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PERFORMANCE EVALUATION OF ANAEROBIC CO-DIGESTION OF PIG DUNG AND POULTRY DROPPINGS FOR BIOGAS PRODUCTION IN A BATCH DIGESTION SYSTEM

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ABSTRACT

The rapid expansion of livestock production in Nigeria has led to the generation of large quantities of organic waste, presenting significant environmental and waste management challenges. Anaerobic co-digestion offers a sustainable approach for converting mixed livestock wastes into renewable biogas while simultaneously addressing waste disposal concerns. This study evaluated the biogas production performance of co-digested pig dung and poultry droppings at Vision Farm, Ogbeke Nike, Enugu State, Nigeria (6.52°N, 7.55°E). A batch anaerobic digestion experiment was conducted using a 3.5 m^3 PVC biodigester. The digester was charged with 656.26 kg of mixed substrates diluted with 1968.75 L of water at a water to waste ratio of 3:1, with 75% of the digester volume occupied by slurry and the remaining 25% serving as gas headspace. Biogas production was monitored daily for 30 days using the water displacement method. Ambient temperature, slurry temperature, and slurry pH were recorded daily. Cumulative biogas production reached 6452.6 L with an average daily yield of 215.1 Ld^{-1}. Peak production of 571.5 L was recorded on day 14. Ambient temperature ranged from 30.5 - 37.0 °C, slurry temperature from 35.0 - 47.0 °C, and pH from 6.03 to 6.90, all consistent with favorable mesophilic conditions for methanogenic microbial activity. Flammable gas was confirmed from day 8, indicating active methane formation. These results demonstrate that anaerobic co-digestion of pig and poultry wastes can effectively generate renewable energy for farm applications under tropical conditions.

Keywords: Anaerobic Co-Digestion, Biogas Production, Pig Dung, Poultry Droppings, Batch Digestion.

1.0 INTRODUCTION

Livestock production plays a critical role in global food security and rural livelihoods; however, the rapid intensification of the livestock sector has generated enormous quantities of animal wastes that pose considerable environmental and public health risks when improperly managed (Gerber, 2013). According to the Food and Agriculture Organization, global livestock manure production contributes approximately 14 - 18% of anthropogenic greenhouse gas emissions, primarily as methane (CH_4) and nitrous oxide (N_2O) (FAO, 2022). In many developing countries, including Nigeria, livestock wastes are commonly disposed of through open dumping, land application without treatment, or discharge into water bodies, resulting in odor nuisance, groundwater contamination, and the proliferation of pathogenic microorganisms (UNEP, 2021). Anaerobic digestion (AD) has emerged as a technically proven and environmentally sustainable technology for the valorization of organic wastes (Eze, et al 2010). The process involves the sequential biological degradation of organic materials by consortia of microorganisms in an oxygen-free environment, ultimately producing biogas and digestate (Harirchi et al, 2022). Biogas typically contains 50 - 70% methane, 30 - 45% carbon dioxide, and trace gases, making it a valuable renewable energy source for heating, electricity generation, and cooking (IEA, 2020). The digestate is rich in macro- and micro-nutrients and can serve as an organic fertilizer, contributing to soil fertility improvement and reduced dependence on synthetic inputs (Li et.al., 2024). Global interest in biogas technology has intensified significantly in recent years. According to the International Energy Agency, global biogas production exceeded 35 billion cubic meters in 2023, driven by increasing demand for low-carbon energy solutions (IEA, 2024). Bioenergy, including biogas, accounted for nearly 55% of the total global renewable energy supply in 2024, underscoring its strategic importance in decarbonizing energy systems (IREA, 2024). Despite this global momentum, the adoption of anaerobic digestion in many sub-Saharan African countries remains constrained by technical, financial, and awareness related barriers. Substrate co-digestion is widely recognized as an effective strategy for enhancing anaerobic digestion performance. Co-digestion involves the simultaneous digestion of two or more organic substrates, improving nutrient balance, buffering capacity, microbial diversity, and biogas yield compared to mono-digestion. Pig dung and poultry droppings represent two of the most abundantly produced livestock wastes in intensive farming systems in Nigeria. Pig manure is characterized by high moisture content and readily biodegradable organic compounds, whereas poultry droppings are rich in nitrogen and microbial nutrients (Akinbile et al, 2023). Their combination can provide a more balanced carbon to nitrogen (C/N) ratio generally optimal between 20:1 and 30:1 which is essential for stable and efficient methanogenic activity (Ayantokun, et al 2025, Akinbile et al, 2023). Several previous studies have reported enhanced methane yield when pig and poultry wastes are co-digested compared to their individual digestion. Empirical trials conducted in 2023 demonstrated that blending approximately 40% poultry waste with 60% swine wastewater increased methane production by more than 20% relative to mono-digestion of poultry waste alone (Adewuyi et.al, 2024).

