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Biogas Production from Co-anaerobic Digestion of Cow Dung and Fruit Peel in a Small-scale Galvanized Steel Anaerobic Digester

Gabriel Bamiyo Dirisu[1,*], Member Mark M. Ekpa[1], Chimezie Gabriel Dirisu[2]

[1]Department of Physics, Federal College of Education (Technical), Omoku, Nigeria
[2]Department of Biology, Federal College of Education (Technical), Omoku, Nigeria
*Corresponding author: dirisu.gabriel@fcetomoku.edu.ng

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Abstract Biogas production is an environmental-friendly biotechnology that minimizes environmental pollution by making use of wastes streams of various types. A biogas reactor (BGR) otherwise known as anaerobic digester is an industrial/environmental technology that employs anaerobic treatment (fermentation) of these wastes to produce biogas, leaving a slurry (digestate) that can serve as biofertilizer. Biogas is a mixture of methane (CH_4), carbon (IV) oxide (CO_2) and other trace gases. In this study, a BGR was designed using 50L steel plate reservoir connected with different pipes with valves for charging substrate, collection of biogas and removal of digester sludge. The biogas produced is collected by downward displacement of water. The substrates used in this study comprises 1:1 fresh cow dung and pawpaw fruit peel mixed with kitchen wastewater. The BGR was maintained for 28 days retention time. The volume of biogas produced and changes in pH and temperature were evaluated. Result shows that the cumulative biogas produced was 89.0 cm^3 at optimum pH and temperature of 6.9 and 33.3°C respectively. It is recommended that the reaction process be scaled up for sustainable biogas production.

Keywords: *anaerobic digestion, biogas, Biogas Reactor (BGR), cow dung, pawpaw peel, slurry, pH*

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1. Introduction

The basic energy requirements of most communities and indeed institutions are largely met by the use of fossil fuels such as diesel, gasoline and kerosene. As the production of energy from these fuels leads to both resource depletion, environmental pollution and associated climate changes, it has become a matter of priority in many countries to identify new and renewable sources of energy, hence the investment into green technologies such as biogas production using anaerobic digester, also known as biogas reactor (BGR), which produce clean biofuel [1,2,3].

The rapid rise in urbanization, leading to increased waste generation and inefficient management /disposal methods within the urban and rural society accounts for the large volumes of waste streams. Whereas metal and plastics are often recycled in the developed countries, household and commercial wastes are often loaded in open dumpsites, constitute a nuisance and causing surface and underground water contamination, which in most cases result in disease outbreak.

Biodegradation, which is the use of biological organisms to break down organic compounds or wastes, has become the panacea to some or all of the challenges arising from increased output of wastes as well as generation of energy for both heating and lightning purposes. Biodegradation for this purpose of biofuel production is carried out in special devise known as anaerobic digester, so called because the reactions leading to the biofuel production is an anaerobic process. AN, also called biogas reactor (BGR) is an airtight chamber that facilitates the anaerobic degradation of blackwater, sludge, and/or biodegradable waste of both plant and animal origin as well as domestic wastes [4,5]. Small-scale digesters for household use are constructed using concrete, bricks, metal, fiberglass, or plastic rubber /drum. Larger commercial biogas digesters are made mainly of bricks, mortar, and steel [6]. The feedstock are charged i.e. introduced into the digester either by continuous feed or in batches. The set up makes it possible for the collection of the biogas, which is a mixture of CH_4 and CO_2 released during fermentation of the organic substrate in the digester [7,8] as well as small percentages of other gases such as H2S. Efficient performance of AD depends on some factors such as pH, temperature as well as adequate carbon to nitrogen ratio [5,9,10]. There are four key biochemical processes of anaerobic digestion [11,12,13] as shown in Figure 1:

1. Hydrolysis-fermentation of polymers (carbohydrate/protein/Lipids) to soluble sugars/amino acids/fatty acids

2. Acidogenesis – production of acid
3. Acetogenesis- oxidation of acids to acetate
4. Methanogenesis – production of methane

