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Effect of temperature and pH variation on anaerobic digestion for biogas production

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ABSTRACT

A comparative analysis study of pH and temperature effects on the anaerobic digestion process of different agricultural wastes was carried out during the production of biogas. The investigation was in two phases. Phase one involved the use of a single substrate of cow dung, cassava peels, yam peels and pineapple peels while the second involved co-digestion of the substrates with cow dung. The composition of gas produced by a single substrate and a mixture of these substrates were determined. The feedstock for each experiment was a 1:1 mixture of the substrates with water. For the co-digestion, one part of the substrate and one part of cow dung were used with two parts of water, making the ratio 1:1:2. Routine measurements of pH and temperature of the feedstock were taken and the composition of the produced biogas was determined. It was deduced that cow dung co-digested with cassava peels gave a higher yield with methane content of 65.3% followed by cow dung only, co-digestion of cow dung and yam peels, cassava peels only, yam peels only and pineapple peels with 63.4%, 51.4%, 46.2%, 42.3% and 0.0%, respectively. Therefore co-digestion, with cow dung and cassava peels is most efficient for biogas production.

Keywords: Anaerobic; biogas; co-digestate; pH; renewable energy; temperature
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Introduction

The need to develop an alternative source of energy to fossil fuel has become increasingly apparent with the incidents of fuel shortages and escalating prices in recent years. Aside from this, the use of fossil fuel as the primary source of energy has led to global climate change as regards to the emission of greenhouse gases, leading to environmental degradation with the resultant adverse effect on the ecosystem. This has reawakened interest in renewable and clean energy production such as wind energy, solar energy, hydrogen energy and small-scale anaerobic fermentation of animal and plant waste for heating purposes (Meegoda *et al.,* 2018). Renewable energy sources such as biogas appear to be one of the efficient solutions to some of our energy challenges because the raw materials for its production are the body wastes of living organisms such as animal droppings, food leftovers and other agricultural waste.

Waste disposal for biodegradable and non-biodegradable waste has been one of the challenging issues confronting the developed and developing nations, including Ghana (Ukpaka *et al.,* 2018). These wastes, when improperly managed, contribute to unhygienic environmental conditions that have the potential of breeding pathogenic microorganisms that could result in adverse health implications to humans; thus rendering the environment unpleasant and unattractive. However, these wastes can be managed appreciably by converting them into biogas, an environmentally friendly form of renewable energy (Ezekoye *et al.,* 2011).

In Ghana, most cooking in poorer households still utilises firewood, charcoal, and other biomass on inefficient fires and stoves, resulting in indoor air pollution. This is evident from the amount of charcoal and firewood that is brought even to the cities from the hinterland, day in day out. The only thing that comes to mind is the felling of trees that has the potential of desertification of the land in remote settlements. The effect of this activity is the environmental degradation and increase in the greenhouse gases that ultimately contribute to global warming by changing the natural course of the climate. In order to mitigate this trend, affordable and efficient heat-generating units must be made available to rural folks. This will help in the curtailment of indoor air pollution, cut household energy costs and reduce time lost in gathering fuelwood. This is where the Biogas comes in; cheaper and requiring raw materials from the body wastes of living organisms such as animal droppings and food leftovers. Many types of biomass can be used as feedstock or raw materials for biogas production. These include fresh or ensiled plant material, animal excrements, residues from agricultural or food production (Longjan & Dehoucheb, 2017; Kavuma, 2013; Marchaim, 1992; Chandra *et al.,* 2012). Prominent among animal excrements are cow dung, poultry and piggery droppings. Residues from households are fruit and vegetable wastes like pineapple peels, banana peels, cassava peels, plantain peels and yam peels.

Anaerobic digestion is the biodegradation of organic matter through the activity of some micro-organisms in the absence of air to produce flammable gas like methane, for heating and drying purposes. The underlying theory and technology of this anaerobic digestion have been used by humans for centuries. It is one of the useful tools that is applied in generating renewable energy in the form of heat. Communities in the most remote parts of Africa, particularly sub-Saharan Africa fell trees that are used as fuel for heating purposes. As a result, there is the desertification of land with contingent climate change in the form of global warming. In order to motivate and encourage usage of this technology, significant interest into investigations on several aspects of the process has arisen recently. Current research is directed not only to the yield of the process but also toward the optimization of the digestion conditions (Anukam *et al.,* 2019).