Furthermore, research on co-digestion of pig manure and rice straw under optimized conditions achieved cumulative biogas yields of up to 553.79 mLg^{-1} VS, illustrating the synergistic potential of substrate blending (Tian et.al, 2023). Microbial community dynamics during co-digestion have been shown to support diverse syntrophic interactions between hydrolytic bacteria, acetogens, and methanogenic archaea, thereby sustaining efficient conversion of complex organic substrates to methane (Ayantokun et.al, 2025). In Nigeria, the energy demands of medium-scale livestock farms including lighting, water pumping, feed processing, and heating are predominantly met using petrol or diesel generators, which are both costly and environmentally polluting (FMARD, 2023). The Nigerian electricity supply sector has been characterized by chronic unreliability and increasing fossil fuel costs, making on-farm renewable energy generation increasingly attractive (NERC, 2024). Integration of biogas systems within livestock operations offers a practical approach to simultaneously addressing waste management challenges and reducing reliance on fossil fuels (Singh et.al, 2025). Despite the considerable potential of Nigerian livestock waste for bioenergy, practical implementation of farm-scale biogas systems remains limited (Nnabuchi, et al 2012). Most existing studies have focused on laboratory-scale or small-scale digester experiments, with few investigations evaluating system performance under real operational farm conditions. This gap showa the need for applied research conducted under actual farm environments to generate practical data for technology adoption.

Therefore, this study evaluated the performance of anaerobic co-digestion of pig dung and poultry droppings under batch conditions at Vision Farm, Enugu State, Nigeria. Specific objectives were: (i) to characterize the daily biogas production profile over a 30day retention period; (ii) to evaluate the influence of major operational parameters including ambient temperature, slurry temperature, and pH on digestion performance; and (iii) to assess the feasibility of utilizing the produced biogas for on-farm energy applications.

2.0 METHODOLOGY

2.1 Study area and substrate source

The study was conducted at Vision Farm located in Ogbeke Nike, Enugu East Local Government Area, Enugu State, Nigeria (Latitude 6.52°N; Longitude 7.55°E). The area lies within the tropical rainforest climatic zone, characterized by warm ambient temperatures and moderate to high annual rainfall, which is conducive to year round livestock production operations. Vision Farm operates a medium scale integrated livestock production system comprising approximately 100 pigs (weaners, growers, and matured animals) and 1,000 layer birds. Based on daily monitoring, the farm generates a mean of 233.6 kgd^{-1} of pig dung and 179.0 kgd^{-1} of poultry droppings, corresponding to a combined daily waste generation of approximately 403.6 kgd^{-1}. These wastes formed the substrates for the anaerobic co-digestion experiment. Table 1 shows the material and equipment used for this work.