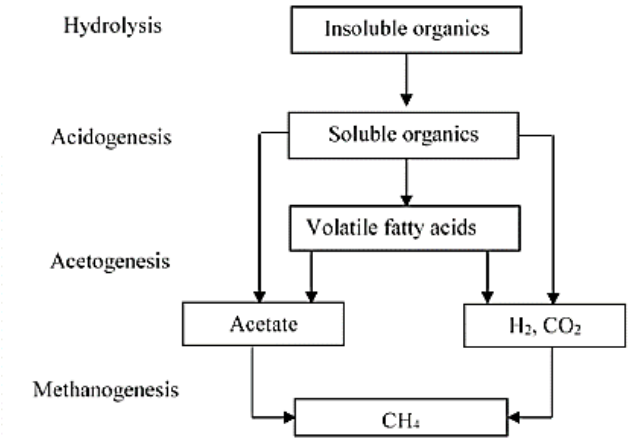

Figure 1. Steps in Biogas Production in an Anaerobic Digester (Source: https://environmentgo.com/biogas-production-process-steps/)

Stage 1 is hydrolysis of organic substrates to release soluble compounds such as sugars. Step 2 involves acidogenic bacteria that turn the soluble compounds into volatile fatty acids (VFAs) and acetic acid (acetogenesis). In step 3, the methanogenic bacteria metabolize these compounds anaerobically to produce a mixture of methane-rich gas and slurry, which is rich in phosphorus [3,14,15]. At the end of the digestion, biogas, which contains 60–70% CH_4 and 20–30% CO_2, with trace quantity of H_2S and other impurities are produced. The gas is collected at the top of the chamber, mixing the slurry as it rises. The pressure built up pushes the gas to the collection vessel and directly to where it is going to be used. The slurry is a valuable resource –biofertilizer -to boost crop production [10]. Thus, BGRs have the potential to minimize health risks and environmental pollution by using human, animal or plant wastes as a substrate for producing bioenergy and fertilizer. In view of the environmental and economic gains of biogas production above, the aim of this study is to design a small-scale anaerobic digester (or BGR) of 50L capacity for biogas production using fresh cow dung and pawpaw peel blend as substrates. It is a practical way of reducing the load of waste dumps, which cause ugly sights and bad odours with public health hazards. The utility value is for heating primarily in the immediate environment such as school Laboratories. Biogas can be connected to a household stove for cooking, to a light fixture with a gauze mantle for lighting, or to other appliances with simple natural gas plumbing.

2. Materials and Method

2.1. Materials

The following materials were used for the purpose of this research work: 50L steel tank as bio-digester, Connecting tubes, Heater, Bunsen burner, Measuring Cylinders, Beakers, Funnel, Polythene Bag, cow dung, pawpaw fruit and kitchen wastewater, hose.

2.2. Instrumentation

Mercury-in-glass Thermometer, Weighing balance, pH meter.

2.3. Design and Construction of BGR

The batch type AD was used in which the substrate mix was charged once with initial stirring and kept for 28days. In stage 1, four (4) lengths of galvanized steel plate was cut to size 500mm x 300mm. This was joined together with an electric welding machine to produce a permanent sealed rectangular shaped box representing the reservoir tank and all the length and breadth of the reservoir tank joints were filled with sealing hardener to avoid leakages of produced gases. Furthermore, an opening was created on top of the reservoir tank and fitted with a Non-return valve and pipe through which the gas is sent to the point of consumption.

Stage 2. On the digester top, three openings was created, first for the screw filler cap (400mm x 250mm) was inserted which serve as a feed to the digester. Secondly, steel wool tank connector (100mm x 100m) which serve as a passage of the gases from the digester to the reservoir tank was fitted with a gate valve to avoid return of the produced gas from the reservoir.

