

Production of Biogas from Co-Digestion of Cow Dung, Saw Dust and Maize Husk

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Abstract

The co-digestion of cow dung, with maize husk for biogas production at laboratory scale was investigated. The study was carried out at a temperature range of 24°C - 30°C and pH range of 5.5 - 6.5 for a period of 60 days with a total solid concentration of 7.4% in the digester sample (fermentation slurry). Water displacement method was used to collect the biogas produced which was subsequently measured. 444.8 mL was the cumulative biogas yield at the end of 60 days retention time in the digester 1, which comprised of cow dung, maize husk, and water. Digester 2, which is made up of sawdust, cow dung, and water produced negligible biogas at the end of 60 days of the experiment. X-RF analysis revealed high presence of elements like silica, aluminium oxides, and aluminium oxides in cow dung, maize husk, and sawdust respectively. The preponderance of alkanes and methyl group in maize husk makes it to produce biogas compared to saw dust as shown by the Fourier transform infrared spectroscopy (FTIR) that was carried out to identify the various functional groups. The potential of maize husk to produce biogas was also established. The kinetic modeling shows that there was an increase in biogas yield as the retention time increases as depicted by the linear model.

Keywords

Sawdust, Biogas, Cow Dung, Maize Husk, X-Ray Fluorescence, FTIR

1. Introduction

Energy is a basic tool for development, the dependence of man on fossil fuels as a primary energy source has led to global climate change, environment degradation and human health problem [1]. These depletion and environmental degradation gave a boost to the renewable and sustainable energy alternatives to the

non-renewable fossil fuel. Maize husk is an agricultural waste that can be transformed either by chemical and or biological means. Agricultural waste from animals such as poultry droppings, cow dung, and swine dung usually produce obnoxious odour and constitutes environmental problems for the people living around the area where such waste are dumped.

These animal wastes have been found to consist of exploitable gas and energy which can be obtained by a process called bio-menthanisation and the gas produced can be used as a source of energy or if burnt directly could be used for heat effect [2]. Bio-waste can be degraded anaerobically in a biogas digester to produce bio-gas and other gas. Maize husk which is a waste from maize, a cereal crop grown widely throughout Nigeria and the world at large, this waste from maize is left behind after harvest. The disposed maize wastes have some positive and negative effects on the environment but like other waste are indiscriminately left on farm lands to be mineralized and used by other crops. Moreover, maize husk is found in non-farm lands like schools, homes, market, etc. It poses a serious environmental threat to human beings but if properly recycled and treated an aerobically could yield biogas. Biogas refers to gas produced by biological breakdown of organic matter in the absence of oxygen. Biogas formation can occur naturally in swamps, marine sediment and water logged soils, rice field, deep bodies of water, sanitary landfills and even in the digestive system of ruminants, and termites [3].

[4], studied the biogas production potential of un-extracted nutrient-rich elephant grass. The work revealed that crushed un-extracted elephant grass straw is biodegradable by mixed microorganisms as effectively as by pure cultures. The work also showed that support with potato dextrose agar as well as nutrients such as urea is essential for attaining substantial gas yield. In conventional mesophilic biogas plants the retention time is 30 to 50 days on an average. The retention time in mesophilic biogas plants has been found to decrease below 15 days in large scale implementation [5]. Co-digestion is the simultaneous digestion of more than one type of waste in the same unit [6]. Advantages include better digestibility, enhanced biogas production/methane yield arising from availability of additional nutrients, as well as a more efficient utilization of equipment and cost sharing [7] [8]. Results of co-digestion of food waste and dairy manure in a two-phase digestion system conducted at laboratory scale showed that the gas production rate of co-digestion was enhanced by 0.8 - 5.5 times as compared to the digestion with dairy manure alone [9]. Temperature has a significant effect on digestion rate with most processes occurring at temperatures in the mesophilic temperature range 75 - 100°F, but anaerobic digestion also can be carried out at the thermophilic temperatures (125 - 140°F). It is well known fact that the thermophilic is more efficient than the mesophilic in terms of retention time, loading rate, and nominal biogas production but it needs a higher energy input, more expensive technology, and greater sensitivity to operating and environmental variables, which makes the process more prob-