Table 1: Specification of materials used in the studies

S/N	Material	Description/Specification	Function/Use in Study
1	Weighing Scale	Camry 20 kg analog spring scale (0.1 kg sensitivity)	Used to measure the quantity of animal waste generated; ensured accurate and consistent data recording in kg
2	Digester Tank	3.5 m³ PVC tank modified with inlet, outlet, gas channel, and pressure control system	Served as the anaerobic digestion chamber for biodegradation of pig and poultry wastes and biogas production
3	Biogas Storage Tube	Flexible rubber tubes	Used for temporary storage of produced biogas; allowed visual monitoring of gas accumulation through inflation
4	Biogas Scrubber	Two-chamber purification unit (NaOH solution and iron filings)	Purified raw biogas by removing CO_2, H_2S, and NH_3, thereby increasing methane concentration
5	Digital Gas Analyzer (PG-300)	Portable analyzer by Horiba	Measured methane content of biogas to assess gas quality after purification
6	Gas Compressor	Electrically powered compressor	Increased biogas pressure for efficient transfer from digester to storage system
7	Biogas Booster Pump	Gas pressure stabilization pump	Maintained steady gas flow and pressure from storage to generator for efficient combustion
8	Thermometer	Standard temperature measuring device	Measured ambient and slurry temperatures to monitor digestion conditions
9	pH Meter	Digital pH measuring instrument	Monitored acidity/alkalinity of slurry to ensure optimal anaerobic digestion and prevent process inhibition

2.2 Biodigester Design and Construction

A batch anaerobic biodigester was fabricated using a 750 gallon PVC GeePee tank with a total volumetric capacity of 3.5 m³ (3500 L). The digester was designed to provide adequate working volume for slurry digestion while maintaining sufficient headspace for biogas accumulation during the digestion process. The biodigester system was equipped with: (i) an inlet chamber for slurry loading; (ii) an outlet chamber for digestate discharge; (iii) gas collection and outlet pipelines; and (iv) monitoring ports for daily measurement of operational parameters. The system was constructed to maintain airtight conditions necessary for sustaining the obligately anaerobic microbial consortia responsible for methane production. The design sketch and the pictorial form of the biogas is shown in figure 1a and 1b respectively.

Figures 1(a and b): Biogas Design (A) Design Sketch (B) Pictorial View of The Biogas Digester.

2.3 Experimental procedure

The digestion experiment was conducted over a hydraulic retention time (HRT) of 30 days under batch operating conditions. Prior to loading, fresh pig dung and poultry droppings were thoroughly mixed to obtain a homogeneous substrate blend. The digester was charged with 656.26 kg of mixed substrates (pig dung and poultry droppings in naturally occurring proportions from the farm measure as shown in figure 2a and 2b) diluted with 1968.75 L of water at a water-to-waste ratio of 3:1. The resulting slurry mixture occupied approximately 2625 L (75% of total digester volume), while the remaining 875 L (25%) constituted the gas headspace for biogas accumulation. After loading, the digester was sealed to maintain strictly anaerobic conditions. Operational parameters, including ambient temperature, slurry temperature, and pH were measured daily at 14:00 h throughout the 30day digestion period.

Figures 2(a and b): Fresh Pig Dungs and Poultry Droppings

2.4 Measurement of Biogas Volume

Biogas production was quantified using the water displacement method. Biogas generated within the sealed digester was directed through a gas outlet pipe into an inverted, calibrated transparent container filled with water. Biogas production was confirmed by igniting the gas, which produced a steady blue flame, indicating the presence of combustible methane. As biogas entered the container, it displaced an equivalent volume of water, which was collected and measured volumetrically. The volume of biogas produced was determined using equation 1 (Sillero et al, 2023)

$$V_g = V_f - V_i \quad \text{......................} \quad (1)$$

where:

Vg = volume of biogas produced (L);
Vf = final water volume after displacement (L);
Vi = initial water volume before gas collection (L).

2.5 Monitoring of Operational Parameters

Biogas was evaluated using gas volume (yield), methane concentration, temperature, pH, and pressure/flow characteristics. Ambient temperature and slurry temperature were measured using a calibrated digital thermometer. Slurry pH was determined using a portable digital pH meter. These parameters were monitored to ensure that the digestion environment remained within acceptable ranges for mesophilic anaerobic microbial activity, particularly for the sensitive methanogenic archaea responsible for methane production (Ayantokun et al 2025, Lyu et al, 2018).

3.0 RESULTS AND DISCUSSION

3.1 Daily biogas production

Biogas production was monitored continuously throughout the 30day digestion period. The daily gas volumes, cumulative gas volumes, and corresponding operational parameter values are presented in Table 2.

