

Anaerobic co-digestion of organic biomasses: an approach towards increases biogas yield

Abstract

This research was aimed at comparatively revealing the effect of co-digestion in biogas production. Co-digestion is anaerobic digestion of several organic substrates simultaneously. Four locally fabricated digesters were used for cow, pig, poultry and mixed substrate respectively. Batch culture method was used for 21 days. Wheelbarrow tube was used as gas collector, which weighed 420g initially. The set-up was monitored by weighing the tubes daily with digital weighing balance. Gas production started in day 1 and stopped at day 21. The weight of the tubes were measured to be 420g. After setting up the digester, the process was recorded as day zero (0). Production of gas was observed by the increase in the size of the tubes. The indigenous bacteria started working on the substrate Poultry gas the highest gas yield as a single substrate. On the comparative level, the mixed substrate showed a very significant gas production. Gas analysis using gas chromatography revealed that the mixed substrate digestion gave the highest methane production of 87.28 %. Co-digestion has proved to be a better approach in biogas production process. It has the following positive effects, higher gas yield, balanced C:N ratio Improved microbial activity, greater process stability, increase methane content, reduced toxicity and better waste management. The research concludes that co-digestion of good organic substrate is a good approach in biogas production to enhance gas yield.

Keywords: biogas, co-digestion, digester, substrate, dungs, chromatography

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Introduction

Biogas is a methane-rich gas generated by the anaerobic decomposition of organic waste with the assistance of archaeobacteria in an oxygen-free environment. It consists of approximately 60% methane, 40% carbon dioxide, and 0.2 to 0.4% hydrogen sulfide.¹ Biogas is produced when organic microorganisms break down materials like food waste or manure in the absence of oxygen, a process known as anaerobic degradation or digestion. This process differs from composting, which is another form of biodegradation that occurs under aerobic conditions. "Oxygen is necessary for organisms to grow and function."² "Biogas is a familiar concept that has become a project attracting significant interest and investment from individuals, countries, and organizations alike.

Co-digestion in biogas production greatly increases methane yield by optimizing carbon-to-nitrogen (C/N) ratios, enhancing nutrient availability, and promoting microbial activity.³ Combining substrates, such as cow dung with food waste or agricultural residues, helps to address problems like inhibition, enhances buffering capacity, and boosts biogas production by 3.11% to 13.99% compared to the digestion of single substrates.⁴ One of the primary benefits of co-digestion in biogas production is the enhancement of nutrient balance and pH stability. Combining substrates with varying characteristics, such as nitrogen-rich manure and carbon-rich waste, establishes a more stable and optimal environment for anaerobic bacteria. This approach helps prevent the accumulation of volatile fatty acids (VFAs).⁵

Due to issues in the energy sector and a worldwide shortage, there is a significant demand for alternatives to the fossil fuels currently in use.⁶ Biogas is a sustainable and renewable energy source that can serve as an alternative to wood and other fuels in various applications. "It helps lower the rising costs of oil products and reduces the need to cut down trees for energy." Urbanization has led to a rapid rise in waste production, resulting in inadequate management practices in

developing countries.⁵ As people consistently generate waste and often find it challenging to manage, the production of biogas has emerged as an effective solution for waste management. The improvement in living standards has resulted in an increased emission of pollutants and greenhouse gases (GHGs) into the environment. "This has led to a global crisis as people continue to rely heavily on fossil fuels."⁶

Problem statement

Through biogas production, improper animal waste disposal can be reduced and corrected by their use as feedstock.⁴ This can serve as waste management. Use of animal waste in biogas production is eco-friendly. When compared with other forms of energy generation, biogas production doesn't pollute the environment. Apart from waste management strategy, animal manure used in biogas production will turn to wealth creation. Originally, animal waste which are regarded as waste can also serve as job creation. Biogas production can be predicted by kinetic model. Due to today's energy demand and the possibility of depletion of non-renewable energy resources, the need to explore and exploit new energy sources that are renewable, secure and ecologically sustainable is pertinent. Alternative energy sources evolving in the last two decades are gaining attention all over the world because they do not cause increase in CO₂ composition of the atmosphere. They are also known to enhance energy conservation and provide new job opportunities. The research provides a chance to improve the effective and efficient management of animal manure waste. We need to discover a better way to improve biogas production. There are several methods to forecast biogas production. "However, the updated Gompertz method has shown to be the best choice." Even though researchers have tried many times to create models for what happens in a digester, classical mathematical modeling has only worked when the process was greatly simplified. This kinetic model suggests that microbial growth starts off slowly and also slows down at the end of the anaerobic process. This updated kinetic model suggests that gas production depends on the total amount of