lematic than mesophilic digestion [10]. Biogas is a promising alternative source of energy to Nigerians compare to the high cost of energy from fossil fuel that is available to the common man in Nigeria and non-availability of this fossil fuel energy source. It is environmentally friendly and cheap to produce by almost every Nigerian. Simulation of biogas, methane and hydrogen production has been reported by [11] and the modeling of biogas production from anaerobic digestion has been based on kinetic models. Since biogas production is associated with micro-organism playing a paramount role in the process, kinetic models particularly the first order kinetics were commonly applied to simulate the anaerobic biodegradation. Like the microbial growth phase, biogas production rate which shows a rising limb and decreasing limb which can be indicated by exponential and linear equation [12]. There is little or no information in literature towards the production of biogas from maize husk; this necessitated the present work which examines the co-digestion of cow dung, with maize husk and saw dust in mesophilic condition.

2. Materials

Cow dung was procured from government approved Abattoir in Agbarho, Delta State. The maize husk was gotten from a cabbage site in Ugbomoro Community while the saw dust was obtained from Uti Sawmill in Effurun, Uvwie Local Government Area of Delta State. Sodium chloride (NaCl), tetra oxo sulphate (VI) acid (H_2SO_4), Buckner flask (500 mL), conical flasks (500 ml), mercury in glass thermometer (range between -10°C - 100°C , with an accuracy of $\pm 0.1^\circ\text{C}$), digital pH meter (HANNA model pH-211), distilled water, delivery tubes, corks, measuring cylinder (200 mL), muffle furnace, Oven (Genlab oven model, Mino/75/f), connecting tubes, mortar and pestle and weighing balance (model BH 600) with an accuracy of 0.01 g were used for the biogas produced.

2.1. Characterization of Substrates

2.1.1. Pre-Treatment of Both Substrates

Maize husk and cow dung were sun dried for three days to remove moisture from them and thereafter oven dried at 110°C for 8 hours. It was then grinded and sieved into small particle size $< 2\ \mu\text{m}$.

2.1.2. Determination of pH

A measured quantity of the sample slurry was transferred into a beaker. The slurry was agitated and left for 24 hours at room temperature. The pH meter (HANNA model pH-211) was then used to measure the slurry pH [13].

2.1.3. Determination of Moisture Content

10 g of the pre-treated sample was weighed initially in petri dish which was placed in an oven at 110°C . The weight was taking after every 10 minutes until a constant weight was obtained (final weight). The moisture content was determined by using the Equation (1):

$$\% \text{Moisture content} = \frac{\text{Initial weight} - \text{final weight}}{\text{Initial weight}} \times 100 \quad (1)$$

The moisture content was determined using standard test ASTM D 2867-91 [14].

2.1.4. Determination of Volatile Matter

5 g of the samples were weighed initially in petri dishes and placed in a muffle furnace at 500 °C for 4 hours. The samples were allowed to cool down in a desiccator and re-weighed again. The lost in weight is now the volatile matter present in the samples using Equation (2).

$$\% \text{Volatile Matter} = \frac{\text{Initial weight of wet sample} + \text{Crucible} - \text{final weight after heating} + \text{Crucible}}{\text{final weight after heating} + \text{Crucible} - \text{Initial weight of the crucible}} \times 100 \quad (2)$$

2.1.5. FTIR Spectroscopy

The structural organization of the substrates was investigated to identify the functional groups presents. The adsorbents were examined using SHIMADZU FTIR-8400S spectrophotometer with the range 500 - 4000 cm^{-1} . KBr was used as background material in the analysis.

