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Performance Analysis of Biogas Production from Onion Leaves and Cow Dung Compositions

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Abstract

Biogas could be obtained from agricultural byproducts; and onion leaves and cow dung is agricultural byproduct abundantly available in Aliero Northwestern Nigeria. This study entails biogas production from onion leaves, cow dung and their mixtures. The onion leaves and cow dung at equal proportions and the sum of their half (Mixture) were poured into three 25 l digesters for experimental investigations. The optimal biogas yields, the component composition of gases and calorific values of the produced biogas were investigated. The result revealed that cow dung, onion leaves and mixtures have maximum biogas productions of 311.86, 379.7 and 481.1 ml/kg respectively, at 31, 28 and 31°C respectively. Moreover, biogas productions from the cow dung, onion leaves and mixtures were reported to have optimal yield of 311.60±35.43, 379.70±68.00 and 481±136.50 ml/week respectively. The calorific value test indicated that, biogas produced from cow dung has higher calorific value of 9.41 kcal/m^3 with 1.05% carbon dioxide, and 10.97% of methane and 0.28% H_2 contents compared to onion leaves and mixture. The result obtained confirmed that cow dung, onion leaves, and mixture are good substrates for biogas production. Moreover, biogas from cow dung is a very good energy potential due to its higher methane content and its utilization for domestic application could replace the use of conventional fossil fuels which are more costly and hazardous to the environment.

Keywords: Biogas onion leaves, cow dung, methane, carbon dioxide, onion leaves.

INTRODUCTION

The world energy demand is rapidly growing; the conventional energy resources are degradable and hazardous to the environment, therefore, exploration and exploitation of renewable energy resources which are environmentally friendly is highly recommended [1, 2]. The application of modern technology on agricultural wastes such as cow dung and onion leaves etc. for biogas production offers an attractive platform to utilize certain categories of biomass for meeting rural energy needs. The processes of cutting down trees for fire wood and its combustion for cooking, leads to the increase of desert encroachment and rate of ozone layer depletion and resulted global warming in the developing world. However, it had been reported that averagely, over 80% of energy consumption for cooking in developing world relied on fuel wood and charcoal on a daily basis Garba [3]. In addition, the use of fuel wood for domestic heating causes desertification and other ecological degradation apart from carbon dioxide (CO_2) emission to the environment [4].

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Hence, inadequate supply of energy restricts socio-economic activities and thereby limits economic growth and adversely affects the quality of life. In view of the depletion problems of fossil fuels, the concept of biogas technology is given attention worldwide. The fuel scarcity and cost of gas and electricity leads to the inhabitants in remote locations and not-connected to national grid in Nigeria and other developing countries mostly depending on fuel wood for cooking purpose; and this has brought depletion of our forest, increase in fuel wood price and hindered rapid socio-economic development [2, 5].

Biogas is the energy generated from organic materials' decomposition of feed stokes such as cow dung, onion leaves, poultry droppings, pig manure, and kitchen waste etc., under anaerobic conditions. Biogas was found to be useful to replace conventional fossil fuel in countries where agriculture sector is an important component to the growth of economy. Considerable numbers of poultry and animal husbandry industries exist in Nigeria today. Substantial quantities of wastes arising from them pose serious environmental pollution and disposal issues. The recycling of these wastes to produce biogas through a process of anaerobic digestion or fermentation involves the breakdown of complex carbohydrates to form fermentable substrates and converted to biogas in a bio-digester in prominent technology [1].

Methane Formation Process

Methane formation process is very significant in biogas production. Biogas is produced through anaerobic digestion which involves several distinct stages. i.e., hydrolysis, acidogenesis, acetogenesis and the final stage methanogenesis are the stages involved in methane formation.

Hydrolysis involves the enzyme-mediated alteration of insoluble organic compounds with high molecular mass such as proteins, fats, lipids, and carbohydrate, soluble organic such as amino acids, fatty acids, monosaccharide, and other simple organic compounds. The process takes place by hydrolysing insoluble large molecules using chemical bonds and this stage is carried out by several different anaerobic and facultative bacteria [6].