gas produced and the growth of methanogens. Instead of looking for natural hard water like spring water or well water, it can be achieved using Magnesium sulphate. Cow blood can serve as source of nutrient to the indigenous bacteria in biogas production. Use of charcoal water in slurry preparation will help in reducing of Carbon dioxide of the substrate by adsorption.

Materials and methods

Materials

The biomasses used in this research include: Poultry dungs, Cow dungs, Pig dungs, and other materials include four 20-litre capacity of locally fabricated digester, four-wheel barrow tube which serve as gas collector, Hose, Valve, water and weighing balance.

Methods

Fresh cow, pig, and poultry manure (feedstock) were collected from Onyewuchi Ejiaku Farms located in Ubah, within the Mbaoma autonomous community of the Owerri North Local Government Area in Imo State. These were collected using a clean trowel and transparent sterile nylon bag. The trowel was use used to collect the fresh dungs from the site and carefully put into the transparent bag. The trowel was later washed and rinsed with clean water and used the second time for compost soil.⁷ This was accomplished using a clean, washed 20-liter paint bucket and a trowel. The feedstock was then manually crushed to decrease the particle size. In addition to using hands to crush the block-form materials, non-biodegradable items such as nylon and stones were also removed. "This is a method of physical pretreatment." The anaerobic fermentation method employed was batch culture.

Preparation of slurry

This was done by measuring out 1000g of piggery dungs, poultry dungs and the cow dungs separately. Another 1000g of the three dungs were measured out again for co-digestion. These were done using a digital weighing balance and an empty paint plastic container of 20-litre capacity. Each of the measurements was put in a separate empty paint bucket of 20-liter capacity. Five (5) liters of water was added to each of the buckets. However, ten (10) litres of water was added to the one containing the three feedstocks for co-digestion. A strong iron rod was used to mix them thoroughly.

Anaerobic digestion

After the mixing, the mixed slurry was poured into the fabricated digester as shown in the diagram. They were allowed to stay. Daily monitoring, shaking and weighing of the tubes were done. These processes continued until the biomass stopped producing gas. This lasted for 21 days.

Gas analysis by chromatography

The analysis was done using gas chromatography. Biogas was measured using Gas chromatography-flame ionization detector. The GC used in this study was measured by Agilent Technologies (6890, USA) equipped with FID detector and capillary column (Elite-5, 30m*0.25mm*0.25µm). The workstation was Total chrome navigator used for data processing as described by Seppanen-Laakso et al. A sample port used was for introducing the biogas sample at the head of the column. A calibrated micro syringe was used to transfer a volume of the biogas sample through a rubber septum and thus into the vaporization chamber. Most of the separations required only a small fraction of the initial sample volume and a sample splitter was used

to direct excess sample to waste. Commercial gas chromatographs involved the use of both split and split less injections when alternating between packed columns and capillary columns. The vaporization chamber was typically heated 50°C above the lowest boiling point of the sample and subsequently mixed with the carrier gas to transport the sample into the column. The temperature for column chamber, inlet chamber and detector was 150oC, 200°C and 250°C, respectively. High purity nitrogen was used for carrier gas in this study, and the flow rate for nitrogen was 2.0ml/min. Carrier gas was supplied at high pressure & was passed into the instrument at a rapid & reproducible rate.

Separation column

The split ratio of gas sample in inlet chamber was 20:1, which is used to control the amount of biogas flew into column, and prevent the unconventional peak, such as flat peak, trailing peak. The flow rate was 450mL/min for air produced by automatic air source (BCHP, SPB-300, China) and 45mL/min for hydrogen produced by hydrogen gas. An Open capillary column was used in this GC (Gas chromatography). The adsorbent was then treated with the liquid stationary phase.