2.1.6. X-Ray Fluorescence Analysis

The elemental compositions of the cow dung and maize husk were analyzed using the X-ray fluorescence.

2.2. Experimental Procedure

Laboratory scale production was used in the production of biogas. All apparatus were properly washed with soap solution, distilled water, and allowed to dry by standing over night in the laboratory. A set of Buckner flasks (500 ml) was used as digester for each of the sample. Another set of Buckner flasks (500 ml) was used. It contained an acidified brine water solution and was connected to the digester by means of a connecting tube and also, on the other side, connected to a conical flask by means of a connecting tube. Thus, the biogas produced in the digester by fermented slurry (sample) passed through the connecting tube to the Buckner flask containing acidified brine solution. The pressure of the biogas produced caused a displacement of the acidified brine water solution through the connecting tube on the other side of the conical flask. The amount of water displaced was then measured as the volume of biogas produced. The digester was operated at ambient temperatures. 7.4% total solid concentration was used in each of the digester. The first digester which consists of maize husk, cow dung and water were mixed together by mass ratio 5 g: 15 g: 250 g respectively. The second digester which is made up of saw dust; cow dung and water were mixed together by mass ratio 5 g: 15 g: 250 g respectively. The slurry was stirred manually, and readings taken within five days interval while temperature reading was taken in the morning and evening throughout the period of the study. The experimental set-up is shown in **Figure 1**.

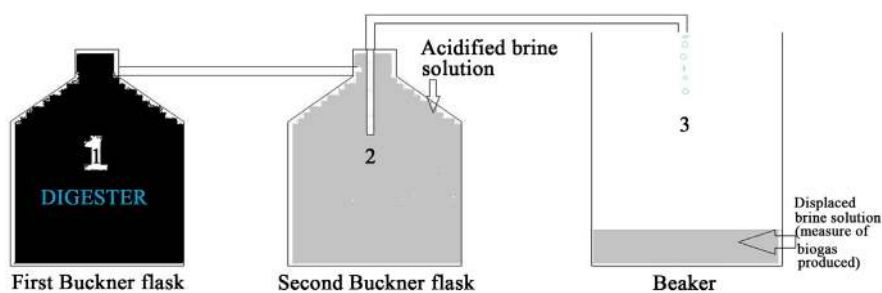


Figure 1. The experimental set-up for the biogas production.

2.3. Linear Kinetic Models of Biogas Produced

Biogas production rates from co-digestion of cow dung, maize husk and sawdust was simulated using linear plot. The ascending and descending limbs could be expressed in this model [12] reported that ascending and descending limb of biogas production rate can be expressed by the linear Equation (3) below:

$$y = a + bt \quad (3)$$

where y is biogas production rate in ml/gm/day, t is time in days for the digestion (ml/gm/day) and b (ml/gm/day) are constant obtained from the intercept and slope of the plot of y against t in ml/gm/day.

3. Results and Discussion

It can be seen from **Tables 1-4** that cow dung has high amount of silica in its element which also suggest that this element also contributes to the digestion of microorganisms for the biogas production. Aluminium oxide is the main element present in both maize husk and sawdust.

3.1. Fourier Transform Infrared (FTIR) Analysis

As shown in **Figure 2**, the broad band with frequency ($3421.6.402 - 3600 \text{ cm}^{-1}$) exhibited RO-H (Alcohol) wide branded band while the broad band ($2900 - 2700 \text{ cm}^{-1}$) exhibited aldehyde. Thiol (S-H) bending, huge band was shown in broad band ($2600 - 2550 \text{ cm}^{-1}$). The broad band frequency of ($1670 - 1615 \text{ cm}^{-1}$) shows that C=C stretch is present. At a broad band of ($1600 - 1590 \text{ cm}^{-1}$) C=C stretch was revealed. At broad band ($810 - 760 \text{ cm}^{-1}$) C-H bend was observed [15]. The highest peak with frequency 1870.32 cm^{-1} suggests that carbonyl compound is the main functional group in the cow dung sample.