Table 2: Daily Biogas Production and Operational Parameters During The 30day Batch Digestion

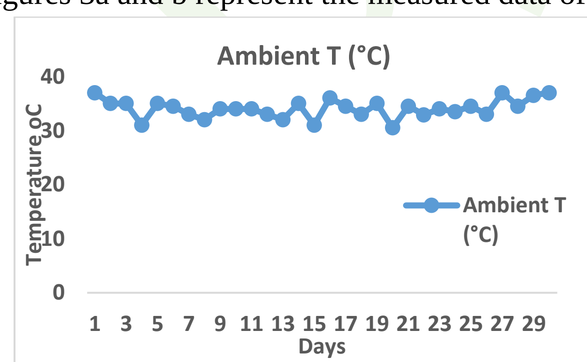
Day	Ambient Temp (°C)	Slurry Temp (°C)	pH	Gas Volume (L)	Cumulative Gas (L)
1	37	42	6.03	7.2	7.2
2	35	42	6.65	86.8	94
3	35	43	6.69	115.7	209.7
4	31	35	6.71	79.6	289.3
5	35	40.5	6.69	94	383.3
6	34.5	39	6.66	28.9	412.2
7	33	40	6.66	79.6	491.8
8	32	42	6.67	101.3	593.1
9	34	42	6.69	180.8	773.9
10	34	42	6.72	202.6	976.5
11	34	41.5	6.76	260.4	1236.9
12	33	38	6.82	282.1	1519

Day	Ambient Temp (°C)	Slurry Temp (°C)	pH	Gas Volume (L)	Cumulative Gas (L)
13	32	43	6.87	477.4	1996.4
14	35	44	6.85	571.5	2567.9
15	31	42	6.85	477.4	3045.3
16	36	44	6.85	520.9	3566.2
17	34.5	38.5	6.87	289.4	3855.6
18	33	37.5	6.89	144.7	4000.3
19	35	44	6.89	173.6	4173.9
20	30.5	35.2	6.89	108.5	4282.4
21	34.5	41	6.87	180.9	4463.3
22	32.9	41	6.90	195.3	4658.6
23	34	41.5	6.85	180.8	4839.4
24	33.5	41.5	6.79	296.6	5136
25	34.5	41	6.75	217	5353
26	33	40	6.82	180.9	5533.9
27	37	44	6.89	231.5	5765.4
28	34.5	43	6.85	180.8	5946.2
29	36.5	44	6.89	246	6192.2
30	37	47	6.89	260.4	6452.6

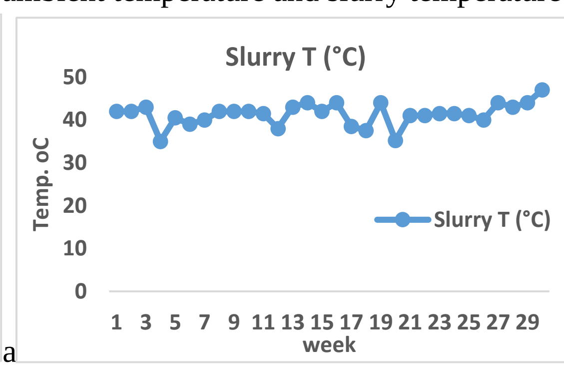
Biogas production increased progressively throughout the digestion period (table 2). Cumulative biogas production reached 6452.6 L over 30 days, with a mean daily production of 215.1 Ld^{-1}. The lowest daily production of 7.2 L was recorded on day 1, while the highest production of 571.5 L was achieved on day 14. After the peak, production showed a general declining trend with intermittent fluctuations, reflecting the gradual depletion of readily biodegradable organic substrates in the closed batch system.

3.2 Ambient Temperature and Slurry Temperature

Figures 3a and b represent the measured data of ambient temperature and slurry temperature (°C).



a



b

Figures 3a and b: Graphical representation of ambient and slurry temperature over a 30days experiment.

Ambient temperature during the experiment ranged from 30.5 °C to 37.0 °C as shown in figure 3a, while slurry temperature varied between 35.0 °C and 47.0 °C as shown in figure 3b (table 2). Slurry temperatures consistently exceeded ambient temperatures, likely due to the exothermic metabolic activity of microbial consortia within the sealed digester and heat retention within the insulated PVC tank.

