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(RESEARCH ARTICLE)

Development of a domestic batch bio-digester for pineapple crowns and cow dung and characterization of feedstocks

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Abstract

A large proportion of global gas consumption is derived from naturally occurring sources that are not readily available and accessible by a common man in the street. This has continued to pose serious challenges to researchers in developing suitable alternatives to the naturally occurring gas supply source. A notable problem associated with the use of gas from natural sources is that it contributes to global warming as a result of the release into the environment of the related by-products from its exploration, production, and usage. The cow dung used in this study consists of 6 % moisture, 15 ash, 96 total solids, 80 % volatile solids, 8.1 pH, and 20 % fixed solids. The result of the characterization revealed 5 % moisture, 5.2 % ash, 95 % total solid, 89 % volatile solid, 6.6 pH, and 11 % fixed solid. The pH of the mixture of PCCD is 7.4 and PCCDBC is 7.6 which is an improvement to the individual pH of cattle dung and pineapple crown. Hence, both cow dung and pineapple crowns are suitable for biogas production.

Keywords: Biogas; Cow Dung; Pineapple Crowns; Biodigester

1. Introduction

A large proportion of global gas consumption is derived from naturally occurring sources that are not readily available and accessible by a common man in the street. This has continued to pose serious challenges to researchers in the development of suitable alternatives to the naturally occurring source of gas supply (Hamzah *et al.,* 2020; Cavalli *et al.,* 2022). A notable problem associated with the use of gas from natural sources is that it contributes to global warming as a result of the release into the environment of the associated by-products from its exploration, production, and usage. It is on record that not less than 10.9×10^9 tons of carbon per year are released into the environment due to the utilization of fossil energy (Cavalli *et al.,* 2022). In an attempt to provide cleaner energy sources, gas production known as biogas from plants and animal wastes is fast gaining the attention of researchers. Biogas is a form of renewable fuel and an energy source, it is a combustible gas mixture produced during the anaerobic fermentation of biomass by bacteria (Adebayo *et al.,* 2013; Kulichkova *et al.,* 2020).

In European countries, up to 70 % of the feedstock used for biogas production comes from the agricultural sector such as dedicated energy crop (DEC), manure, and agricultural residues. According to the European Biogas Association, DEC constitutes 50 or more percent as a substrate for biogas production in Austria, Cyprus, Germany, and Latvia; for comparison, agricultural residues account for 40-60% of biogas generation in Cyprus, Germany, Denmark, France, Italy, and Poland (Kulichkova *et al.,* 2020).

Nigeria is blessed with about 1.42 million metric tonnes per year of pineapple production. The pineapple crown has continued to constitute a serious environmental problem, including landfilling and drainage blockage. This pineapple crown can be used for biogas synthesis (Efunwoye *et al.,* 2019). With an estimated 20.7 million cattle herds in Nigeria,

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the country has been ranked 5th in African cattle population. On average, a cow produces 5.4 kg of dung per day, poor management of the cow dung can result in environmental pollution (Yusuf *et al.,* 2020). The indiscriminate discharge of pineapple crowns into the environment has continued to raise concern as it constitutes a nuisance. An increase in natural gas demand for heating and other purposes has a directly proportional increase in the number of gaseous pollutants released to the environment thereby resulting in air pollution and global warming. The use of Pineapple crowns and cow dung for biogas production could be a big opportunity for Nigeria to be enlisted among the biogas producers in the world. Co-digestion is the term used to describe the anaerobic simultaneous digestion of several organic wastes in a single digester. Co-digestion is used to improve the production of methane from materials that are low-yielding or challenging to digest (i.e., feedstocks). Care must be given while choosing appropriate co-digestion feedstocks that increase methane output for the co-digestion process (and avoid materials that may inhibit methane generation). Considering the huge waste generation from both pineapple crowns and cow dung in Nigeria, this study is therefore aimed at the development of an anaerobic co-digester for biogas synthesis from these wastes.

The successful implementation of this study will lead to the conversion of agricultural waste to energy. The biogas produced is more environmentally friendly than the gas from mineral sources. Biogas production via the co-digestion process is renewable and will not require huge capital investment.