3.2. FTIR of Maize Husk

It can be seen in **Figure 3** that frequency ($3550 - 3000 \text{ cm}^{-1}$) depict RO-H (Alcohol) wide broad band. C-H stretch of CHO (carboxylic acid) group very wide band was shown with frequency (2900 cm^{-1} and 2700 cm^{-1}) while ($2820 - 2780 \text{ cm}^{-1}$) frequency corresponds to C-H stretch of -N-CH₂. The broad band ($1725 - 1700 \text{ cm}^{-1}$) correspond to C=O stretch ketone R₂C=O. The broad band of $1650 - 1590 \text{ cm}^{-1}$ revealed primary amine, NH bond. The broad band of ($1465 - 1415 \text{ cm}^{-1}$)

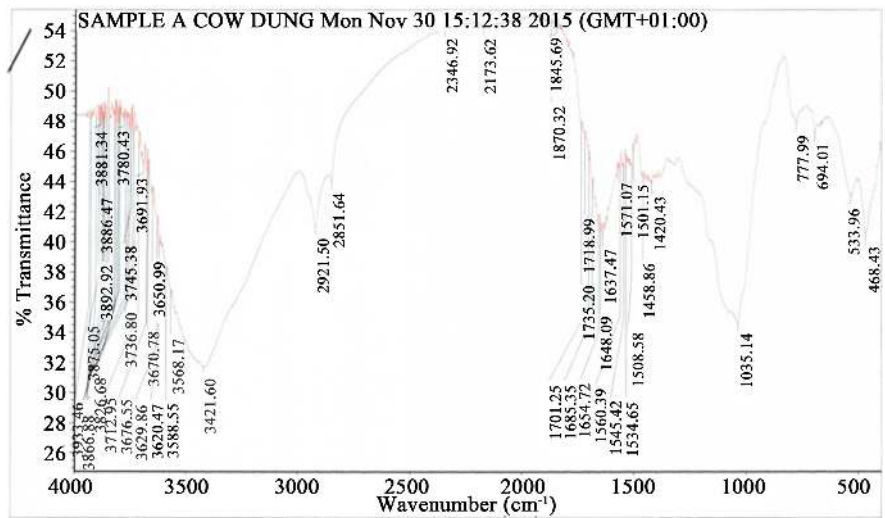


Figure 2. FTIR spectra of cow dung.

Table 1. Characterization of cow dung, maize husk and sawdust.

Properties	Cow dung	Maize husk	Saw dust
Moisture content (%)	5.5	5.9	4.4
Volatile matter (%)	89	92.4	94.3
pH	5.71 - 7.2	5.96 - 6.5	5.5 - 6.3
Particle size	<2 µm	<2 µm	<2 µm
Temperature (°C)	24 - 30	24 - 30	24 - 30
C/N	19	60	82
N (%)	2.4	0.09	0.7
TPH (mg/kg)	4901.4	177.8	1.7
Carbon content (% fraction)	42	45.8	50.4

Table 2. Elemental compositions of cow dung.

Element	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	K ₂ O	CaO	TiO ₂	Fe ₂ O ₃
Concentrations (%)	1.521	0.871	20.034	21.936	3.026	2.672	2.138	0.631	3.456

Table 3. Elemental Compositions of Maize husk.

Element	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	K ₂ O	CaO	TiO ₂	Fe ₂ O ₃
Concentrations (%)	2.140	1.267	20.373	12.851	1.741	3.085	0.842	0.596	6.593

Table 4. Elemental compositions of sawdust.