Biogas is a mixture of gases that is composed chiefly of methane, CH_4: 40 – 70% by volume, and CO_2: 30 – 60% by volume; generated as a result of biodegradation of organic material under anaerobic condition by the action of bacteria. Other gases are also generated but mostly in insignificant quantities. These are ammonia (NH_3), hydrogen sulphide (H_2S), oxygen (O_2) and carbon monoxide (CO) (Kawunma, 2013). The set-up or unit that is used in the production of biogas is a bio-digester and in its operation, the parameters that are of interest to researchers are the type and amount of biomass used as feedstock, size of digester, pH, pressure, retention time and temperature of the reaction mixture (Ezekoye *et al.,* 2011; Mirmohamadsadeghi *et al.,* 2019).

A biogas digester is an airtight container in which bacteria break down organic waste through a process of anaerobic fermentation. In addition to the production of methane-rich gas for cooking and heating, it helps in the recycling of organic waste with positive impacts on the environment, human and animal health. Even the byproduct of the process, which is in the form of liquid effluent, is a good source of fertilizer and nutrients for crops grown on land and water (Buntha *et al.,* 2009). In a typical anaerobic digester, the principal component is a digester chamber, a facility for slurry preparation, storage for the processed slurry, a gas collecting space and an area for the mechanical equipment such as the stirrer for agitation. Components such as a pressure gauge, thermometer and pH meter are important to monitor the variation of pressure, temperature and pH respectively. In setting up a smooth-running bio-digester, the ease of accessibility of the various component is given prominence.

Every bio-digester has dual characteristics of batch and continuous stirred tank reactor (CSTR) at the same time. The batch nature is that the digester is filled with the reactant feedstock that is allowed to remain in the digester until the desired treatment is finished. The slurry, which is biodegradable, is then removed and replaced with a new batch of material after expiry of the retention time (Ukpaka *et al.,* 2018). The CSTR nature of the digester, however, is the intermittent stirring of the reactants until the reaction is complete. Biogas digesters can vary greatly in capacity; ranging from small-scale units used by households to larger communal and industrial digesters. Feedstocks utilized in the digester include many types of biomass such as animal, food and agricultural waste. However, materials that are difficult or hard for the bacteria to digest like lignocellulose in woods, are avoided.

Anaerobic digestion is characterized by a series of biochemical transformations caused by the degradation of organic matter. The process involves four distinct stages of hydrolysis, acidogenesis, acetogenesis and finally methanogenesis. In the first stage fats, complex carbohydrates and proteins are hydrolyzed to their monomeric forms by respective enzymes. In stage two, the monomers are further degraded into short chain acids. These short chain acids are then converted to intermediate products of hydrogen, carbon dioxide and acetate in the third stage. With the help of methanogens, the intermediate products are converted to methane and carbon dioxide in the final stage (Ramatsa *et al.,* 2014).

Cassava and yam are the most cultivated crops in Ghana, with a per capita production of 0.6 tonnes (Kemausour *et al.,* 2014). In most of the communities where these crops are cultivated and processed - especially the cassava processing communities - several tonnes of the peels are generated as a waste product. With an expected increase in food production, there is an attendant increase in waste generation from the peels. Though used as feed for farm animals, the huge quantities generated, coupled with the remoteness of many of the communities that process them, make it difficult for all the waste to be utilized. For example, at Adeiso and Bawjiase in the Central Region; then Asueyi and Akrofrom in the Bono East Region, where cassava processing into gari and starch take place, a lot of waste is left to rot or burnt, with environmental consequences (Andoh, 2010; Kemausuor *et al.,* 2015). There is therefore the need to explore other measures to manage the waste accruing from the process in order to ensure good environmental management practices within the processing communities. The production of biogas from livestock manure and its co-digestion with other biomass, in particular, is one of the alternative utilizations of organic wastes that can be implemented to create a green environment. Before waste could be used as co-digestate in biogas production, it must be rich in nutrients necessary for optimum bacterial growth (Bayitse *et al.,* 2014). For example, manure which has a high buffering capacity and possesses the characteristic nutrients for bacterial growth can serve as an excellent co-substrate for biogas production. Co-digestion with manure would give the balance of nutrients, at appropriate carbon-nitrogen (C/N) ratio and stable pH needed to increase methane production (Bayitse *et al.,* 2014).