Figure 1 Pineapple Fruit

Figure 2 Fresh Cow Dung

2. Materials and methods

2.1. Materials

The pineapple crown was sourced from Lapi Market, Niger State and it was grounded with a locally fabricated grinding machine. Cow dung was collected from Mandate Market Ilorin, Kwara State and it was ground with a locally fabricated grinding machine. Tap water was sourced from Gerewu Ilorin, Kwara State. Iron steel rod was purchased from Saw mail Ilorin, while bio-char was obtained from the Mechanical Engineering Department, Kwara State University, Ilorin. Digital weighing balance, pH paper, digital thermometer, pressure gauge, high-density polyethylene drum, and gas cylinder were all purchased from J Power Tools Centre Limited, Ilorin, Kwara State.

2.2. Methods

The process flow diagram for the experimental setup is presented in Figure 3

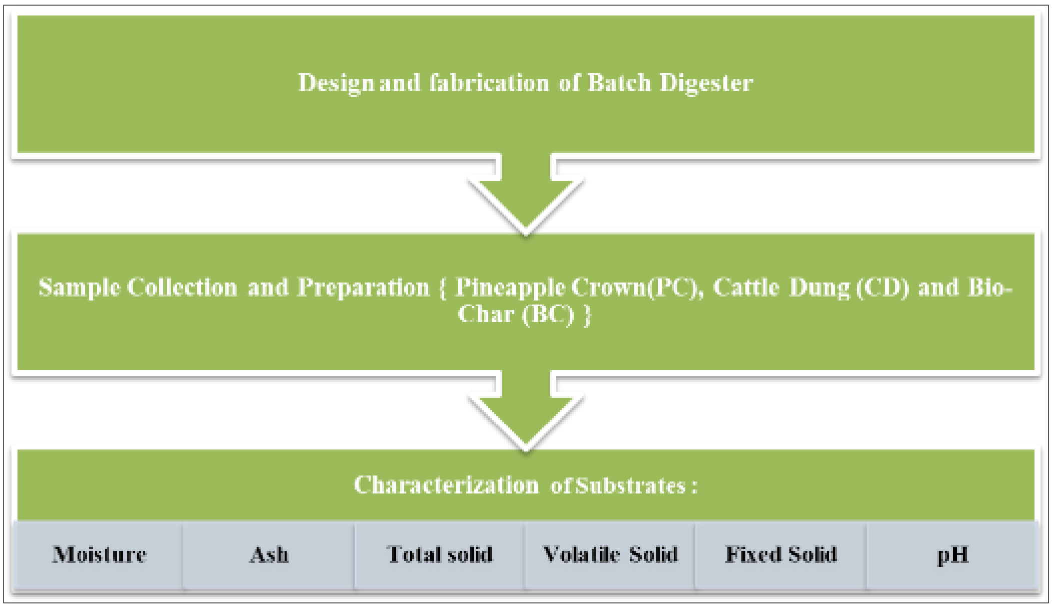

Figure 3 Flow Diagram of Batch Production of Biogas from PCCD and PCCDBC

2.3. Description and design of the digester

The construction of batch biogas digesters was done using a 170 L high-density polyethylene (HDPE) drum. A manual stirrer was fabricated and attached at the bottom, while a digital thermometer, pressure gauge, gas outlet taps, and 2" ball valve (for loading the digester) were attached at the top cover. A stand for the digester was also constructed using a 1"x 6mm flat bar and 1" square pipe.

