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Production of Biogas from Plantain Peels, Using Cow Dung as Substrate

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ABSTRACT: *In a biodigester setup, the researchers investigated the production of methane gas using plantain peel and cow dung as substrates. Two buncher flasks, corks, a glass tube, and a calibrated conical flask comprised the biodigester setup. The setup involved anaerobic digestion processes, analyzing different ratios of cow dung and plantain peel to produce biogas. The main anaerobic digestion process was carried out in Buncher flask one, after which the methane gas formed was sent to Buncher flask two through a rubber tube, where the by-products such as carbon dioxide and hydrogen sulfide were absorbed from the methane gas and the refined biogas was stored in a storage tube. For this study, there were seven setups of cow dung and plantain peel in digester1, digester2, digester3, digester4, digester5, digester6, and digester7 in the ratios of 0g;100g(100%), 10g(10%): 90g(90%), 20g(20%): 80g(80%), 30g(30%): 70g(70%), 40g(40%): 60g(60%), and 50g (50%): 50g(50%), respectively. After 15 days of retention, the slurry with the highest yield is digester 1, with 574 ml/day. The obtained kinetic modeling indicates a rise in yield as the retention time increases. Furthermore, it was observed that continuous mixing boosted the biogas production yield. The results provided valuable insights into the potential for biogas production from agricultural and animal wastes through anaerobic digestion, highlighting the impact of functional groups on biogas yield.*

Keywords: Methane gas, Anaerobic digestion, Biodigester set up, Plantain peel, Cow dung

INTRODUCTION

When organic matter breaks down biologically in the absence of oxygen, it produces methane gas, also known as biogas, a colorless, flammable gas. "Biogenic materials" refers to the anaerobic digestion (AD) of biodegradable materials, including biomass from cow dung, green trash, and agricultural residues like sugar cane and cassava. The bacterial fermentation of organic material under anaerobic conditions (without oxygen (O2)) produces the gas known as "biogas". Biogas, a type of biofuel, originates from biological material. Among the many organic materials and wastes that can generate it are sewage sludge, animal manure, and municipal trash. Materials such as biodegradable garbage, straw, manure, sugarcane, leftovers from industrial and agricultural processes, and specifically developed energy crops can also produce energy (Raja & Wazir, 2017). Swamp gas, marsh gas, and "will o' the wisp" are just a few of the many names for biogas. It contains 50 to 60 percent methane, which makes up most of the natural gas and is present in it in 50 to 60 percent amounts. In places like rice paddies, ponds, or marshes, plants naturally deteriorate, producing biogas. Biogas, when generated and collected under controlled circumstances in an airtight container, can serve as a significant energy source. The ancient Chinese experimented with burning the gas produced when manures and vegetables were allowed to rot in a confined vessel. Communities in Bombay, India, and pre-biogas England collaborated with Volto, Beacham's, and Pasteur to dispose of garbage in sealed containers and collect the resulting biogas at the turn of the 20th century (Mattocks, 1984). Methane, commonly known as marsh gas or natural gas (CH_4), makes up 40–70% of biogas, along with 30–40% carbon dioxide (CO2) and trace amounts of other gases such as hydrogen, nitrogen, and hydrogen sulfide.

The process of processing biodegradable organic waste for the creation of biogas is called anaerobic digestion, and it is quite easy. Cow dung, also known as animal manure, is utilized as an inoculum before substrate treatment. By almost 92%, the biogas output increased under thermophilic conditions. In addition to being chemically and biologically intensive, the fermentation of organic waste is also a waste management technique. Chemicals and microbes break down the large organic polymers in the biomass into smaller molecules during the process. The anaerobic digestion process turns biomass into liquid digestate, which is rich in nutrients, and biogas, which is composed of methane, carbon dioxide, and trace amounts of other contaminating gases (Raja & Wazir, 2017). Biogas has an ignition temperature in the region of 650° to 750°C and is roughly 20% lighter than air. It burns with a clean, blue flame that is odorless and colorless (after burning), much like liquified petroleum gas (LPG) gas. Because it is created through the treatment of waste, biogas is a renewable fuel. Inside a facility known as a biodigester, biogas is produced. (Macharia, 2015) Biogas is the future of energy, and if properly channeled, it can yield a lot. This research is aimed at the production of biogas from plantain peels and corn stalks using cow dung as a substrate. The objectives include characterizing plantain peels and cow dung using FTIR and XRF, studying the effect of loading/mixing rate on biogas production, characterizing the biogas produced using gas chromatography, and examining the kinetics of biogas production. This study demonstrates the advantages of biogas for producing renewable energy and maintaining the environment. The breakdown of organic waste produces biogas, a combination of carbon dioxide and methane that has the potential to drastically lower greenhouse gas emissions and reliance on fossil fuels. Furthermore, as a reliable energy source for transportation, heating, and electricity production, biogas serves as a flexible and sustainable alternative to conventional energy sources.