Stage 3. On the digester, 50mm from the bottom, another opening screw filler cap (400mm x 250mm) was inserted which serve as a drain/discharge to the digester and also fitted with a gate valve.

Stage 4.Support stand for the complete system. A galvanized steel angle iron of 200 mm x 200mm was used to construct a general stand, which serve as a carrier for the whole set-up, which made it mobile (Figure 2).

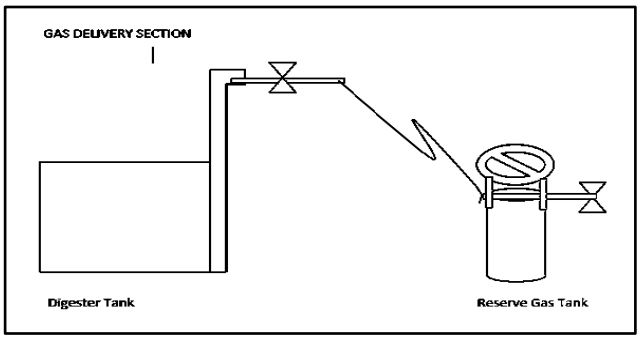

Figure 2. Final portable digester reserve tank and its distribution of the biogas system [Authors' design]

2.4. Collection and Processing of Substrates

2.4.1. Collection of Cow Dung

Fresh cow dung were obtained from the abattoir along Ikiri road, Omoku, Rivers State.

2.4.2. Collection of Pawpaw Fruit

Unripe pawpaw fruit was harvested from a farm garden in Ahoada road, Omoku Rivers State, Nigeria. The pawpaw was peeled, cut into bits and wet-grinded with Kitchen Blender (Philip, Japan). It was sieved using a mesh and the filtrate was kept refrigerated for use while the residue was used the biogas project.

2.4.3. Collection of Kitchen Wastewater

The tap at the back of kitchen washer was opened and wastewater was collected in a clean plastic bowl.

2.4.4. Preparation of Digester Slurry

Forty gram (40g) of fresh cow dung (CD), and 40 cm^3 of pawpaw fruit peel (PP) were placed in an open basin. Then, 25 litre of kitchen wastewater was used to mix the CD and PP in an open plastic basin. It was stirred for proper mixing and thereafter charged into a 50-L plastic rubber, which served as the biogas or anaerobic digester. The retention time for the digestion processes was 21 days.

2.5. Physicochemical and Microbial Characteristics of the Substrates

2.5.1. Proximate Analysis

The proximate analysis and other chemical characteristics of individual substrates were determined using standard methods. Parameters estimated are % moisture, & ash, % crude Lipid, % crude protein, % carbohydrate and % crude fibre, total nitrogen, and total carbon [16,17,18].

2.5.2. Determination of pH of the Slurry in the Bioreactor

The pH of the slurry were determined daily using pH meter (Search Tech, model PHS 3C.

2.5.3. Determination of Slurry Temperatures of BGR

The temperatures of the slurry in the BGR was monitored daily throughout the retention period after charging of the bioreactors with mercury in glass thermometer (0-100°C).

2.5.4. Microbiological Enumeration

Total heterotrophic bacteria count of cow dung, pawpaw fruit peel and slurry were determined by inoculating samples in nutrient agar plates. Plates were incubated aerobically and anaerobically for 24 hours and 48 hours respectively. The colonies that developed were counted and expressed in colony forming unit per gram (CFU/g).

2.5.5. Determination of Quantity of Produced Biogas

The quantity of biogas produced in BGR was obtained by downward displacement of water by the biogas measured after 3days interval. The plastic container was calibrated to enable reading of water and gas volume. The **v**olume of gas produced was measured by the volume of water displaced from the first bottle into the second bottle as a result of gas pressure built up inside the vessels.