2.3.1. Assumption made in Digester Design

Below are the lists of the assumptions made to arrive at the design of the digester:

- The height of the upper trapezium is 240 mm
- The height of the middle cylinder is 530 mm
- The height of the lower trapezium is 240 mm
- The length of the shaft is 609.6 mm
- The diameter of the shaft is
- 60 % of the digester volume will be filled with slurry while the remaining 40 % can accommodate the gas if there is a problem with the gas storage tank. This can also serve as a safety allowance
- HDPE was used for the construction of the walls of the digester due to its high corrosion resistance and low cost
- Steel (Yield stress Ys = 200 N/mm^2) was used for the construction of the mixer due to its ability to withstand corrosion and stress
- For manual agitation, the value of average human power is assumed to be 0.75 KW (4.4 Kj/min) (Jekayinfa *et al* 2014**)**
- Both the upper and bottom have equal dimension
- For manual turning, 40 RPM is assumed for crank turning (Jekayinfa *et al* 2014**)**

2.4. Detailed Design Calculation

The digester consists of three segments. Both the top and bottom segments are trapezoidal, while the middle is cylindrical. The detailed design is shown in Figures 4 and 5

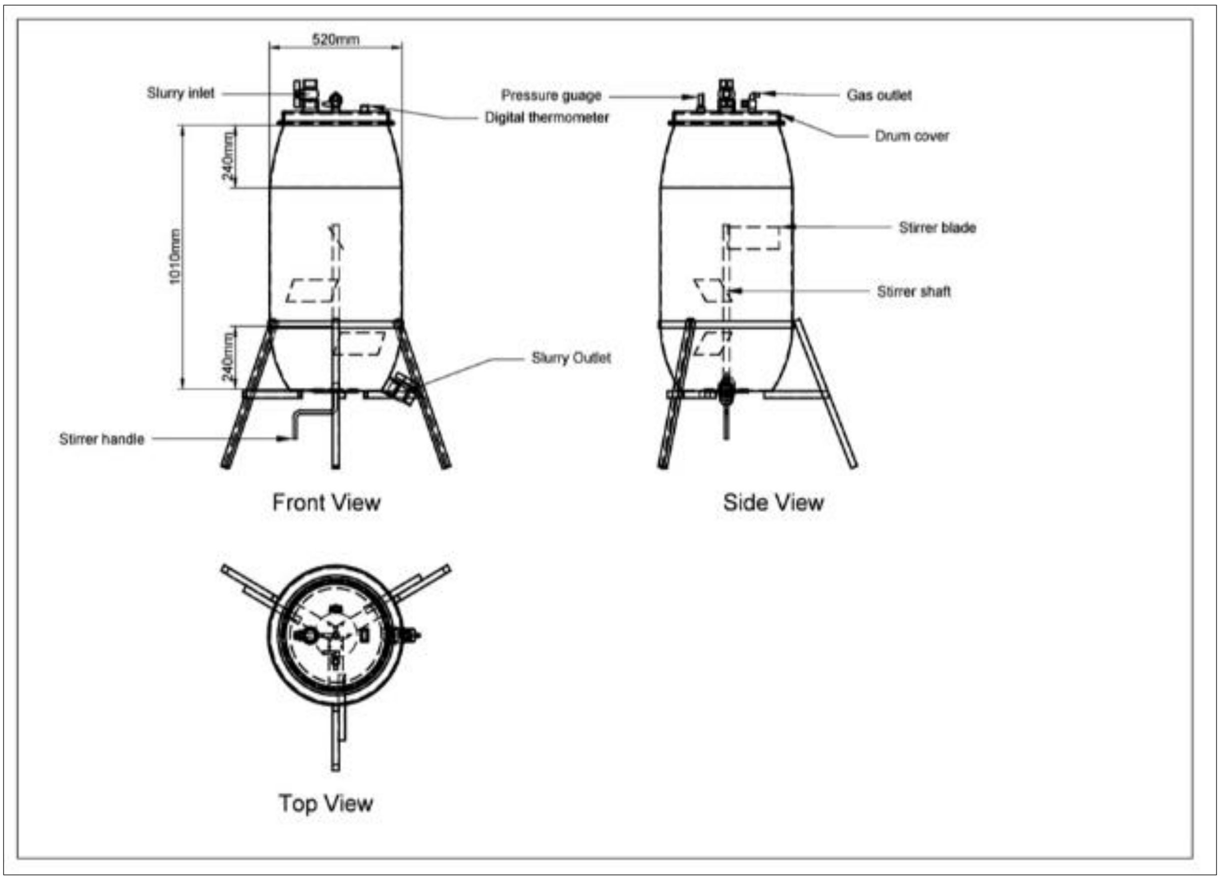

Figure 4 2D Detail Drawing of Digester

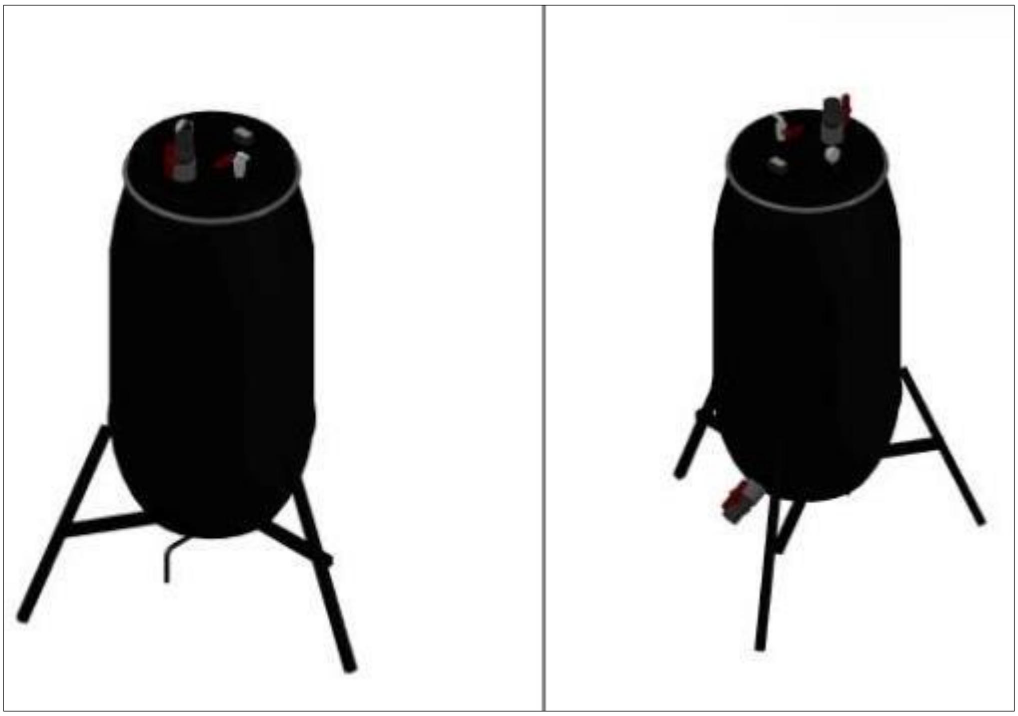

Figure 5 3D Drawing of Digester

Digester Design Calculations

Total Volume of Digester,

$$V(t) = Volume\ of\ upper\ segment\ (Vu) + volume\ of\ middle\ segment\ (Vm) + volume\ of\ bottom\ segment\ (Vb)$$

Note: since $V_u = V_b$

$$V(t) = 2(V(u)) + V(m)$$

$$V(m) = \pi r^2 h$$

- Diameter, d = 520 mm (0.52 m)
- Radius, *r* = 0.26 m
- Height, *h* = 530 mm (0.53m)

$$V(m) = 3.142 \times 0.262^2 \times 0.53$$

$$V(m) = 0.1126\ m^2$$

- The volume of the upper trapezoidal, Vt = Area of trapezoid * height
- Upper length, a = 360 mm (0.36 m)
- Base length, *b* = 520 mm (0.52 m)
- Height, *h* = 240 mm (0.24m)

$$V_{(u)} = \frac{1}{2}(a+b)h\ X\ h$$

$$V_{(u)} = \frac{1}{2}(0.36+0.52)0.24\ X\ 0.24$$

$$V_{(u)}) = 0.0253\ m^3$$

- $V_{(t)} = 2(V_{(u)}) + V_{(m)}$
- $V_{(t)} = 2(0.0253) + 0.1126 = 0.1632\ m^3 = 163.2$ L (Since $1m^3 = 1000L$)

2.5. Maximum Allowable Stress (Ms) on Steel Shaft

Equation 3…. Is used to calculate maximum allowable stress.