Column oven or thermostat chambers

The oven temperature was programmed as follows: 120°C held for 4min, ramp at 10°C/ min to 180°C, held for 2min, and finally ramp at 5°C/ min to 300°C. The gas used as carrier gas at a flow rate of 1.0mL/ min and detector make-up gas of 29Ml min⁻¹. The injection volume of the GC was 10.0µL. The total run time for a sample was 43 min. The thermostat oven was to control the temperature of the column to conduct precise work. The oven can be operated in temperature programming method. In this temperature programming method, the column temperature was either increased continuously or in steps as the separation progresses.

The flame ionization detector (FID)

Detector was present at the end of the column & gave the quantitative measurement of the components of the mixture as they elute in combination with the carrier gas. e. Amplification & Recorder system.

Results

The results obtained after the 21 days are as follows (Figures 1-3).

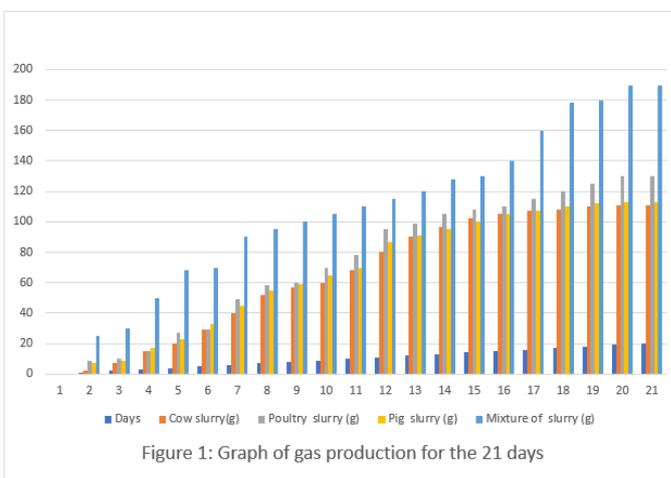


Figure 1: Graph of gas production for the 21 days

Figure 1 Graph of gas production for the 21 days.



Figure 2 Locally fabricated digester showing for single substrate and mixed substrate (inside).



Figure 3 Locally fabricated digester showing for single substrate and mixed substrate (outside).

Discussion

The weight of the tubes was measured to be 420g. After setting up the digester, the process was recorded as day zero (0). Production of gas was observed by the increase in the size of the tubes. The indigenous bacteria started working on the substrate.

According to Osuji et al,⁸ the hydrolytic bacteria started degrading the lignin network of the lignocellulose. At this stage, carbohydrate is converted to fermentable sugar; protein is converted to amino acid while the lipids are converted to fatty acids.⁹

This step takes longer time due to limiting accessibility of the extra cellular enzymes to intra cellular polymeric materials that are protected by cell covering.¹⁰

However, this research cannot specifically state the day the hydrolysis stage was completed. But gas production started at day 1 as represented in Table 1.

Table 1 Weight of tubes with gas for each day (weight of tube = 420g)

Days	Cow slurry(g)	Poultry slurry (g)	Pig slurry (g)	Mixture of slurry (g)
0	420	420	420	420
1	422	429	427	445
2	427	430	429	450
3	435	435	437	470
4	440	447	443	488
5	449	449	453	490
6	460	469	465	510
7	472	478	475	515
8	477	480	479	520
9	480	490	485	525
10	488	498	490	530

Table 1 Continued...

11	500	515	507	535
12	510	519	511	540
13	517	525	515	548
14	522	528	520	550
15	525	530	525	560
16	527	535	527	580
17	528	540	530	598
18	530	545	532	600
19	531	550	533	610
20	531	550	533	610

In this research; according to Osuji et al,¹¹ Novia, 2002, the hydrolysis is a limiting stage. It takes place slowly. This could be attributed to the process of the bacteria trying to adjust to the new environment. Maximum gas production for the single substrate (cow, poultry and pig dungs) was 10g.