This work is making an attempt on how to mitigate the dangers posed by leaving our waste to pollute the environment, but on how it could be transformed into our energy needs in the form of heating in conformity with Ghana's Strategic Energy Plan of increase of biomass energy to a penetration of 20% by the year 2020 (Energy Commission, 2006).

The aim of the study is to fabricate a batch type of anaerobic reactor for the determination of biogas production potentials of peels of cassava and yam co-digested at different combinations with cow dung and other biomass for the purpose of heating. In order to understand the dynamics of the process involved and make it efficient. The specific objectives of the study are determination of the relative amounts of biogas production by single feedstock as compared to co-digestion with other biomass, then pH and temperature variations of the digestion for the different biomass.

Materials and Methods

Materials

TABLE 1
Construction equipment/tools used in building the biogas units

Name of equipment/ material	*Location obtained from*
Digester tank	Bel Aqua depot, Accra
PVC pipe	PVC vending shop, Kasoa
Gas bag	Hospital supplies shop, Korle-bu
Thermometer	Adat water, Accra
pH meter	Adat water, Accra
Valve	PVC vending shop, Kasoa
Gas collector (rubber tube)	Motor tyre repair shop, Nima
Gas Analyzer Analyser (GA2000Plus)	Environmental Laboratory, CSIR-IIR
Faucet	PVC vending shop, Kasoa
Manual stirrer	Chemistry Laboratory, GAEC
Soldering iron	Mechanic spare parts shop, Cape Coast
Hand trowel	Construction material shop, Kasoa
Weighing balance	Hardware shop, Agbogbloshie

Building of the Biogas Unit: - A Modified Fixed-Dome Digester in Terms of Operation

A 15-litre plastic bottle was used as a digester for the biogas experiment. Using a soldering iron, two holes were created through which two PVC pipes were fixed into the digester. One of the pipes which run vertically into the tank serves as the inlet of feedstock into the digester. The other one which serves as the outlet of the slurry was fixed two inches from the bottom of the tank and protrudes outwards perpendicularly to the first one. A gas tube was then connected to the digester to serve as a pathway for biogas into the gas collector. A valve was used to control the flow of gas in and out of the gas tube as described elsewhere (IRENA, 2016). All perforations were sealed with fine granules of earth and adhesive. To ensure the process occurred anaerobically, the digester was painted black such that it is opaque to all forms of light, including sunlight. Finally, a tap was connected to the outlet pipe of the digester to serve as the exit point of the feedstock. Figure 1 is the pictorial view of three of the built digesters in operation.

Preparation and biogas production from single feedstock

Five kilograms of cow dung obtained from an animal pen unit were mixed with water in the ratio of 1:1 to form a slurry. Solid matter such as stones and sticks were removed to obtain a homogenous mixture. This feedstock was then fed into the digester through the inlet pipe with a funnel fitted to the top. During the experiment, the digester was stirred with a paddle stirrer at certain time intervals. Between the hours of 9:00 am and 10:00 am in the mornings and then 2:00 pm and 3:00 pm in the afternoons, about 20 ml of the feedstock was collected into a rubber container through the tap. The pH meter was then inserted into this solution and the reading taken while the ambient temperature was also read. This procedure was carried out daily during the retention time of 21 days. The entire process was repeated for cassava peels, pineapple peels and yam peels as feedstocks.

Preparation and biogas production from co-digestion

Two different digesters were prepared for cassava peels & cow dung and yam peels & cow dung as feedstocks. The cassava peels and yam peels were chopped into smaller pieces of dimension less than 5 mm and dried for one week in the sun.

Bio-digester 1:

Approximately 2.5 kg each of cassava peels and cow dung were weighed and mixed with 5 kg of water in the ratio of 1:1:2. Initially, the cow dung was mixed with the water into a homogeneous slurry. Using a funnel, this fine slurry was introduced into the inlet of the bio-digester. Then, the chopped 2.5 kg cassava peels were introduced into the digester using a hand trowel. The inlet of the bio-digester was then sealed and the mixture stirred thoroughly. The first reading of the ambient temperature and pH of the solution was then taken.