The second stage which is acidogenesis, involves degradation of soluble compounds produced in the first stage by a diversity of different anaerobes through different fermentation processes. The production of carbon dioxide, hydrogen gas, organic acids, alcohols, some organic-nitrogen compounds and some organic-sulphur compounds were observed through fermentation process [7]. The methane-forming substrate materials is acetic acid as a principal organic acid.

Moreover, acetogenesis is the third stage of formation process in which the other intermediate products and acids that acetate were formed. The fermented substrates are further being converted to acetic acid as well as carbon-dioxide and hydrogen by different anaerobic oxidation reactions involving so called acetogenic bacteria [8].

The methanogenesis is the fourth stage in which methanogenic micro-organisms converted acetic acid, hydrogen and carbon dioxide to methane and carbon dioxide i.e. biogas. Gerardi reported that, the remaining compounds like alcohols, and organic-nitrogen compounds, which methanogens cannot degrade will be accumulated in the digester [7].

Biogas Compositions

It had been highlighted by Karena *et al*. and Madu *et al*. that those biogases from agricultural waste consist of methane (CH_4) and carbon dioxide (CO_2) and produces blue flame with heating value ranges from 4500–5000 kcal/m^3 when its methane content is in the range of 60–70% [9, 10]. The overall constituents of the biogas are given in Table 1.

Benefits and Uses of Biogas

The benefits derived from biogas production and its uses are highlighted in this unit. Biogas is used for domestic and industrial heating, lighting, electricity generation and as motor vehicle fuel. The benefits

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Table 1. Typical composition of biogas [11].

Substances	Chemical symbol	% water vapour
Methane	CH_4	50–75
Carbon dioxide	CO_2	25–20
Nitrogen	N_2	0–10
Hydrogen	H_2	0–1
Hydrogen sulphide	H_2S	0–3
Oxygen	O_2	0–0

obtained from the biogas are: sustainable energy source, waste management, reduced fossil fuel usage and rural development, according to Krich *et al.* [11].

Anaerobic Digestion

Anaerobic digestion is described as a process of controlling decomposition of biodegradable materials under managed conditions in a free space. The temperatures suitable for anaerobic digestion are mesophilic or thermophilic. The cow dung biomass has been reported with significant amount of biodegradable components (carbohydrates, lipids and proteins) which makes it a substrate favourable for biogas production and rich in methane CH_4 [12]. The anaerobic digestion process involves the principles of biochemical transformations, described as follows: liquefying the organic materials of the substrates like cellulose and hemicelluloses by extracellular enzymes, and treatment with acidogenic archaea species. The rate of hydrolysis depends on the pH values, room temperature, composition and concentration of intermediate compounds. From the soluble organic components, including the products of hydrolysis, organic acids, alcohols, hydrogen, and carbon dioxide were released due to the presence of acidogens. The acetic acid, hydrogen and carbon dioxide were obtained from acidogenenesis. Also, methane is formed by the action of methanogenesis which involves acetic acid, hydrogen and carbon dioxide. The microorganisms are responsible for catalysing the complex macromolecules into low molecular weight compounds (methane, carbon dioxide, water and ammonia) according to Madu and Sodeinde [10].

MATERIAL AND METHODS

Construction of Digesters and Substrate Formation

Three biogas digesters of 25 l each were made by using plastic Jerry cans, and half (½) inches holes were made on the lids (cover) of each of the three digesters. Three, ½ in, 2 m PVC hoses were inserted into the Jerrican through the holes on the lids. The hoses on the lids were sealed tightly in order to prevent entry of oxygen and loss of biogas. The hoses from the digesters were connected to the measuring cylinders through the plastic water bath (Container). Three setups of constructed digesters are shown in Figure 1. The samples of cow dung and onion leaves were collected from Aliero local government area. The fresh cow dung was collected from local breed cattle and were allowed to dry under sun radiation for 7 days, after which 10 kg of it was grinded using grinding machine. Also, 10 kg of fresh onion leaves were collected from Aliero market and the leaves were crushed into pieces using mortar and pestle. The substrates were made by making solution of the grinded samples with water and fed directed into the digester for decomposition.