Hydrolysis: In the process of hydrolysis, the microbes release extracellular enzymes that convert the organic material into more straightforward and soluble molecules (Macharia, 2015). Aderinlewo and Layode (2018) investigated the impact of pretreatment with plantain peel ash on cow dung production of biogas. The study found that adding plantain peel ash to cow dung substrate increases biogas production. Tambuwal et al. (2020) found that fresh and dry plantain peels produce less biogas than banana peels and thus require pre-treatment to increase biogas yield in their study of biogas production from banana and plantain peels blended with cow dung in an in vitro biodigester system. Chinenyenwa et al. (2023) also investigated the best way to pretreat plantain peel waste for biogas production. The researchers proposed applying the study's findings to biogas production in industry, emphasizing the importance of treating the substrate first to improve the anaerobic digestion process's ability to produce biogas. Uheuegbu and Onuorah (2014) investigated the production of biogas from plantain peels. The results revealed that the product (ash content) indicates the mineral content of the waste, implying that it would be an excellent biofertilizer, providing adequate mineral sources to the soil. Using locally available materials, they demonstrated plantain peels' potential and capability to generate biogas in a digester. The combination of peels and animal waste resulted in significantly higher biogas production and retention. Sambo et al. (2015) investigated biogas production in Nigeria by co-digesting selected agricultural wastes. The study concluded that fermenting agricultural wastes to produce biogas and sludge with agricultural value provides an alternative and efficient way to manage agricultural waste and energy in Nigeria. Bacterial and anaerobic bacteria produce enzymes that degrade insoluble organic materials such as cellulose, protein, fat, and a wide range of other organic compounds. Small, soluble organic compounds produced during this stage provide a starting point for bacteria in the following stage. Bacteria can complete carbohydrate hydrolysis in hours, but protein and fat hydrolysis takes days. While facultative anaerobes can absorb dissolved oxygen in water, lignocellulose and lignin degrade slowly and inefficiently. This results in a reduction in redox potential, which is beneficial to the AD process. At this point, the AD process converts carbohydrates to simple sugars (Gummert et al., 2019). Yaru 2021 conducted research on the Comparative Biogas Ignition Time of Cattle Dung Mixtures with Cassava and Plantain Peel. The cattle dung mixture with cassava peels was found to be the best of the three substrates for biogas production, with a 55-day ignition time and the highest bacteria population.

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Acidogenesis is the process by which bacteria convert low-molecular-weight substances into acetic acid (CH3COOH), hydrogen (H2), and carbon dioxide (CO2). These bacteria require carbon and oxygen to produce acetic acid. They accomplish this by utilizing the oxygen contained in the fluid. The acid-producing bacteria create an anaerobic environment (one without oxygen), which is required by methane-producing microbes (Macharia, 2015). Methanogenesis: During this stage, methanogenic bacteria convert the primary acids produced in Stage 2 into methane. Methanization refers to the reaction that occurs during the methane generation process. (Machia, 2015). This phase produces only methane in the absence of oxygen. This process is thought to be exothermic. In Stage 4, two methane-producing processes take place: the reduction of CH3COO and the conversion of H2 to CO2. Hydrogenotrophic methanogens convert H2 and CO2 into methane, whereas acetotrophic methanogens reduce acetate (CH3COO) to methane. (Gummert et al., 2019.)

MATERIALS AND METHODS

Sample collection and Experimental Materials

In the production of biogas, two samples were used: plantain peel and cow dung. The cow dung was gotten from an abattoir located at Agbarho Effurun Delta Street, Uvwie Delta State, and the plantain peel was obtained from a bole joint at the Federal University of Petroleum Resources Delta State. Materials used for the experiment are as follows: sodium chloride, distilled water, sulfuric acid (H2SO4), cow dung, and plantain peel. During the research, the apparatus and instruments used were as follows: weighing balance, Buckner flask, hose, conical flask, pH meter, stirrer, measuring cylinder, sieve, black polyethylene bag, and beaker. The plantain peel and cow dung were dried under sunlight for about two weeks and then grinded and sieved into small particles of <2mm (Table 1). There are seven setups, which have the following composition of cow dung and plantain peel: 100:0. 90:10, 80:20, 70:30, 60:40, 50:50, 0:100.