Bio-digester 2:

Approximately 2.5 kg each of yam peels and cow dung were weighed and mixed with 5 kg of water in the ratio of 1:1:2. The entire process as described for bio-digester 1 was repeated for yam peels & cow dung. Table 2 shows the various amounts of feedstocks with the corresponding amount of water combined to form the substrate slurry as explained earlier for Bio-digester 1.

TABLE 2

Feedstocks and corresponding amounts of water utilised

Parameters	*Cow Dung*	*Cassava Peels*	*Yam Peels*	*Pineapple Peels*	*Cow Dung + Cassava Peels*	*Cow Dung + Yam Peels*
Mass of feed-stock used (kg)	5	5	4	4	2.5 + 2.5	2.5 + 2.5
Mass of water used (kg)	5	5	4	4	5	5
Total mass of slurry (kg)	10	10	8	8	10	10

Data Analysis

The readings on the equipment were taken thrice and entered in the Microsoft excel tables. Through the programming, the mean and the standard deviation of each entry for the, pH and Temperature, were calculated in order to minimize possible errors in the readings to the barest minimum. The accepted results were then used in the construction of the graphs that follow.

Results

Collection and Analysis of Biogas Produced

The gas accumulated from the 13th to 18th day of the experiment was transferred into a gas bag from the storage tank (gas collector) and sent for analysis using the gas analyser. This is in conformity with the findings by Anti (2012), that rate of CH_4 production for all varieties of feedstock were relatively constant within the aforementioned retention times.

Fig. 1: Pictorial representation of the three biodigester set

TABLE 3

Composition of various gases contained in biogas produced for different feedstocks

The following graphs are the representation of the pH and temperature against the retention times for each of the feedstocks used.

Cassava peels

FEEDSTOCK	*CARBON (IV) OXIDE (CO_2) %*	*HYDROGEN SULPHIDE (H_2S) %*	*NITROGEN (N)%*	*METHANE (CH_4) %*
Cow dung	30.2	0.7	5.7	63.4
Cassava peels	41.5	3.0	9.3	46.2
Yam peels	46.7	4.8	6.2	42.3
Pineapple peels	0.0	0.0	0.0	0.0
Cow dung + Cassava peels	29.2	1.8	3.7	65.3
Cow dung + Yam peels	39.9	3.9	4.8	51.4