In spite the fact that the digesters required in this work were 25 l each, for the cow dung, onion leaves and mixtures, the variable of the percentage content of substrate in each digesters were estimated. For effective operation, 50% of each digester was left free space (i.e. to be occupied by bubble gas).

$$50\% \text{ of } 25 \text{ liter digester} = 50\% \times 50\ l \tag{1}$$

$$50\% = \frac{50}{100} = 0.5 \tag{2}$$

$$25 \times 0.5 = 15.5\ l \tag{3}$$

$$25\ l - 12.5\ l = 12.5\ l \tag{4}$$

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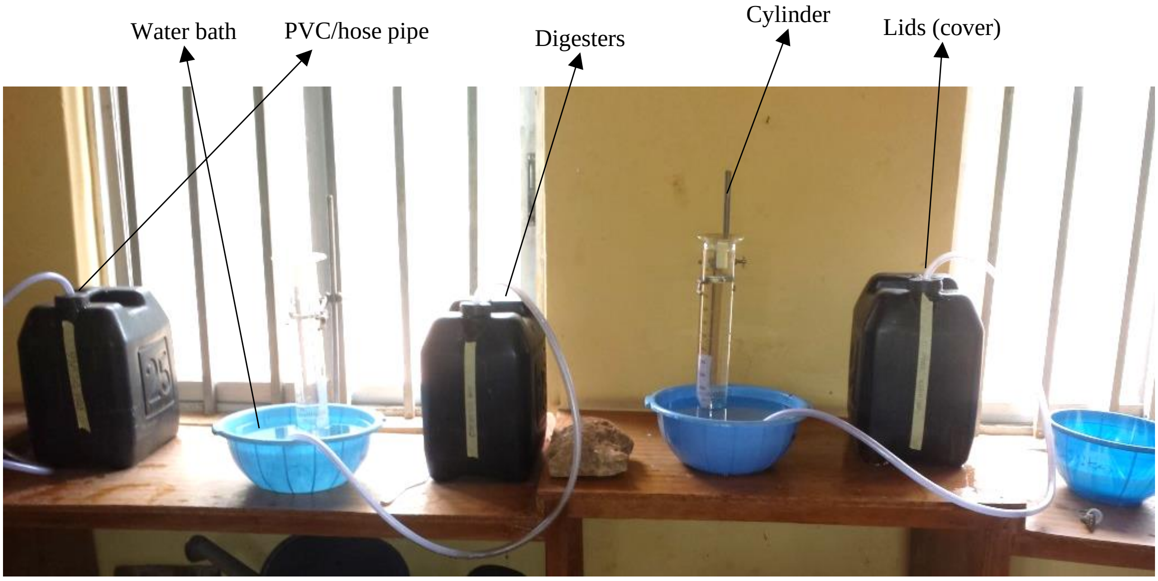

Figure 1. Shows the three constructed biogas digesters.

By using this estimation, 6.3 kg of cow dung was charged into the digester with water in the ratio of 1:5 of specimen to water. The slurry was properly stirred and poured into the digester. Furthermore, 6.3 kg of onion leaves substrate and 6.3 l of water was mixed into the digester in the ratio of 1:2 of the sample and water. Furthermore, the mixture of cow dung and onion leaves, 6.3 kg of mixture (waste) was charged into the digester with 6.3 l of water in the ratio of 1:5, of substrates to water. The three digesters containing the substrates were kept in the laboratory under the same condition. The pH values of the substrates were measured before it commences digestion.