- Ms= 0.27Ys

Where Ys is the ultimate yield stress for steel, the value is 200 MPa (Jekayinfa *et al.,* 2014)

- $M_s = 0.27 \times 200 =$
- $M_s = 54$ Mpa
- $M_s = 8.1\ N/mm^2$

Shaft Diameter, d

$$d = \sqrt[3]{\frac{5.1T}{M_S}}$$

T = torque transmitted through the shaft

$$T = \frac{9.55\ X\ 10^6 P}{N}$$

P = 0.75 KW

N = 40 rpm

$$T = \frac{9.55\ X\ 10^{6}0.75}{40}$$

T = 179062.5 Nmm

$$d = \sqrt[3]{\frac{5.1\ X\ 179062.5}{54}}$$

$$\sqrt[3]{16911.46}$$

D = 25.67 mm

Fabrication of Flange for Biogas Digester

Two 5 mm thick 170 mm external diameter flanges with 6 holes for a 14 mm bolt and a 30 mm diameter hole at the center were fabricated. The flange was placed at the bottom of the 163.2 L drum and the areas to be drilled which are the six-hole for 14mm bolts and the 30 mm hole at the center of the flange were marked. A linear ball bearing was housed at the center of the flange, and drilling of the aforementioned was carried out with a hand drilling machine.

Fabrication of Stirrer

Three 200 mm x 100mm x 1mm stainless Plates were cut from a flat sheet for the construction of the stirrer blades (Figure 6) with the aid of a hand-cutting machine, 13mm diameter, and 600mm long shafts were cut using a hand saw. The three blades were then welded on the shafts tilted at a reasonable distance along its length. A linear ball bearing was welded at one end of the shafts and one flange was also welded to the linear bearing. Silicone gum was applied to the face of the two flanges and then held together with six 14 mm bolts and nuts, it was then tightened using a 14 mm spanner. A handle was constructed with a 13mm rod which was welded to the linear ball bearing.

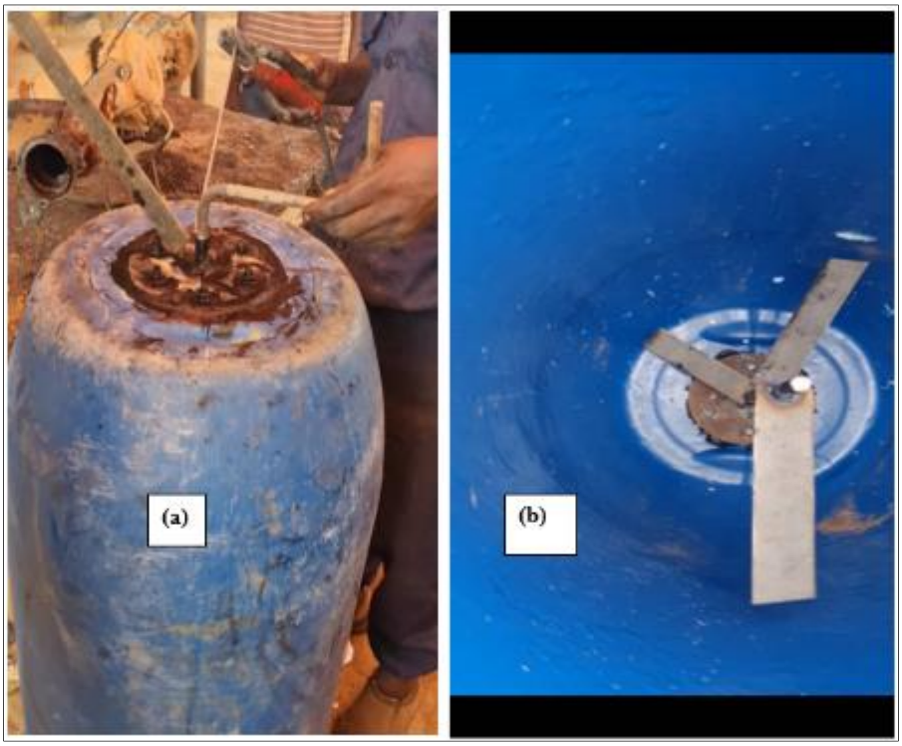

Figure 6 Installation of Stirrer to Digester (a: outside view; b: inside view)

Fabrication of Digester’s Stand

The digester stand was fabricated by cutting and bending a 1"mm flat bar to the circumference of the drum and a 1" square pipe was cut to a length of 500 mm for the legs and it's been welded together.