2.5.6. Testing of Biogas ignition

The flammability of the biogas produced was determined using a burner. The burner was connected to the bioreactor's tap with a hose. To confirm the presence of biogas and its ability to burn, the tap was then opened to allow the gas flow gas to the burner. Ignition of the burner with a blue flame confirmed purity of the biogas produced during the co-digestion process.

2.6. Statistical Analysis

The data obtained were analyzed by descriptive statistics and regression using Microsoft Excel data analysis tool Pak.

3. Result and Discussion

3.1. Characteristics of Biogas Substrates

Table 1. Characteristics of Cow Dung (CD) and pawpaw peel (PP)

Parameter	CD	FP
Moisture (%)	27.00	34.00
Ash content (%)	9.00	2.00
Lipid (%)	3.90	4.70
Protein (%)	11.04	8.30
Carbohydrate (%)	34.06	40.00
Crude fibre (%)	15.00	21.00
Total Nitrogen (mg/g)	6.34	3.02
Total organic Carbon	35.4	54.01
Total heterotrophic bacteria (cfu/g)	1.92×10^9	ND
Total anaerobic bacteria count (cfu/g)	2.79×10^9	ND

ND-not determined.

Table 1 shows the characteristics of substrates (CD and PP) used in this study. CD had higher moisture, ash, and protein content than PP, while there was a slight increase in carbohydrate, and crude fibre content. Cow dung had slightly lower carbohydrate (34.06%) and fibre (15.00%) due to digestion by ruminants while PP had carbohydrate content as 40.00% and 21.00% respectively. This is expected as the peel still has its lignocellulosic materials undigested. This also explains the higher total carbon (54.01%<35,4%) in PP. On the other hand, moisture (27.00%), ash (9.00%), and protein (15.00%) of CD were higher than those of PP (24.00%, 2.00% and >8.30%) respectively. Total nitrogen was also higher due to the high protein content in cow dung (11.04% <3.02%). Unripe PP used in this study has proximates comparable with those reported by [19], although there were higher percentage of ash (5.98%), protein (11.67%) and crude fibre (32.51) content. Compared also with [20], the composition are as follows: Crude protein, 8.30% <10.30%, moisture content 4.15<24.00%>15.24%; crude fibre, 21.00% <27.1; ash was 2.00<13.30%; crude lipid 4.702<30%; and carbohydrate 40.00>27.00%. A high moisture content in a substrate is required to facilitate digestion in a BGR [21]. The fibre also provides buffering and stability of the BGR. PP is also rich in vitamins, minerals and proteolytic enzymes [22], which the participating microbes would need for growth and other biochemical processes in the digester.

3.2. Microbiological Load of Digester Slurry

Cow dung is the source of microbial inoculum for the digestion of the substrates used in this study for biogas production. The total anaerobic bacteria and aerobic bacteria count were 2.79×10^9 and 1.92×10^9 cfu/g respectively (Table 2). Aerobic bacteria are usually responsible for the initial hydrolytic steps, where the

complex organic compounds are broken down to more soluble forms. Figure 2 shows the changes in the bacterial load of the slurry as fermentation takes place. Total heterotrophic aerobic bacteria count ranged from 4.1 x 10^5 to 2.8 x 10^6 cfu/ml while total anaerobic bacteria count was 1.1 x 10^7 to 4.7 x 10^6 cfu/ml. The number of aerobic bacteria increased with increase in retention time and later dropped while the trend was opposite for anaerobic bacteria count. This trend can be explained by the phases of fermentation occurring in the digester. An initial high number of aerobic bacteria is due to the initial hydrolysis of more complex organic substrates-cow dung and fruit peel to soluble form. This also explains the low count of total anaerobic bacteria and later an increase with the development of anaerobic condition in the digester, which favour their growth and metabolism. The microbial count in the fresh substrate in most microbial groups is usually higher than the later stages. The bacterial count in this study was lower than that of [23], who observed an initial total aerobic bacterial count of 2.3 x 10^7 cfu/ml on first day and decreased to 8.5 x 10^6 cfu/ml. This is further supported by [24], who observed an initial higher count 9.7x10^8 cfu/ml after 84 days retention time and later decline.