Experimental Procedure and Data Collection

The three equal setups of digesters in the laboratory containing solutions of onion leaves, cow dung and their mixture were arranged and labelled as A, B and C respectively. The substrates in digesters were allowed to undergo anaerobic decomposition. The observations were made when each of the substrates in the digesters begins production of biogas. As the produced gases start rising, it flows through PVC/hoses to the inverted cylinders in a water bath. The biogas flows through the hoses, formed bubbles over the water in a container and passes into the inverted cylinder. The biogas bubbles gradually depressed the water down and occupied the free space at the top. The volume of produced biogas was recorded at the water level in a calibrated cylinder in millilitre. The daily yield of biogas production in millilitre was recorded from each digester. The pH values of the slurry were measured at the end of the experiments. However, the ambient and room temperature at 20 min intervals were recorded. The volume of biogas produced was collected from all the experimental setups in millilitres at an interval of 24 h daily. The average daily ambient and room temperature were equally measured. The average weekly biogas productions were evaluated from the daily data. The cumulative biogas yield of each setup was evaluated and the data were tabulated. The three urine bags were used for the collection of produced biogas from the respective digesters, for composition and calorific value analysis. Figure 2 presents the schematic diagram of experimental setup. Digesters feeding the urine bags with biogas are shown in Figure 3.

The composition and calorific value analysis is very significant in this study. The task was conducted at biogas laboratory, Energy Research Centre, Ahmadu Bello University Zaria, Nigeria. The biogas samples collected in the urine bags were analysed using Non-Dispersive Infrared (NIDR) gas analyser, 3100P Model. The presence of carbon monoxide (CO), Carbon dioxide (CO_2), Hydrogen gas (H_2), Methane gas (CH_4) and Oxygen gas (O_2) in biogas produced from sample A, B and C and their calorific values in kcal/m^3 of each samples were identified.

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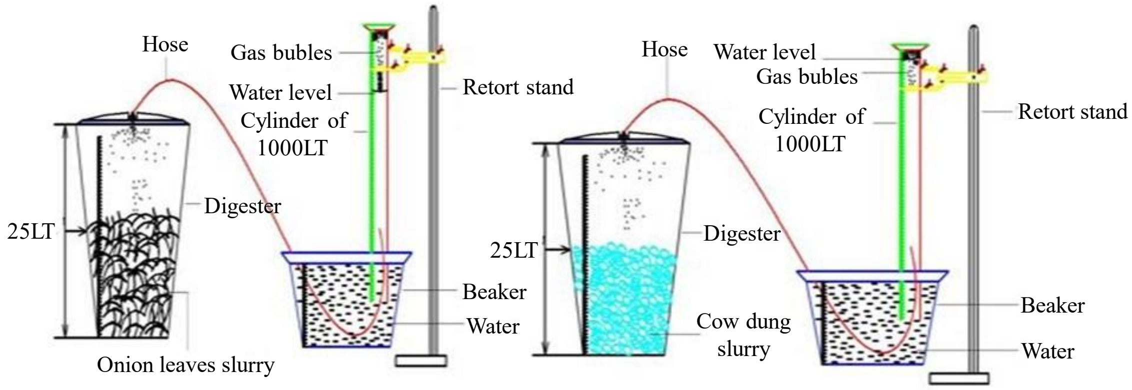

Figure 2. Schematic diagrams of experimental setup from onion leaves and cow dung.

Figure 3. Digesters feeding the urine bags with biogas.

RESULTS AND DISCUSSION

Results of Average Weekly Biogas Production Yield

The result of the average weekly biogas production from the onion leaves with respect to room temperature is presented in Figure 4. It has been observed that biogas produced by onion leaves attained its higher level of production in the first week with average weekly biogas production of 379.7 ml/week at room temperature of 31°C. Biogas production from onion leaves drastically decreased to 85.3 ml in the 4th week at room temperature of 27°C, but fluctuation was observed in biogas production with 41.1 and 49.0 ml from 5th to 6th week at temperature of 27°C. The biogas production finally receded to zero in the 7th week at temperature of 28°C. This indicated that room temperature has influence on biogas production.