Methods

The production of biogas was carried out on a laboratory scale, apparatus used were rinised with distilled water and allowed to dry standing for a few hours (Figure 1 and 2). A set of seven Buckner flask were used as digesters which 500ml each while another set of seven flasks were used, each containing acidified brine water each connected to the various digester with a tube and afterwards holes are bored in the cork covering the flask containing the solution and a glass tube is inserted into the flask and the output to a measuring cylinder. The pressure from the biogas produced caused a displacement of acidified brine. the volume displaced was then measured as the amount of biogas produced. The digester was operated at room temperature. The first digester contained cow dung only and was mixed with water by mass ratio of 100g : 100ml of water respectively. The second digester contained cow dung and plantain peel and was mixed with water by mass ratio 90g :10g: 100ml respectively. . The third digester contained cow dung and plantain peel and was mixed with water by mass ratio 80g :20g: 100ml respectively. . The fourth digester contained cow dung and plantain peel and was mixed with water by mass ratio 70g :30g: 100ml respectively. . The fifth digester contained cow dung and plantain peel and was mixed with water by mass ratio

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60g :40g: 100ml respectively. . The sixth digester contained cow dung and plantain peel and was mixed with water by mass ratio 50g :50g: 100ml respectively. . The seventh digester contained cow dung and was mixed with water by mass ratio 100g:100ml respectively. After the interval of three days the slurry was stirred and readings were taken

Figure 1 Biogas production setup

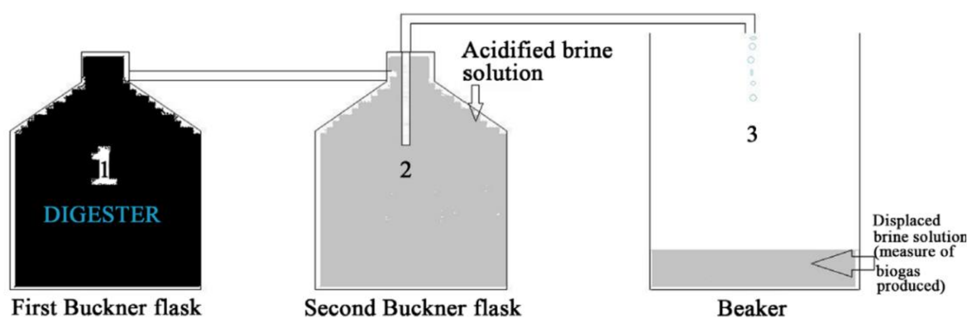

Figure 2 Diagrammatic Representation of the Experimental setup

Characterization of the substrate

Classification of substrate size

The cow dung which was pretreated was sieved to particles less than 2mm.

Determination of temperature

The digesters were all operated under room temperature.

FTIR (Fourier transform infrared spectroscopy) analysis.

The structural organization of the samples (plantain peel and cow dung) was investigated to identify the functional groups presents (Table 1). The samples was examined using SHIMADZU

FTIR-8400S spectrophotometer with the range 500 - 4000 cm−1. KBr was used as background material in the analysis.

X-ray fluorescence analysis

Elemental compositions of samples were analyzed using x- ray fluorescence Kinetic modeling of biogas

In other to go about the kinetic modeling mathematical equations were used, the accumulation was simulated using logic growth model and exponential rise to maximum

Linearplot.

$$y = a + bt$$

Where y is biogas production rate in ml/gm/day

T is time in day for digestion

a&b are constant from interception and slope of y vs t in ml/gm/day ascending lim b is positive or negative

exponential plot:

$y \ = a + be^{ct}$

Where y is biogas production rate in ml/gm/day

T is time in day for digestion

a&b are constant in ml/gm/day

c is constant in per day from ascending limb is positive or negative

logistic kinetic model

it can be expressed as

$c = a \div 1 + be^{-kt}$

Where c cumulative biogas production ml/hm

K kinetic rate constant in per day

T retention time

a,b are constant in ml/gm/day

Preparation of acidified brine solution.