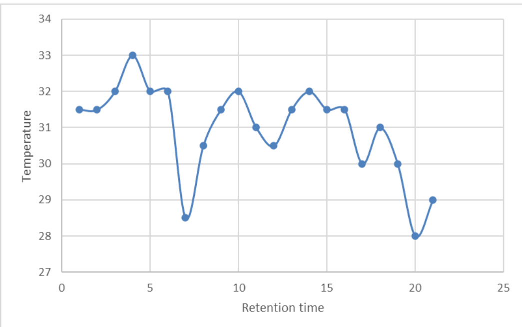

Fig. 2: A graph of temperature against retention time for cassava peels

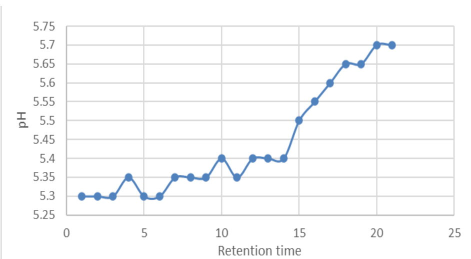

Fig. 3: A graph of pH against retention time for cassava peels

Pineapple peels

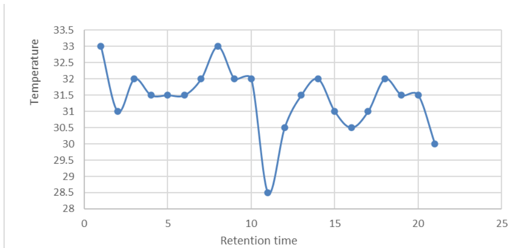

Fig. 4: A graph of temperature against retention time for pineapple peels

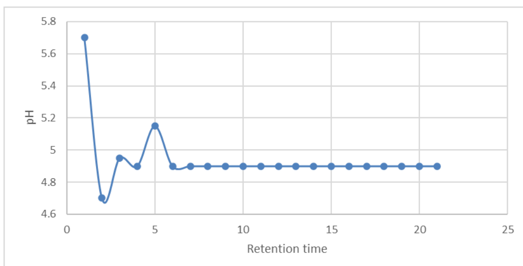

Fig. 5: A graph of pH against retention time for pineapple peels

Cow dung

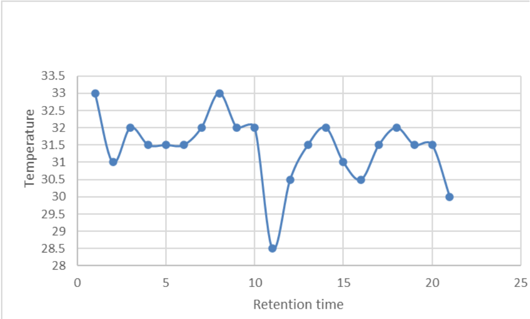

Fig. 6: A graph of temperature against retention time for cow dung

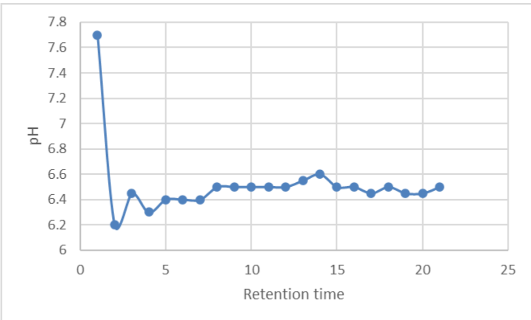

Fig. 7: A graph of pH against retention time for cow dung

Yam peels

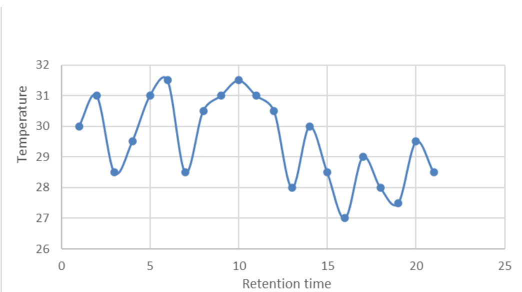

Fig. 8: A graph of temperature against retention time for yam peels

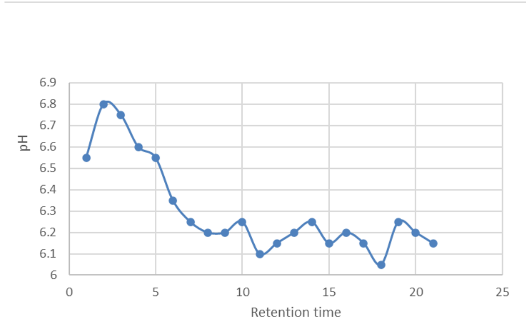

Fig. 9: A graph of pH against retention time for yam peels

Temperature variation for the Co-digestion experiments

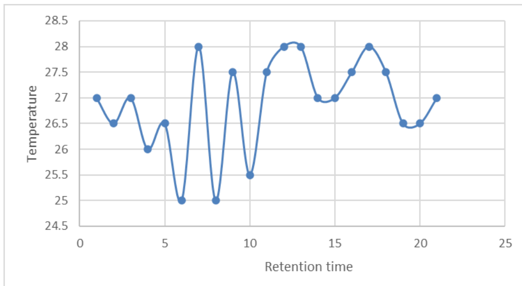

Fig. 10: A graph of temperature against retention time for bio-digesters 1 & 2

Co-digestion of cassava peels and cow dung

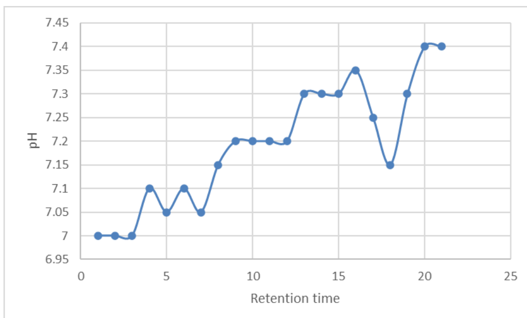

Fig. 10: A graph of pH against retention time for cassava peels and cow dung

Co-digestion of yam peels and cow dung

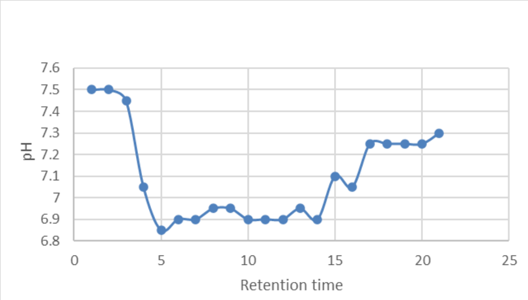

Fig. 12: A graph of pH against retention time for yam peels and cow dung

Discussion

The diagrammatic representation of the results obtained are shown on the graphs from Figure 2 to Figure 12. While figures 2, 4, 6, 8 and 10 depict the variation of temperature against the retention times, the rest of the figures from 3, 5, 7, 9, 11 and 12 depict variation of pH of the reaction mixture against the retention times. The temperature graphs showed that, during the course of the experiment, there were fluctuations from the minimum temperature of 25°C right up to the maximum recorded temperature of 33°C. For example, figure 6 revealed fluctuations from the beginning till the end of each experiment with minimal difference. Similar behavior was obtained for the rest of the temperature versus retention time graphs. The temperature range falls within the mesophilic range of the biogas production, which according to Kawuma (2013), results in satisfactory production of biogas.