Result in Figure 5 shows that cow dung remained stagnant in the first week. It commenced production in the 2nd week and reached its peak with average weekly production of 311.86 ml in the 3rd week at room temperature of 28°C. In the 4th week, the production slightly dropped to 282.9 ml at temperature of 27°C. While, in the 5th week, cow dung produced 111.2 ml/week of biogas at temperature of 27°C. The production capacity in cow dung has increased in the 6th and 7th week with average weekly biogas production of 204 and 159.7 ml/week at room temperature of 29 and 27°C respectively. Moreover, in week-8 and 9, the production level began to decrease and continued decreasing up to 12 weeks where the weekly average biogas production had reduced to 35.7 ml/week at a particular temperature of 15°C. Hence retention period of cow dung was observed in the 13th week at temperature range of 16°C.

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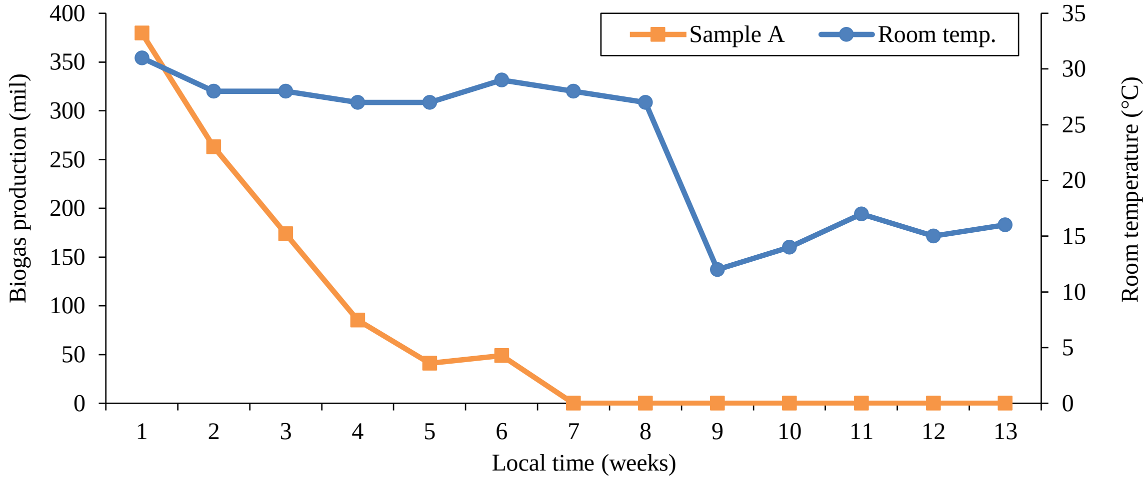

Figure 4. Biogas Production vs. Room Temperature against number of weeks for sample A (onion leaves).