Element	Na ₂ O	MgO	Al ₂ O ₃	SiO ₂	P ₂ O ₅	K ₂ O	CaO	TiO ₂	Fe ₂ O ₃
Concentrations (%)	0.862	-0.409	20.498	11.333	1.027	0.779	0.875	0.594	6.599

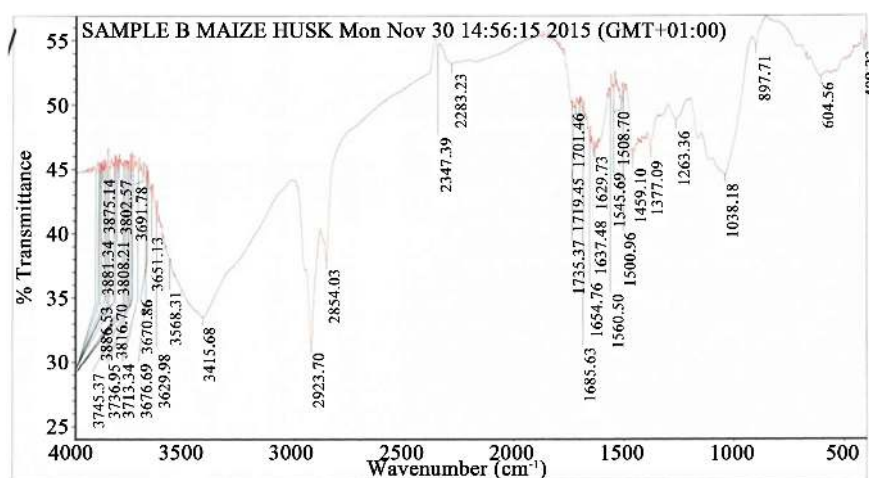


Figure 3. FTIR of maize husk.

showed the presence of C-H bend Alkyl group. The broad band 810 - 760 cm^{-1} shows the presence of C-H bend. The presence of the alkanes and methyl group makes the maize husk to produce biogas compared to saw dust.

3.3. FTIR of Sawdust

As shown in **Figure 4** the OH (secondary Alcohol) stretch broad band was shown with frequency (3626.52 cm^{-1}) while 3391.07 cm^{-1} indicates normal polymeric "O-H" stretch. None bounded hydroxyl group O-H stretch, primary alcohol was shown in broad band 3646.03 cm^{-1} (Coates, 2000). C-H, SP^3 band was exhibited between (2852.95 - 2922.82 cm^{-1}) while C=O huge band was noticed at broad band (1651.55 cm^{-1} and 1732.37 cm^{-1}). The highest intensity (peak) with frequency 2149.60 cm^{-1} suggests that C=C, short and narrow is the main functional group in the hardwood sawdust.

3.4. Cumulative Biogas Production

Figure 5 showed the cumulative biogas produced from the digester 1 for 60 days of fermentation. There was no production in the two digesters for the first four days of fermentation this can be explained as a result of the inoculum that is either in the lag phase or methanogens undergoing a metamorphic growth process by consuming methane precursors produced from the initial activity as reported by [16]. Production started on the 5th day in the digester 1 with a volume of 1.0 mL in digester 1 and none in digester 2. There was a steady increase in biogas production till there was a sudden increase in biogas production for the digester 1 within a retention time of 35 - 60 days while there was no biogas production in digester 2. This sudden increase is as a result of an exponential increase in micro-organisms which leads to an increase in fermentation rate and corresponding increase in biogas production. The initial pH for the slurry in digester 1 is 5.96 while 5.50 is the initial pH for digester 2. This observed pH change may be due to the high volatile solids in the saw dust and maize husk which were transformed into a volatile fatty acids and other acidic metabolites during acidogenesis