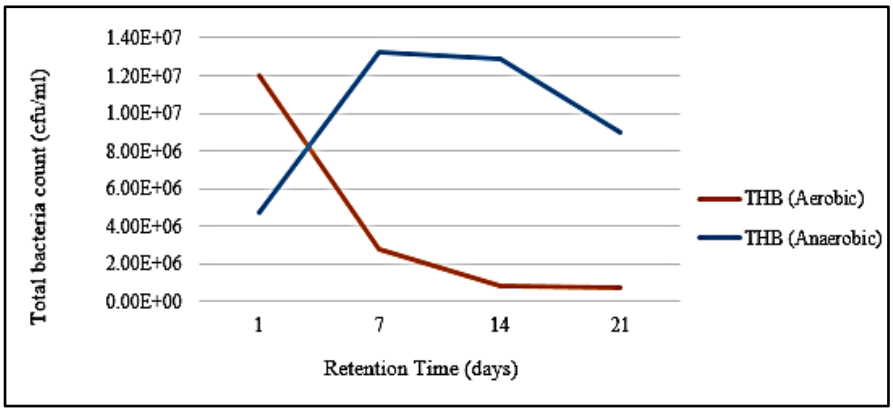

Figure 3. Total heterotrophic bacteria count of slurry during co-digestion of cow dung and pawpaw peel

Daily, weekly and cumulative biogas production from co—digestion of cow dung and pawpaw peel

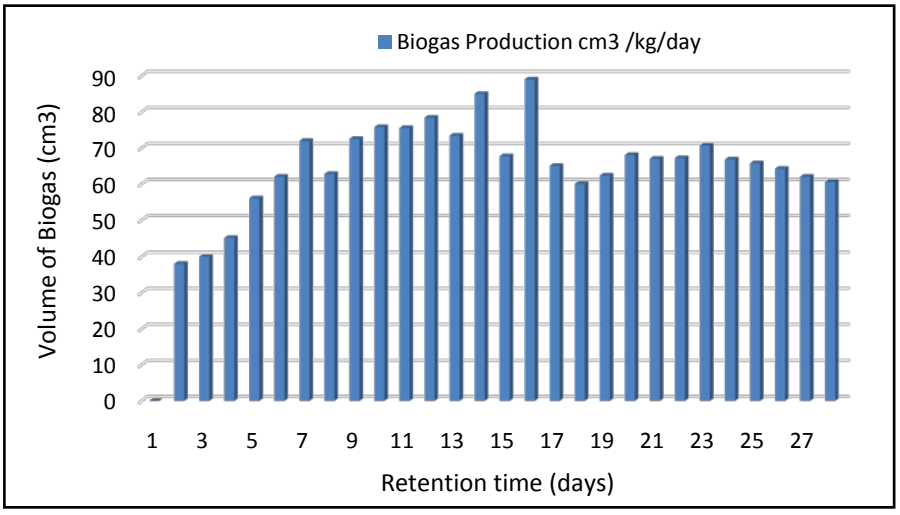

Figure 4. Daily Biogas production during co-digestion of cow dung and pawpaw peel