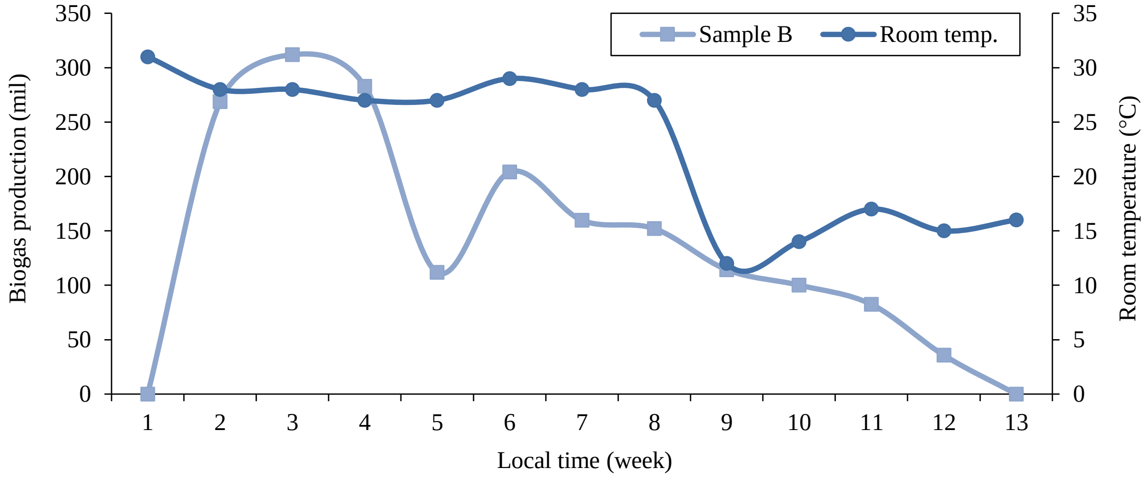

Figure 5. Biogas Production vs. Room Temperature against number of weeks for sample B (Cow dung).

Result in Figure 6 shows biogas produced by mixture of cow dung and onion leaves. The biogas production attained its peak level in the 1st week with average weekly biogas production of 481.10 ml at room temperature of 31°C. The rate of production slightly dropped to 312.5 ml/week with temperature of 28°C in the 2nd week. Meanwhile, in the 3rd week, the production level drastically reduced to 188.3 ml at the temperature of 28°C and later receded to zero in the 4th week when the room temperature increased by 27°C.

The result presented in Figures 4 and 6 show biogas production by the onion leaves and mixture substrates in which the commencement of production was by 1st week of the experiment. Onion leaves and mixture commenced production immediately in the 1st week with average weekly production of 379.7 and 481.10 ml respectively at room temperature of 31°C each. The early production of biogas from onion leaves and mixture in the 1st week was due to the variation in temperature and pH values. However, the temperatures were under mesophilic range of 30–40°C. Also, the pH values of onion leaves and mixture before anaerobic digestion were at neutral and very strongly alkaline which are favourable for the bacteria known as microbes to react. Also because of the microbes that acted on the biodegradable materials in the substrate to produce biogas are highly sensitive to pH value. However, cow dung remained stagnant in the 1st week with 0.00 ml as a result of 6.61 pH values which is slightly acidic, therefore anaerobic digestion could not occur, because the methanogens which convert waste to biogas cannot produce in acidic form.

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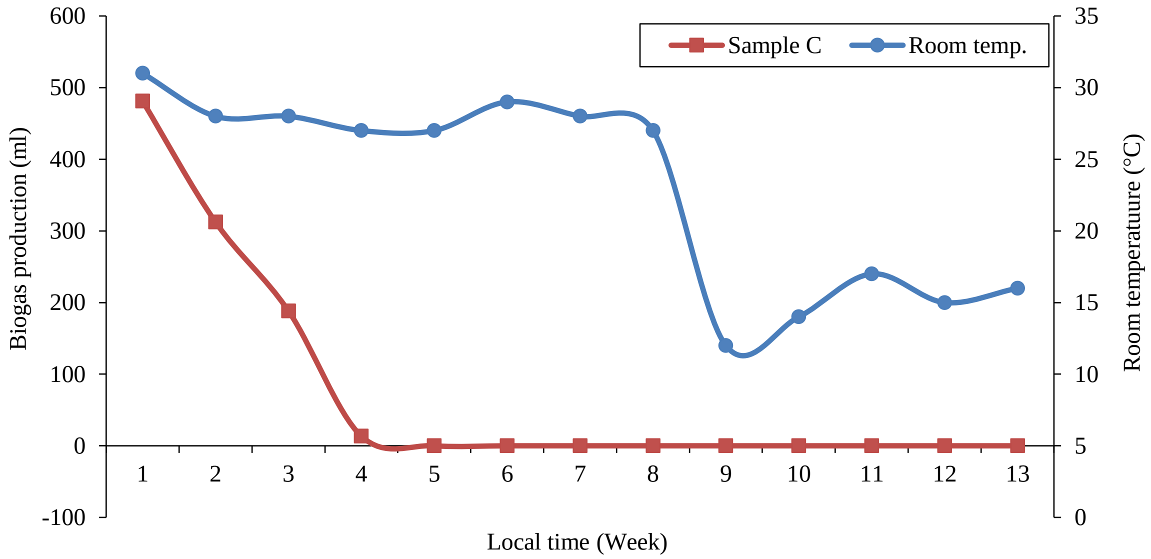

Figure 6. Biogas Production vs. Room Temperature against number of weeks for sample C (cow dung and onion leaves).