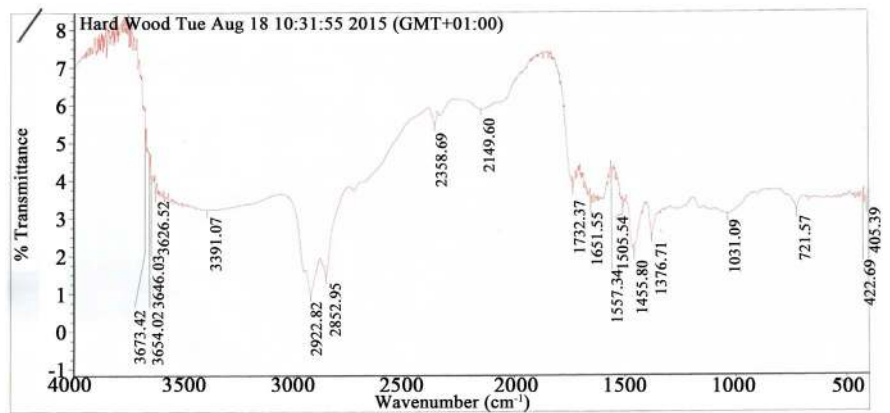


Figure 4. FTIR of sawdust.

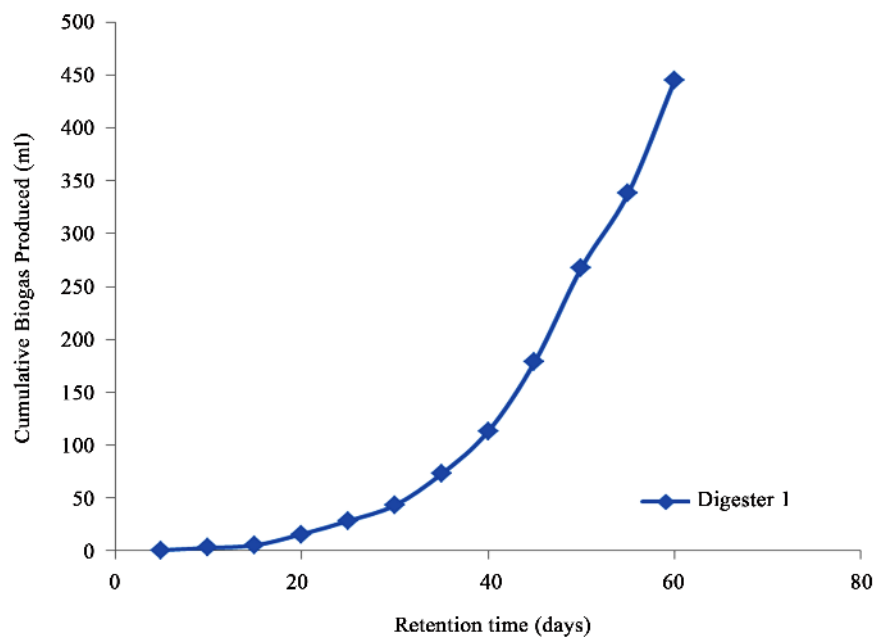


Figure 5. Cumulative biogas produced with retention time.

by the activities of the facultative aerobes and aerobes that were metabolized subsequently by the methanogenic bacteria to generate biogas [17] [18] [19]. The value of the pH increased in the two digesters as retention time (days) increased throughout the period of biogas production. As the pH start to increase the biogas production rate also increase with the retention time. This increased biogas yield with increase in pH may be due to increase in metabolic activity within the microorganisms present in the digester.

As shown in Figure 6 the slurry temperature range of 25°C - 29°C was observed during the process of fermentation. The highest volume of biogas was observed for digester 1 at a temperature of 27°C while no biogas production was observed in digester 2. [20] [21], reported that ambient temperature affects the rate of digestion due to the outside walls of the digesters surface making direct contact with the atmosphere. The digester walls absorb or loose heat depending

on the temperature gradient between the digester and its immediate environment. This indicated that seasons affect the rate of heat loss or gain from the digester which in turn affects the microbial activities in the slurry at each stage of fermentation [21].