Firstly 148.9g of NaCl was dissolved in 750ml of distilled water, and it was stirred with a magnetic stirrer till the solution was super saturated. And few drops of H_2SO_4 was added to the solution

Biogas means gaseous fuel, especially methane, produced by the fermentation of organic matter. Biogas typically refers to a mixture of different gases produced by the breakdown of organic matter in absence of oxygen. Biogas can be produced by anaerobic digestion with anaerobic bacteria, which digests material inside a closed system, or fermentation of biodegradable materials. Biogas is a commonly used bio fuel around the world and is generated through the process of anaerobic digestion or the fermentation of biodegradable materials such as biomass, manure, sewage, municipal waste, rubbish dumps, septic tanks, green waste and energy crops. This type of biogas comprises primarily methane and carbon dioxide. The actual composition of biogas will vary depending uponthe origin of the anaerobic digestion process – i.e. the feedstock. Biogas is

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somewhat lighter than air and has an ignition temperature of approximately 700 °C (diesel oil 350 °C; petrol and propane about 500 °C). The temperature of the flame is 870 °C. Biogas consists of about 60 % methane (CH4) and 40 % carbon dioxide (CO2). It also Biogas means gaseous fuel, especially methane, produced by the fermentation of organic matter. Biogas typically refers to a mixture of different gases produced by the breakdown of organic matter in absence of oxygen. Biogas can be produced by anaerobic digestion with anaerobic bacteria, which digests material inside a closed system, orfermentation of biodegradable materials. Biogas is a commonly used bio fuel around the world and is generated through the process of anaerobic digestion or the fermentation of biodegradable materials such as biomass, manure, sewage, municipal waste, rubbish dumps, septic tanks, green waste and energy crops. This type of biogas comprises primarily methane and carbon dioxide. The actual composition of biogas will vary depending upon the origin of the anaerobic digestion process – i.e. the feedstock. Biogas is somewhat lighter than air and has an ignition temperature of approximately 700 °C (diesel oil 350 °C; petrol and propane about 500 °C). The temperature of the flame is 870 °C. Biogas consists of about 60 % methane (CH4) and 40 % carbon dioxide (CO2). It also Biogas means gaseous fuel, especially methane, produced by the fermentation of organic matter. Biogas typically refers to a mixture of different gases produced by the breakdown of organic matter in absence of oxygen. Biogas can be produced by anaerobic digestion with anaerobic bacteria, which digests material inside a closed system, or fermentation of biodegradable materials. Biogas is a commonly used bio fuel around the world and is generated through the process of anaerobic digestion or the fermentation of biodegradable materials such as biomass, manure, sewage, municipal waste, rubbish dumps, septic tanks, green waste and energy crops. This type of biogas comprises primarily; methane and carbon dioxide. The actual composition of biogas will vary depending upon the origin of the anaerobic digestion process – i.e. the feedstock.Biogas is somewhat lighter than air and has an ignition temperature of approximately 700 °C (diesel oil 350 °C; petrol and propane about 500 °C). The temperature of the flame is Biogas consists of about 60 % methane (CH4) and 40 % carbon dioxide (CO2). It also

RESULTS AND DISCUSSION

Table 1 Characterization of cow dung and plantain peel

Properties	Cow dung	Plaintain
PH	5.7 -6.0	5.0 -5.5
Particle size	<2mm	<2mm
Temperature	20-25	20-25

Fourier Transform Infrared (FTIR) Analysis:

This shows the various wavelengths of each functional group present in each sample and the rate of absorption of light.