Furthermore, the hydrolysis stage can be called a breakdown stage.¹¹ In this stage, polymers like Carbohydrate, protein and lipids are broken down into sugar, amino acids and fatty acids respectively. In the process of anaerobic digestion of the three substrates, it could be observed from Table 1 that poultry dungs gave the highest gas yield. The pig and cow in decreasing order followed this. Gas production is a function of the polymer in the substrate that depends on the type of food the animals fed on.

Effect of the co-digestion of cow, poultry and pig dungs in this research

In this research work, anaerobic co-digestion of the substrate can be defined as the simultaneous digestion of the several organic matter at same time. There are improvement of efficiency and stability in biogas production. From Tables 1&2, the following were observed

Table 2 Actual weight of the gas produced (Weight of tube and gas – weight of tube (420g))

Days	Cow slurry(g)	Poultry slurry (g)	Pig slurry (g)	Mixture of slurry (g)
0	0	0	0	0
1	2	9	7	25
2	7	10	9	30
3	15	15	17	50
4	20	27	23	68
5	29	29	33	70
6	40	49	45	90
7	52	58	55	95
8	57	60	59	100
9	60	70	65	105
10	68	78	70	110
11	80	95	87	115
12	90	99	91	120
13	97	105	95	128
14	102	108	100	130
15	105	110	105	140
16	107	115	107	160
17	108	120	110	178
18	110	125	112	180
19	111	130	113	190
20	111	130	113	190

- a Gas yield increment.
- b There is improvement in nutrient which is the C:N ratio.
- c There are bioaugmentation and biostimulation enhancement.
- d Hydrolysis stage took a shorter time of say 12hours. This was evidenced by the weight of gas produced within 1-5 days of process.
- e There is increase in methane gas production as shown by the gas analysis using gas chromatography (87.28%) (Tables 3-6).¹²

Table 3 Sample A [Cow dungs] Methane composition 55.22%

Components	Concentration	% Composition
CO	0.40	2.17
CO ₂	2.40	13.01
METHANE	10.15	55.22
ACETIC ACID	1.15	6.26
METHANOL	0.18	1.01
ETHYL ACETATE	1.11	6.01
SO ₂	-	
ACETONE	0.70	3.76
ACETONITRILE	0.30	1.60
TOTAL	18.40	

Table 4 Sample B [Poultry dungs] Methane composition 77.97%

Components	Concentration	% Composition
CO	0.30	1.30
CO ₂	3.10	13.20
METHANE	18.10	77.97
ACETIC ACID	0.51	2.17
METHANOL	9.90	42.66
ETHYL ACETATE	0.09	0.38
SO ₂	0.42	1.82
ACETONE	0.74	3.18
ACETONITRILE	0.42	1.80
TOTAL	23.19	

Table 5 Sample C [Pig dungs] Methane composition 77.93%

Components	Concentration	% Composition
CO	0.29	0.13
CO ₂	0.99	0.45
METHANE	171.76	77.93
ACETIC ACID	5.79	2.63
METHANOL	10.07	4.57
ETHYL ACETATE	17.06	7.74
SO ₂	2.73	1.24
ACETONE	5.90	2.68
ACETONITRILE	6.10	2.77
TOTAL	220.42	

Table 6 Sample D [Mixed substrate] Methane composition 87.28%

Components	Concentration	% Composition
CO	0.80	0.93
CO ₂	5.09	5.92
METHANE	75.13	87.28
ACETIC ACID	1.97	2.29
METHANOL	2.70	3.14
ETHYL ACETATE	0.20	0.24
SO ₂	0.72	0.84
ACETONE	0.11	0.12
ACETONITRILE	-	
TOTAL	86.08	

Conclusion

Co-digestion has proved to be a better approach in biogas production process. It has the following positive effects.

- a Higher gas yield.
- b Balanced C:N ratio.
- c Improved microbial activity.
- d Greater process stability.
- e Increase methane content.
- f Reduced toxicity.
- g Better waste management.
- h High gas yield gives more money.

Conflict of interest

There is no conflict of interest in this research work.

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