Result of Optimal Yield of Biogas Production

The result in Table 2 presents optimal biogas production from onion leaves, cow dung and their mixtures. It has been observed that the biogas production from onion leaves and mixture was higher in the 1st week due to the quick action of microbes as a result of temperature and pH as earlier stated. The total production from onion leaves was 1.015.4 ml in 7 weeks; cow dung produced a total of 1,595.11 ml in 11 weeks, while the mixture has a total production of 997.05 ml in 4 weeks. This implies that cow dung can serve as an important feedstock for biogas production if digested alone and if co-digested with onion leaves will give insufficient production, but it has an advantage of early production. Furthermore, it has been shown that the optimal yield of biogas production was obtained by a sample C (a mixture of cow dung and onion leaves). It produced average weekly yield of 481.10±136.50 ml/week in the 1st week and the experiment was conducted in summer season at average room temperature of 32°C. However, in the same week, sample A has 379.70±68.00 ml/week of biogas production while sample B does not commence production. The biogas yield by sample C has drastically reduced to 15.43±30.61 ml/week in the 4th week, at average weekly temperature of 31°C.

Table 2. Optimal yield of biogas production.

No. of weeks	Average room temperature (°C)	Sample A biogas production in (ml/week)	Sample B biogas production in (ml/week)	Sample C biogas production in (ml/week)
1	32	379.7±68.0	0.00±0.00	481.1±136.50
2	33	262.90±44.42	268.60±68.80	312.29±54.58
3	29	173.86±40.72	311.86±35.43	188.23±58.22
4	31	89.57±37.46	302.86±15.78	15.43±30.61
5	32	20.00±27.23	107.14±21.32	0.00±0.00
6	30	85.71±71.29	156.28±54.88	0.00±0.00
7	28	4.00±6.85	197.43±73.73	0.00±0.00
8	33	0.00±0.00	154.28±14.32	0.00±0.00
9	27	0.00±0.00	137.80±30.00	0.00±0.00
10	29	0.00±0.00	106.86±4.81	0.00±0.00
11	28	0.00±0.00	95.00±4.47	0.00±0.00
12	30	0.00±0.00	85.00±0.00	0.00±0.00
13	29	0.00±0.00	0.00±0.00	0.00±0.00

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Meanwhile, the biogas yield from sample B reached its maximum production of 311.60±35.43 ml/week in the 2nd week at average weekly temperature of 33°C. It continues, but the production has gradually reduced to 85.00±0.00 ml/week and later stop in the 12th week at temperature of 30°C. Moreover, Sample A has begun production in the 1st week, but decreases to 4.0±6.85 ml/week at average weekly temperature of 28°C and finally stopped in the 7th week. Moreover, it has been shown that the optimal yields of biogas production from onion leaves, cow dung and mixture in the 1st week are 379.70±68.8, 0.00±0.00 and 481.10±136.50 ml at temperature of 32°C respectively. The nonproduction by the cow dung in the 1st week was resulted from pH value. The obtained was 6.61 and it is slightly acidic on the pH scale, and no production takes place under such pH scale because methanogens that produced biogas are responsive to pH value. Furthermore, the retention time for onion leaves, cow dung and mixture substrates reported were 5th week, 8th week and 13th week respectively. Onion leaves had its retention time in the 8th week at room temperature of 33°C which falls under mesophilic temperature range. The substrate stopped production in 8th week because its pH changed to 4.22 which is extremely acidic, therefore at this pH value, bacteria responsible for biogas production could not act on the substrate.