3.3 Slurry pH

Figure 4 show a graphical representation of a slurry temperature, measured during the process of 30days experiment.

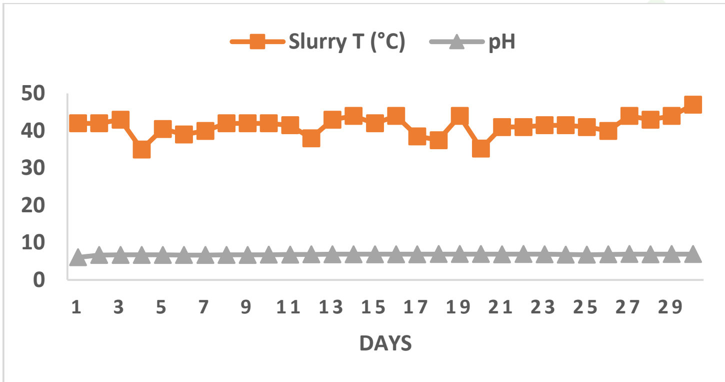


Figure 4: slurry pH measurement

Slurry pH values recorded throughout the digestion period ranged from 6.03 on day 1 to 6.90 on days 22, 27, 29, and 30 (figure 4, table 2). The initial low pH observed on day 1 is consistent with the onset of acidogenic activity and the production of volatile fatty acids (VFAs) during the early hydrolysis and acidogenesis stages. pH values gradually increased and stabilized in the range of 6.65 - 6.90 from day 2 onward, reflecting the progressive buffering capacity of the co-digested substrate mixture and the establishment of methanogenic conditions.

3.4 Discussion

3.4.1 Biogas production dynamics

The progressive increase in biogas production observed during the initial phase of digestion is characteristic of batch anaerobic digestion systems and is attributable to the lag phase of microbial growth and adaptation to the digestion environment (Angelidaki, 2018). During the first few days, hydrolytic and acidogenic microorganisms decompose complex organic polymers into simpler monomers and volatile fatty acids, generating conditions progressively more favorable for methanogenic archaea (Harirchi et.al, 2022). The relatively low gas production on day 1 (7.2 L) is consistent with limited methanogenic activity during the early adaptation phase, a pattern widely reported in batch digestion studies (Tian, et al 2023, Akinbile, et al 2023). Peak biogas production of 571.5 L was recorded on day 14, corresponding to the period of maximum microbial metabolic activity and highest substrate degradation rate. This peak production day falls within the range of 10 - 18 days commonly reported for batch co-digestion of pig and poultry wastes under mesophilic conditions (Adewuyi, et al 2024, Singh, et al 2025). Following the peak, the progressive decline in daily biogas yield is attributable to the depletion of readily biodegradable organic matter in the closed batch system, as the readily fermentable fractions of the substrate are exhausted over time (Tian et.al, 2023). The average daily biogas yield of 215.1 Ld^{-1} produced from 656.26 kg of mixed substrate is comparable to yields reported in similar studies. Batch co-digestion of animal manure substrates under tropical conditions typically yields between 150 and 300 Ld^{-1} depending on substrate composition, loading rate, and system configuration (Akinbile, et al 2023, Adewuyi, et al 2024). The total cumulative yield of 6452.6 L over 30 days demonstrates effective substrate valorization within the batch system.

3.4.2 Effect of Temperature On Digestion Performance

The temperature conditions recorded during this study were consistent with the mesophilic digestion range. Mesophilic anaerobic digestion is widely recognized as operating optimally between 30 °C and 40 °C, conditions under which microbial communities are more stable and diverse, and the process is more robust to substrate composition fluctuations (Ayantokun, et al 2025, Lyu, et al 2018). The ambient temperature at the study site (30.5 - 37.0 °C) was therefore naturally conducive to mesophilic digestion, without the requirement for external heating an important practical advantage for farm-scale systems in tropical regions. Slurry temperatures consistently exceeded ambient temperatures throughout the experiment (35.0 - 47.0 °C), reaching upper mesophilic or lower thermophilic ranges on several days. This elevated slurry temperature is likely due to exothermic microbial metabolic processes within the sealed digester and the thermal insulation properties of the PVC tank. Research indicates that methane production rate increases with temperature within the mesophilic range, as higher temperatures accelerate enzymatic reactions and substrate hydrolysis (Ayantokun, et al 2025, Angelidaki, et al 2018). The observed correlation between days of elevated slurry temperature (days 13-16, 27, 29-30) and increased biogas production supports this relationship.