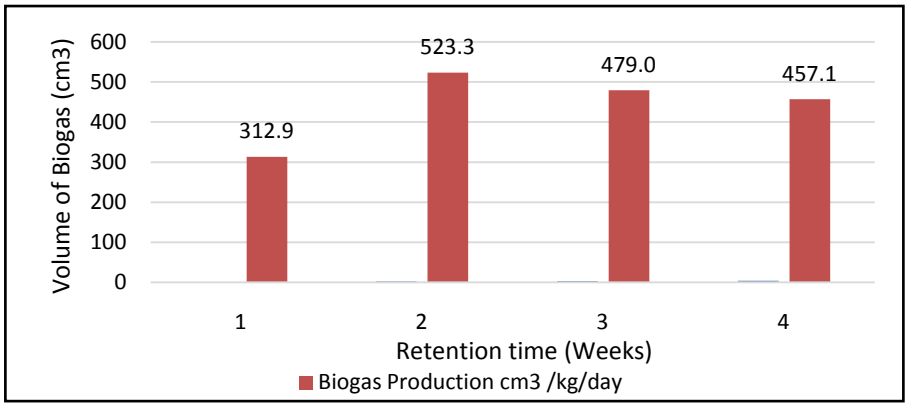

Figure 5. Weekly Biogas production during co-digestion of cow dung and pawpaw peel

The amount of biogas produced during anaerobic digestion of the mixed substrate, measured by the volume of water displaced from the digester on a daily and weekly basis are shown in Figure 4 and Figure 5 respectively. Co-digestion of CD and PP gave a total of 1772.3 cm^3 of biogas after 28 days retention time with a mean of 63 ± 16.86. The highest biogas yield was 89 cm^3 on the 16th day (Figure 4). On a weekly basis, mean biogas yield (cm^3) were 44.7 + 12.86, 74.8 + 6.72, 68.4 + 9.54 and 65.3 + 3.39 in weeks 1, 2, 3 and 4 respectively. Total weekly biogas yield were 312.9 cm^3, 523.3, 479.0 cm and 457.1 cm^3 respectively. The highest biogas yield occurred in week two (Figure 5). There was a significant difference between weekly biogas production, $F (1, 6) = 42.79$, $p < .05$. Biogas was not produced until after the 2nd day. The result obtained in this study are either higher or lower than some reported values. Oyewole et al [25] recorded total biogas of 1298 cm^3/kg from CD slurry after 22days retention time, with a mean of 72.1cm^3/kg/day. Their highest biogas yield was 90cm^3 on day 14 at optimum pH 7.0 and temperature 33.3°C. Ozor et al [26] reported a mean biogas volume of 8.35 cm^3, and cumulative total of 100.20 cm^3 biogas from CD digestion in 18days. Makhura et al [27] using different concentrations of CD reported that digestion with 20% solids produced a higher accumulated gas volume of 14267.55 ml while 3441.24 ml, 433.76 ml and 704.4 774.84 ml were recorded when 10%, 50% and 65% CD were used respectively. Mean temperature was 23.3°C. Using *Carica papayas* fruit peels only as substrate, biogas yields of 0.1839m^3 and 0.1361m^3 for the pretreated and untreated peels respectively [2]. Co-digestion of CD and PP was used in this study rather that singly because substrate blend is believed to provide a buffer and sand cause the BGR to be stable so as to produce more methane [9,27,28]. This is supported by [29], who observed that 100% CD digestion gave 86.49L biogas (54.29% methane), while 75%CD+25% Jatropha cake digestion yielded 114.30L biogas (53.9% methane). Higher methane production with co-digestion of poultry dung and food waste than food waste only have also been independently reported [22,30,31].

3.3. Temperature and pH Changes with Biogas Production

There were variations in the temperature and pH of digester slurry throughout the retention period of 28days. Temperature readings ranged from 28.6°C to 34.2°C. The mean ± SD temperature (°C) was 31.2 ± 11.53. The optimum temperature for the production of the highest volume of biogas from co-digestion of CD and PP was 33.3°C at pH 6.9 on day 16 of the retention time (Figure 6). This is within the mesophilic range specified in biogas standard for methanogens.

The optimum temperature recorded in this study is slightly lower than 35°C reported by [4] with 6.19L of biogas from mix-blend of CD and corn chaff. Temperature is critical in the performance of BGR hence the need for process optimization in order to enable the methanogenic bacteria to thrive in the digester. Studying temperature effect, Wang et al [12] reported that at 35°C, the total biogas production was 18075ml with 57.5% methane following co-digestion of corn straw and cow manure. With a decrease in temperature from 30–20°C, the total biogas as well as the average methane content. Thus, a low temperature hindered the performance of the acidogenic and methanogenic phases, while moderate temperatures above 25°C were more conducive to high biogas production efficiency. CD and Jatropha cake was co-digested under mesophilic temperatures with >80L biogas yield [29].