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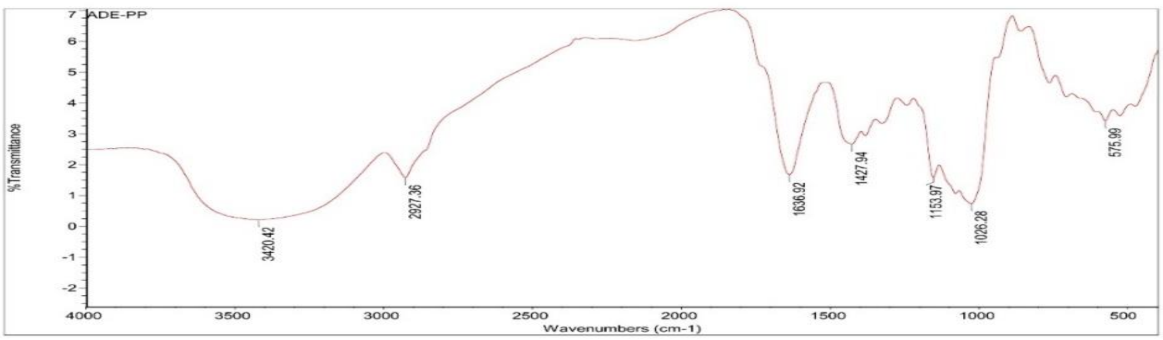
Figure 3 shows the FTIR spectrum of a pure plantain peel sample. 3420.42, which is the strong peak that has a low transmittance, shows the presence of a hydroxyl group (O-H) hydrogen bonded, which means high concentrations of the hydroxyl group of polymeric compounds such as lignin, which contains the functional group of alcohol and carboxylic acids. The medium peak, which is 2927.36 cm1, shows a C-H of alkane. 1636.92 cm1 shows a C=C alkene. The band at 1427.94 cm1 shows hydroxyl group bending, which is the presence of alcohol, while the medium band at 1153.97 cm1 indicates the C-N bond of aliphatic amine. The strong band, which is 1026.28 cm1, indicates C-O tertiary alcohol. This indicates that it contains hemicellulose, cellulose, and pectin.



Thu Nov 30 21:43:30 2023 (GMT+13:00)
FIND PEAKS:
Spectrum: ADE-PP
Region: 4000.00 400.00
Absolute threshold: 3.627
Sensitivity: 50
Peak list:

Position:	575.99	Intensity:	3.418
Position:	1026.28	Intensity:	0.731
Position:	1153.97	Intensity:	1.578
Position:	1427.94	Intensity:	2.668
Position:	1636.92	Intensity:	1.669
Position:	2927.36	Intensity:	1.578
Position:	3420.42	Intensity:	0.221

Figure 3 FTIR spectra of plantain peel

Figure 4 shows the FTIR spectrum of cow dung, and it can be seen that the frequency (3449.11 cm−1) indicates an O-H (alcohol) wide broadband. The C-H stretch of the CHO (carboxylic acid) group showed a very wide band with a frequency of 2362.49 cm1, while the broadband (1642.68) corresponds to the C=O stretch ketone. The broad band of 1384.86 cm1 revealed the primary amine, the NH bond.

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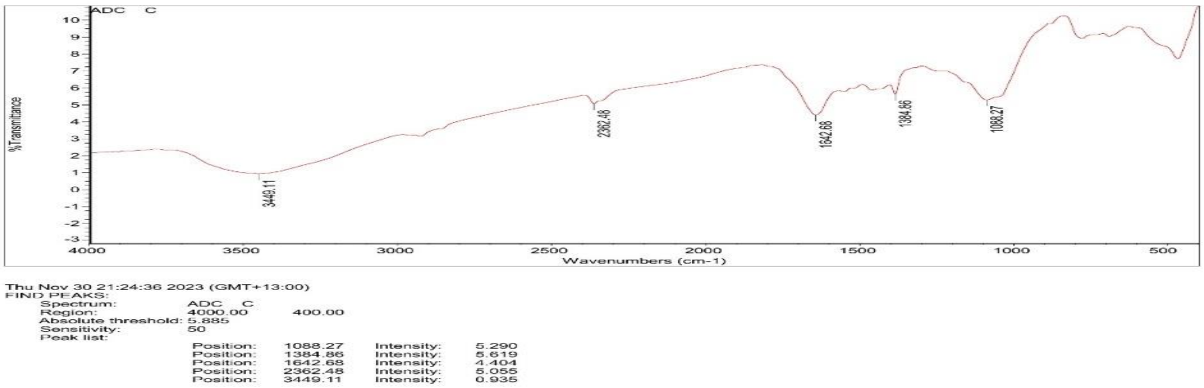

Figure 4: FTIR spectra of cow dung

X-ray Florence analysis

This shows an analytical method that is non-destructive and used to find a material elemental makeup X-ray fluorescence analysis of a cow dung sample

This shows the elements present in the sample with high concentrations are tin (Sn) with a concentration of 2.20%, while vanadium, chromium, and arsenic are not present (Table 2).