Observation of the pH versus retention time graphs shown, indicated a sudden decrease in the pH from the inception of the experiment, then followed by a gradual increase within 14 days from the start up to a range where yield of biogas was appreciable (Ukpaka *et al.,* 2018). Except for the figure 5, for pineapple where the pH showed a plateau within acidic region where biogas production was not realized as depicted in Table 3, the pH for the other substrates were all within a range where biogas production was possible (Yeboah, 2016; Ugwoke *et al.,* 2011; Ukpaka *et al.,* 2018; Olanrewaju, 2018).

By careful scrutiny of the figures, it would be observed that the average pH value of the yam peels was 6.55 on the first day increased up to about 6.9 on the 4th day before it started decreasing down to about 6.15 on the last day of the experiment, as shown in figure 9. Cow dung on the other hand, from figure 7, had a pH value of 7.7 on day one and gradually decreased to 6.5 on the last day. For pineapple peels the pH at the beginning of the experiment was 5.7 but sharply decreased to an average value of 4.9 from day six and remained same until the last day of the experiment as depicted in figure 5. This is because the highly acidic nature of the reaction mixture coupled with the presence of lignocellulose, does not favor any flammable biogas yield, as reported by Yeboah (2016) and corroborated to a large extent by Ugwoke *et al.* (2011) and Olanrewaju (2018).

Co-digestion of yam peels with cow dung resulted in an average pH value of 7.5 on the first day which reduced to about 6.85 within one week and later rose up to just pH of 7.3 on the last day, about 0.2 unit short of the initial pH of the slurry, as shown in figure 12. The reason for the decrease in the pH value of the substrate was due to the dilution of the reaction mixture with water and the peels, from the initial, airtight and charged cow dung with probable initial production of ammonia. Hence rapid reduction in flammable gas production during the digestion period as was suggested by Olanrewaju (2018). This emphasizes the fact that at higher pH that was recorded on the first week of digestion, the highest peak of gas production was attained. At slightly low pH range which was recorded on the last days of digestion, there was little or no gas production. As the digestion process was ongoing, a sudden drop in pH was also recorded and this was probably due to quick production of volatile fatty acids (VFAs) as was obtained from the work of (Ukpaka *et al.,* 2018).