Anaerobic digestion produces acidic intermediates and as expected low pH was observed in the bioreactor. The pH obtained in this study ranged from 5.5 to 7.1 with a mean ± SD of 6.3 ± 0.5. The optimum pH of 6.9 reported here falls within the prescribed 6.8-7.2 [9,31]. This pH range is lower than 6.51 - 7.89 observed by [23]. They also noted that pH decreased from 7.89 (initial) to 6.21 at the end of 3weeks digestion of CD slurry. In another study of co-digestion of CD with swine dung and poultry dropping, mean pH of 6.90 ± 0.18 in 25 days was reported [3]. Furthermore, [24] observed that 84 days digestion of CD reduced the pH from 8.1 to 4.8, with the release of 101.7L of biogas at 23°C. The variation in pH may also be due to the activities of acetic acid and methane-producing bacteria that hydrolyze organic acid and inorganic compounds containing sulphur. Although the initial and final pH of the slurry in this study were 5.5 and 6.0 respectively, there was no significant correlation between biogas yield and pH, r (0.67>05). This is evidenced in the fluctuations observed, and this may be attributed to the range of anaerobic digestion intermediates and by-products.

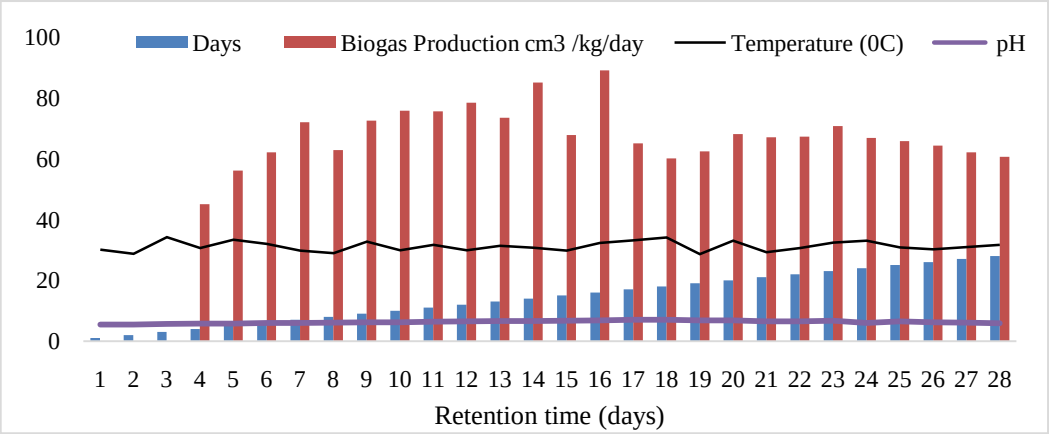

Figure 6. Changes in temperature and pH during co-digestion of cow dung and pawpaw peel

3.4. Testing of Produced Biogas

Ability of the produced biogas to burn with blue flame indicate that it has high methane content, which is almost similar to the hydrocarbon cooking gas used for domestic and industrial heating. This is one of the economic gains of the biogas projects [30,31,32].

4. Conclusion

The biogas projects is a green and entrepreneurial biotechnology, which benefits humanity from the energy, environmental and economic point of view. Biogas was produced from co-digestion of cow dung and pawpaw peel in a 50L galvanized steel anaerobic digester designed and constructed for this purpose. Although the biogas produced in this study was not analyzed for its composition, its degree of burning indicated a high methane content. Further study is required for the resolution of the produced biogas into its components and for bioconversion of biogas to biomethane, which has low potential for global warming compared to natural gas.

Acknowledgements

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