It can be seen in **Figure 7** that as the retention time increases rate of biogas produced also increases. The coefficient of correlation (R^2) shows that the correlation is a good one having a value of 0.8319; the plot suggests that it was an ascending limb since the value of b is positive. The digester 1 has constant a and b with a numerical value of -1.1858 ml/gm/day and 0.0747 ml/gm/day respectively. It was established from the plot that biogas production rate will increase linearly with increase in time and after reaching a maximum point after some-time (days) it would decrease linearly to zero as retention time increases.

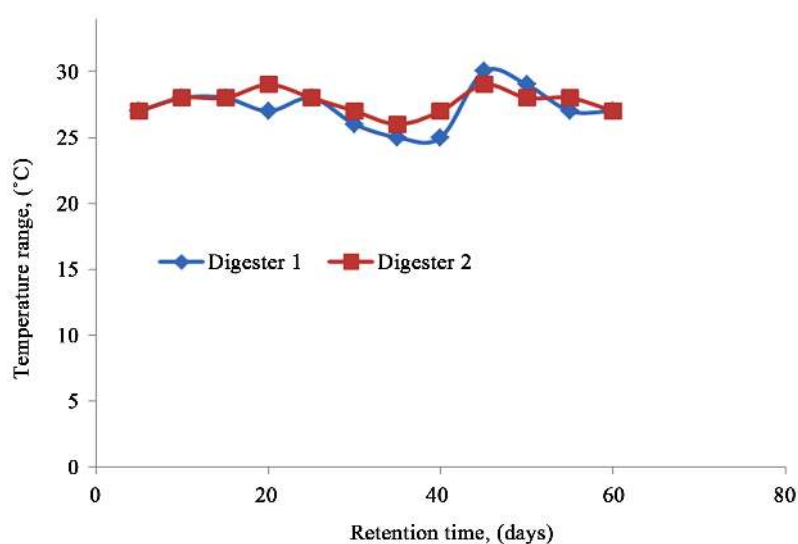


Figure 6. Temperature variation with retention time.

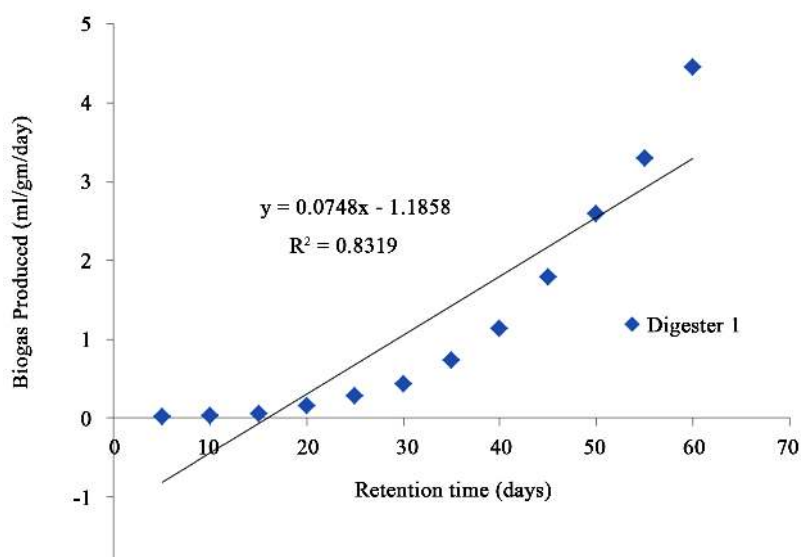


Figure 7. Linear model for biogas produced against retention time.

4. Conclusion

Anaerobic digestion of maize husk, sawdust, and cow dung for biogas production was established in this work. The data obtained from the biogas produced fitted well to linear kinetic model. It was shown that the variation in temperature, pH, and retention time had effect on the volume of biogas produced. The preponderance of alkanes and methyl group, and the lower number of carbon to nitrogen ratio in maize husk enables it to produce biogas compared to saw dust. This makes maize husk to be a good substrate for biogas production. The residue of this anaerobic digestion retains a rich fertilizer value of the initial plant waste products.

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