It has also been reported that, the cow dung has reached its retention time in the 13th week at average room temperature of 29°C, which is psychrophlic temperature (<30ºC), and at this temperature range biogas could not be produced, as the bacteria responsible for the production of biogas could not act at this temperature condition. Also, the pH of the substrate had changed to 6.43 after experiment which is slightly acidic and in this pH value, microbes could not act on the substrate. Meanwhile the mixture maintained 5th week as its retention time at an average temperature of 32°C which is mesophilic temperature but after the experiment the temperature reduced to 29°C which is psychrophlic and caused the substrate to stop production, although the pH of the substrate was 7.2 which is slightly alkaline.

Result of Component Composition of the Produced Biogas and Calorific Values

The results of the investigated component composition of the produced biogas and their respective calorific values of each sample are presented in Table 3 for (Onion leaves, Cow dung and their mixture). The result from Table 3 shows that biogas produced from onion leaves is found to have higher percentage composition of carbon monoxide (CO) 0.03%. Higher percentage composition of carbon dioxide (CO_2) 1.05% was observed by the biogas from cow dung which is 80% greater than that of onion leaves and mixture. However, the percentage composition of methane gas (CH_4) is high in cow dung with 10.97%. Furthermore, cow dung has high percentage composition (0.28%) of hydrogen gas (H_2) but very low percentage composition of oxygen gas (O_2) which is 18.48% compared to onion leaves and the mixture. However, the gas analysis identified in Table 2 clearly indicates that cow dung possessed high calorific value of 9.41 kcal/m^3 compared to onion leave and mixture which have 0.03 and 0.04 kcal/m^3 respectively.

The result presented in Table 2 further indicates that biogas from onion leaves has lower calorific value of 0.03 kcal/m^3. This was because it has 0.00% of hydrogen gas and very lower percentage composition 0.04% of methane gas which are combustible fuels. However, the low yield of methane gas from onion leaves was because it was found in the class of vegetable waste that has higher fibre cellulose content and low glucose content. In addition, biogas from onion leaves has percentage composition 0.03% of carbon monoxide which is toxic to the environment and the presence of toxic gas in onion leaves contributed to low calorific value. Moreover, the higher calorific value of 9.41 kcal/m^3

Table 3. Present substrate composition and calorific value.

Sample	Composition					Caloric value (kcal/m^3)
	CO (%)	*CO_2 (%)*	*CH_4 (%)*	*H_2 (%)*	*O_2 (%)*	
A	0.03	0.21	0.04	0.00	20.86	0.03
B	0.00	1.05	10.97	0.28	18.48	9.41
C	0.00	0.00	0.13	0	20.9	0.04

biogas produced from cow dung was obtained due to the presence of high percentage composition (10.97%) of methane gas and 0.28% hydrogen gas which are combustible fuels. Also, the great advantage enhanced by the biogas from cow dung was its 0.00% of carbon dioxide and 0.00% carbon-monoxide (CO), meaning that its combustion does not pollute the environment with toxic gases. Furthermore, the biogas from mixture substrate has also very low calorific value of 0.04 kcal/m^3, because the percentage composition of hydrogen and methane gas which are combustible fuels are lower at 0.00 and 0.13% respectively, but it has advantage of 0.00% of carbon monoxide.

CONCLUSION

The analysis of biogas production from onion leaves, cow dung and mixture of onion and cow dung substrates were conducted. The onion leaves and mixture substrates had early production, but the optimal total biogas production was observed by the cow dung substrate. The digestion of the substrate depends duly on the room temperature, and which caused changes in the pH value of the solution. The presence of higher composition of methane (CH_4) and hydrogen gasses (H_2) in biogas from cow dung, enable enhancing higher calorific value. However, cow dung, onion leave, and mixture are good substrates for biogas production, but cow dung has greater potential over onion leaves and mixture. Therefore, if this research is developed to the level of utilization, the use of firewood and fossil fuels for domestic application could be replaced with biogas to free the environment from pollution due to toxic gases emissions.

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