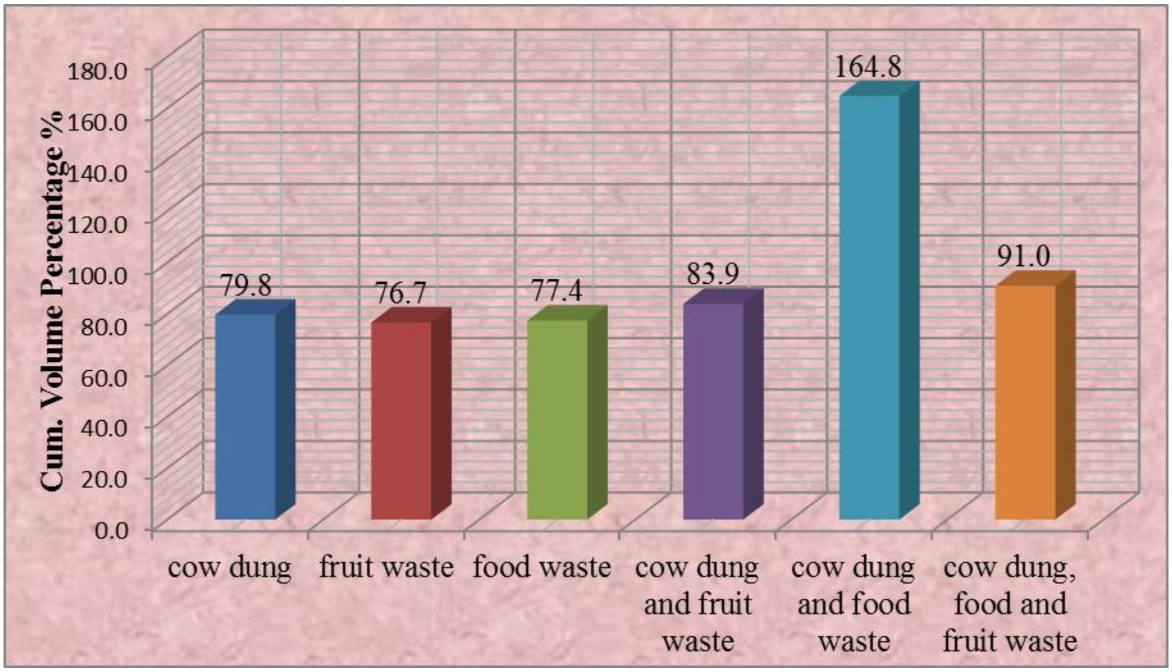

Figure 9. Percentage of Biogas Produced

CONCLUSION

The study on the production of biogas from the digestion of cow dung, fruit waste, food waste, and from the co-digestion of cow dung and fruit waste, cow dung and food waste including cow dung, fruit and food waste has shown that biogas can be produced from these wastes through anaerobic digestion for biogas generation. These wastes are always available in our environment and can be used as a source of fuel if managed properly. The study revealed further that cow dung as animal waste has great potentials for generation of biogas if only one type of waste is to be used and co-digestion of cow dung with food waste if co-digestion is to be used. The utilization should be encouraged due to high volume of biogas yields.

Moreover, it has been found that temperature variation and pH are some of the factors that affected the volume yield of biogas production and the temperature ranges also signifies a mesophilic thermal stage of biogas production (25℃ - 45℃). The temperature in which the production of biogas was at the peak for each waste (cow dung, fruit waste and food waste) was attained at day 22, day 24 and day 30 with the temperature for these days was 27.7℃, 26.9℃ and 27.1℃ respectively and for each co-digestion (cow dung and fruit waste, cow dung and food waste and cow dung food and fruit waste) was attained at day 24, day 14 and day 19 in which the temperature for these days was 27.1℃, 26.4℃ and 26.9℃ respectively. Finally, it was observed that the pH decreases as the retention period increases hence the decrease in the pH explains the gradually change of stage of the production of biogas, from hydrolysis to acidogenesis in which the slurry become acidic and form substrate after which it produces biogas.

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