3.4.3 Effect of pH on digestion performance

The pH trajectory observed in this study followed the classical pattern of batch anaerobic digestion. The initial acidic pH on day 1 (6.03) reflected the early dominance of hydrolytic and acidogenic activity, during which volatile fatty acids accumulate and suppress pH (Harirchi et.al, 2022). The rapid pH recovery to the range of 6.65 - 6.90 from day 2 onward indicates effective buffering of the co-digested substrate mixture, attributable to the ammonia released during protein hydrolysis of the nitrogen-rich poultry droppings. This buffering effect of nitrogen-rich substrates in co-digestion is a well-established advantage of mixing poultry waste with pig manure (Akinbile, et al 2023, Adewuyi, et al 2024). Methanogenesis is known to be sensitive to pH, operating optimally between pH 6.5 and 8.0, with the highest methane concentrations generally obtained near neutral pH (Nnabuchi et al 2012, Singh et al 2025). The pH values recorded in this study (predominantly 6.65 - 6.90 after day 2) fell within this functional range, confirming favorable conditions for methanogenic archaea. The overall pH stability throughout the experiment indicates a well-balanced microbial community capable of sustaining efficient methanogenesis.

3.4.4 Flammability confirmation and methane formation

Flammable biogas was confirmed from day 8 of digestion onward as shown in figure 3.3. This corresponds to the period of significant increase in daily gas production (from 101.3 L on day 8) and the transition from primarily acidogenic to active methanogenic conditions in the digester. The lag period of approximately 7 days before methane rich biogas formation is typical of batch anaerobic digestion systems without inoculation, where methanogenic archaea populations require time to establish after initial acidification (Ayantokun et.al, 2025). The gas were stored in a tube and gradually discharged using a burner as shown in figure 3.3.

Figure 5: Flame test (gas stored in the tube)

3.4.5 Implications for Farm Energy Applications

The average daily biogas production of 215.1 Ld^{-1} represents a meaningful renewable energy output for a medium scale farm operation. At standard biogas calorific values and conversion efficiencies, this daily yield could contribute to farm lighting, water heating, and supplementary cooking fuel needs. Integration of anaerobic digestion systems in Nigerian livestock farms such as Vision Farm would reduce dependence on fossil fuel-based generators, lower operational energy costs, and contribute to farm sustainability by converting waste liabilities into energy assets (Lyu et al 2018, NERC 2024). The digestate produced as a co-product also represents a valuable organic fertilizer for crop production within an integrated farm system.

4.0 CONCLUSIONS

This study evaluated the anaerobic co-digestion of pig dung and poultry droppings for biogas production in a batch digestion system under real farm conditions at Vision Farm, Enugu State, Nigeria. The following conclusions were drawn from this work; (a) anaerobic co-digestion of pig dung and poultry droppings successfully produced 6452.6 L of biogas over a 30day retention period, with a mean daily production rate of 215.1 Ld^{-1}, (b) Peak biogas production of 571.5 L was recorded on day 14, consistent with the establishment of active methanogenic populations following the initial acidogenesis phase, (c) ambient temperature (30.5 - 37.0 °C), slurry temperature (35.0-47.0 °C), and pH (6.03-6.90) all remained within ranges favorable for mesophilic anaerobic digestion, and no external temperature control was required, (d) flammable methane rich biogas was confirmed from day 8, demonstrating effective progress through the four stages of anaerobic digestion, (e) the results demonstrate the feasibility of integrating farm scale batch biogas systems in Nigerian medium scale livestock operations as a sustainable approach to waste management and on-farm renewable energy generation.

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