For cassava peels and the mixed masses of cow dung and cassava peels, there was pH increase as reaction progresses. The pH value of cassava peels was 5.3 on the first day and it increased gradually to 5.7 on the last day of the experiment. Although gases were produced, they were not flammable as the pH range was not favorable for methane production. With respect to the mixed masses of cow dung and cassava peels, there was also a gradual pH increase. However that increase was within a flammable gas pH range, from an average pH value of 7.0 on the first day to 7.4 on the last day. The pH rise could also have come about probably due to the fact that nitrogen gas was liberated and it accumulated in the form of ammonia and thus inhibiting the activities of the methanogenic bacteria (Adelekan & Bamgboye, 2009). But the results as presented on Table 3, indicated that more flammable gas was produced. A constant pH which was observed after retention time of 20 days digestion period, was similar to the findings of Ukpaka *et al.* (2018) indicating cessation of the anaerobic digestion process.

No biogas yield was recorded for pineapple peels. The initial pH of the slurry was 5.7 which reduced drastically within a day to as low as pH value of 4.9 due to increase in probably the production of acidogenic bacteria as reported by Perera (2011). This low pH value range of the medium was one of the reasons for the failure in biogas yield as it inhibits the methanogenisis process. Though the temperature was within the mesophilic range, the effect of the pH far outweighed that of the temperature as the yield of the organic acid increases (Anti, 2012; Yeboah, 2016). This is because hydrolytic bacteria which is responsible for hydrolysis reaction in the initial biogas production process, has been inhibited from carrying out its activity of reducing the complex polymers into simpler monomers for onward reaction in methanogenesis stage. One other factor that hinders the production of biogas with pineapple peels as the substrate is the presence of D-limonene, one of the constituents of the fruit waste. This D-limonene, according to Yeboah (2016), is an anti-microbial agent inhibiting the activities of bacteria that are involved in the digestion process. However, its slow degradation through decomposition over a long period of retention time of about 100 days, could show some level of flammable biogas production, though to a very small extent as reported by Ugwoke and Ekpe (2011).

Another factor that is considered of a substrate is its C:N ratio. The ideal range for flammable gas production of any substrate is between 20:1 and 30:1. So if the C/N of a given substrate is outside this range, it has to be co-digested (or mixed) with another with moderate C:N ratio so that overall, the ideal range could be attained for more efficient biogas production (Marchaim, 1992; Adelekan & Bamgboye, 2009). According to Orhorhoro *et al.* (2016), the C/N ratio for cow dung, cassava peels and yam peels are 24, 55 and 36 respectively. Since the C/N ratios for yam peels and cassava peels are outside the ideal range, it is not surprising that the biogas produced for their co-digestion with cow-dung was higher. From Table 3, cow dung & cassava peels yielded the highest amount of methane with 65.3%, followed by cow dung only with 63.4%, cow dung & yam peels with 51.4%, cassava peels only with 46.2%, yam peels with 42.3% and pineapple peels with 0.0%. These particular results were obtained due probably to the pretreatment of the cassava and yam peels by reducing the moisture content through drying prior to charging into the bio-digester. Another factor that could have had an effect is the amount of edible component that was cut off with the peels and finally the type of fodder used in feeding the cow being of lower nitrogen content (Bayitse *et al.,* 2014).

Conclusion and Recommendation

The experiment proved that cow dung co-digested with cassava peels yielded the highest percentage of methane with 65.3% followed by cow dung, cow dung & yam peels, cassava peels only, yam peels only and pineapple peels with 63.4%, 51.4%, 46.2%, 42.3%, 0.0%, respectively. This further confirms that the co-digestion of cassava peels with cow dung improved biogas production compared to the individual substrates and co-digestion of cow dung with yam peels.

Temperature within the range of 27.5°C to 33°C with the corresponding pH range of 5.3 – 7.7 for all the feedstocks produced appreciable amount of biogas with the exception of pineapple peels feedstock.

Cassava peels, which have high potential for biogas production when co-digested with other forms of manure, should not only be limited to feeding of animals or relegated to waste bins. Instead, they should also be utilized for biogas production that will serve as a source of cheap and renewable energy source.

With the ever increasing need for clean energy, it is recommended that further investigation must be pursued with respect to pineapple peels as feedstock for biogas production for a longer retention time as well as its co-digestion with cow dung. Furthermore, the use of yam peels as co-digestate to cow dung needs to be discouraged because it yields less biogas than when cow dung alone is used as the feedstock.

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