Table 2: Elemental composition of cow dung

Element	Concentration
Fe	0.22747 %
cu	0.000730 %
Ni	0.00560 %
Zn	0.007583 %
Al	0.05433 %
Mg	0.01421 %
Na	0.0333 %
S	0.51756 %
P	0.32901 %
Ca	1.0513 %
K	0.6475 %
Mn	0.011060 %
Rb	0.001053 %
Sr	0.001580 %
Br	0.00334 %
Cl	0.2188 %
Cr	0%
V	0%

W	0.0668 %
Bi	0.134 %
Sn	2.20 %
Si	1.16 %
As	0%

X-Ray flouresence analysis of cow plaintain peel sample

This shows the elements present in the sample with high concentrations is potassium(k) with a concentration of 2.9417 % while vanadium, chromium, sodium,sliver are not present (Table 3).

Table 3 elemental composition of plantain peel

Element	Concentration
Fe	0.06514 %
cu	0.000273 %
Zn	0.007583 %
Al	0.03435 %
Mg	0.02422 %
Na	0%
S	0.02422 %
P	0.20949 %
Ca	0.3988 %
K	2.9417 %
Mn	0.004170 %
Rb	0.00782 %
Sr	0.002287 %
Br	0.00116 %
Cl	0.3847 %
Cr	0%
V	0%
W	0.0745 %
Bi	[0.050] %
Sn	[0.74] %
Si	0%
As	0%
Nb	0.1067 %
Ta	0.01637 %
Pb	1.088 %

Effect of loading /mixing rate on biogas produced

After loading the digesters after 9 days, the total gas produced across the seven setups was as follows: 187 ml, 124 ml, 0 ml, and 0 ml. After manually stirring, the yield across the various digesters is as follows: 387ml, 272.5ml It was observed that there was an increase in the yield of production after stirring, and it was established that if there is continuous mixing, there will be an increase in the production (Table 4).

Table 4: Cumulative Biogas production rate

Digesters	Cumulative Biogas production rate ml/day
1	574
2	396.5
3	232.85
4	235.3
5	0
6	0
7	0

Biogas production from digester

After 15 days of retention time, digester 1 produced a total of 574 ml/day of biogas, and digester 2 gave a total of 396.5 ml/day. The kinetics of the biogas production for digester 1 and 2 are shown in the linear model (Figure 5 and Table 5). The linear plot was used, and it shows the increase in production time as the retention time increases. The correlations (R^2) for digesters 1 and 2 are 0.8753 and 0.9659, which are good. It shows that the plot increases there by allowing a and b to have numerical values for both digesters, which are 15.543 and 20.905 for digester 1 and for digester 2, 11.167 and 17.667 for a and b, respectively. so as it shows, there is a linear increase with time, and when there is a zero, production will decrease linearly (Figure 6).

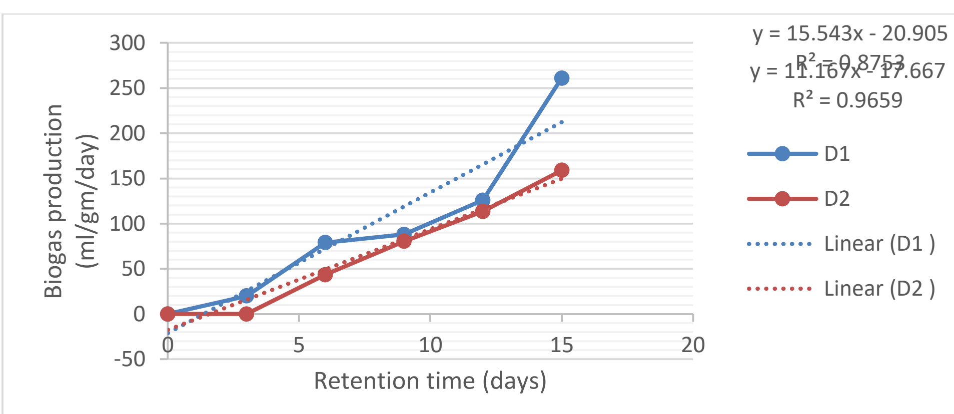

Figure 5: Production time as the retention time increases for 1 and 2

The kinetics of the biogas production for digester 3 and 4

Figure 5: The linear plot was used, and it shows the increase in production time as the retention time increases. The correlations (R^2) for digesters 3 and 4 are 0.8417 and 0.8316, which are good. It shows that the plot increases there by allowing a and b to have numerical values for both digesters, which are 8.2952 and 23.414 for digester 3 and for digester 4, 8.559 and 24.976 for a and b (Figure 6 and Table 6).

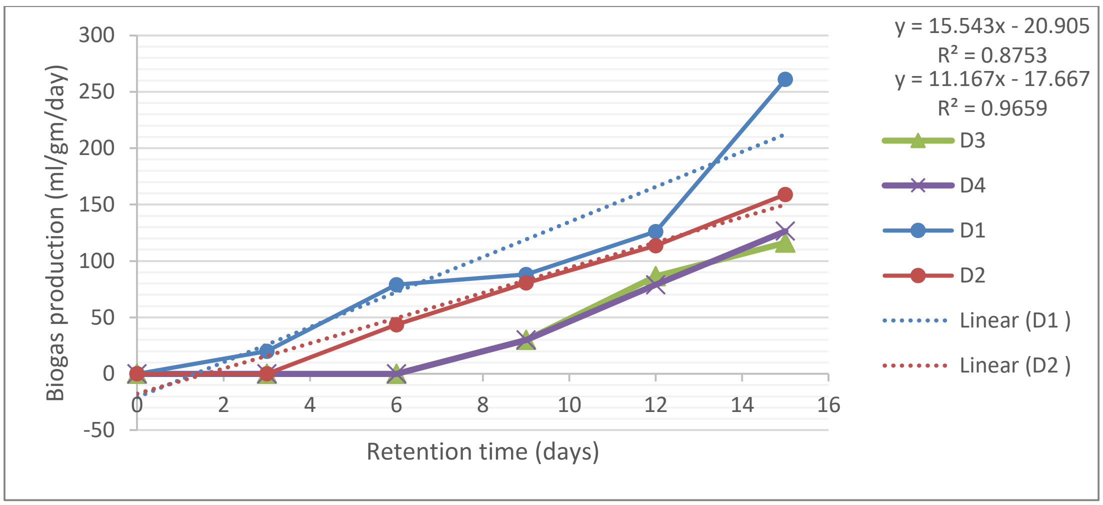

Figure 6: Production time as the retention time increases for 3 and 4

This values are gotten from the total biogas produced form the data of plaintain peel and cow dung.

Table 5: Showing the constants and coefficient of the linear model

Model	Slurry (plantain peels and cow dung)	
LINEAR	Digester 1	Digester 2
A	15.543	11.167
B	20.905	17.667
R^2	0.8753	0.9659

Table 6: Showing the constants and coefficient of the linear model

Model	Slurry (plantain peels and cow dung)	
LINEAR	Digester 3	Digester 4
A	8.2952	8.559
B	23.414	24.976
R^2	0.8417	0.8316

CONCLUSION

In conclusion, the research demonstrates the potential for biogas production from plantain peel and cow dung through an anaerobic digestion process. The designed biodigester setup effectively utilized plantain peel and cow dung as substrates to produce methane gas. The study involved analyzing the various functional groups present in the samples and their impact on biogas production. Observation of the biogas yield across different digesters highlighted the influence of continuous mixing on production, indicating an increase in yield after stirring. Furthermore, the study established that varying proportions of cow dung and plantain peel affected biogas production, with the digester containing 100% cow dung yielding the most biogas. The findings showcase the potential of anaerobic digestion as a reliable and sustainable alternative for managing environmental pollution resulting from improper waste disposal methods. Additionally, the research provides valuable insights into the influence of functional groups on the amount of biogas produced, offering a promising avenue for further exploration and potential applications in waste management and energy production.

Recommendations

1. **Optimal Substrate Ratio**: The digester setup using 100% cow dung yielded the highest biogas production. Therefore, it is recommended to consider using a higher proportion of cow dung in the substrate mixture for efficient biogas production.
2. **Continuous Mixing**: Continuous mixing of the substrate was observed to increase the yield of biogas production. Therefore, it is recommended to implement continuous mixing in the biodigester setup to maximize gas production.
3. **Utilization of Biogas**: Biogas production from plantain peel and cow dung presents a viable alternative for both animal and agricultural waste management. It is recommended to explore opportunities for utilizing the produced biogas as a renewable energy source, thus contributing to environmental sustainability and reducing reliance on fossil fuels.
4. **Environmental Benefits**: This research underscores the environmental benefits of anaerobic digestion in mitigating pollution resulting from improper waste disposal methods. It is recommended to promote the adoption of anaerobic digestion technology as a sustainable waste management solution, particularly in areas with high agricultural and animal waste generation.
5. **Further Investigation**: The correlation analysis and linear plot revealed valuable insights into the relationship between production time and biogas yield. Further investigation into optimization strategies based on these findings is recommended to enhance the efficiency of biogas production processes.

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