Modification of Gas Storage Tank

Two gas cylinders (13.6 Kg each) were modified by installing a pressure gauge (Figure 7) with calibration ranging from 20 to 300 mmHg on them. This is to ensure proper monitoring of the gas pressure in the cylinder. Silicone gum was then used to seal up all the edges to prevent gas leakage.

Figure 7 Pleasure Gauge

Digester Temperature Monitoring

A Digital liquid crystal displace thermometer (Figure 8) with measurement in centigrade temperature was attached to the digester for temperature reading. The specification of the thermometer is shown in Table 1

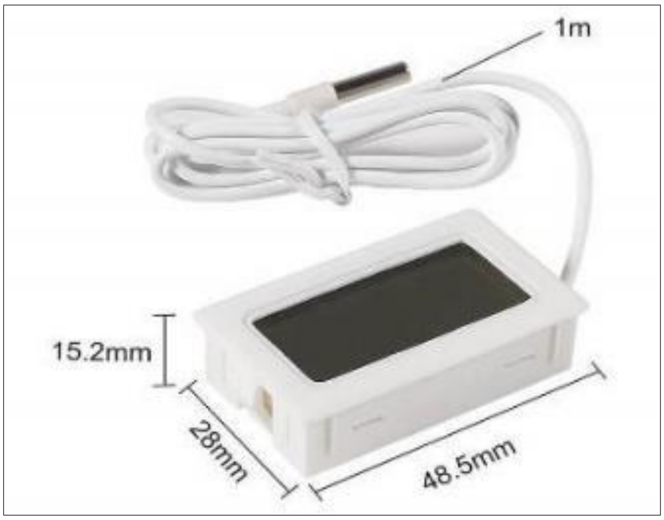

Figure 8 Digital Liquid Crystal Displace Thermometer

Table 1 Specification of Digital Liquid Crystal Displace Thermometer

Parameters	Value
Temperature Range	-50 °C to 110 °C
Temperature Accuracy	±1 °C
Operating voltage	1.5 V
Sampling period	2 seconds
Unit dimensions	48.5X28X15.2 mm
LCD Dimension	46.5*27 mm
Cable length	1 m (3.3 Feet)

2.6. Sample Collection and Preparation

The pineapple crown was collected from local fruit vendors in Lapi Market, Niger State. The pineapple crown leaves (Figure 9) were separated and washed to ensure they were free before sun drying for some days and it was ground into particle size ≤ 0.425 mm with the aid of a locally fabricated grinding machine, the weight of the ground pineapple crown is 3 kg.

Figure 9 Pineapple Crown Reduction Stages

Bio-char (Figure 10**)** from pyrolysis of sugarcane bagasse was collected at the Mechanical Engineering Department, Kwara State University, the size was reduced into nanoparticles (75.68 nm) using a ball mill machine (Figure 11) which worked for two hours.

Figure 10 Bio-char

Figure 11 Ball Mill Machine

Cow dung was collected at Mandate Market, Ilorin, Kwara State, and sun-dried for five days. The dry cow dung (Figure 12) was crushed to reduce the particle size (≤ 0.425 mm) for easy digestion.

Figure 12 Dry Cow Dung

2.7. Biogas production

2.7.1. Anaerobic Co-Digestion Mechanisms

The digesters were incubated at mesophilic (25–35 °C) conditions for a certain period. It is a multi-step biological process where the organic carbon is mainly converted to carbon dioxide and methane. The process can be divided into four steps: hydrolysis/liquefaction, acidogenesis, acetogenesis, and methanogenesis (Al-Kanmun and Torii, 2015). The mechanisms of the anaerobic digestion process as shown in Figure 13

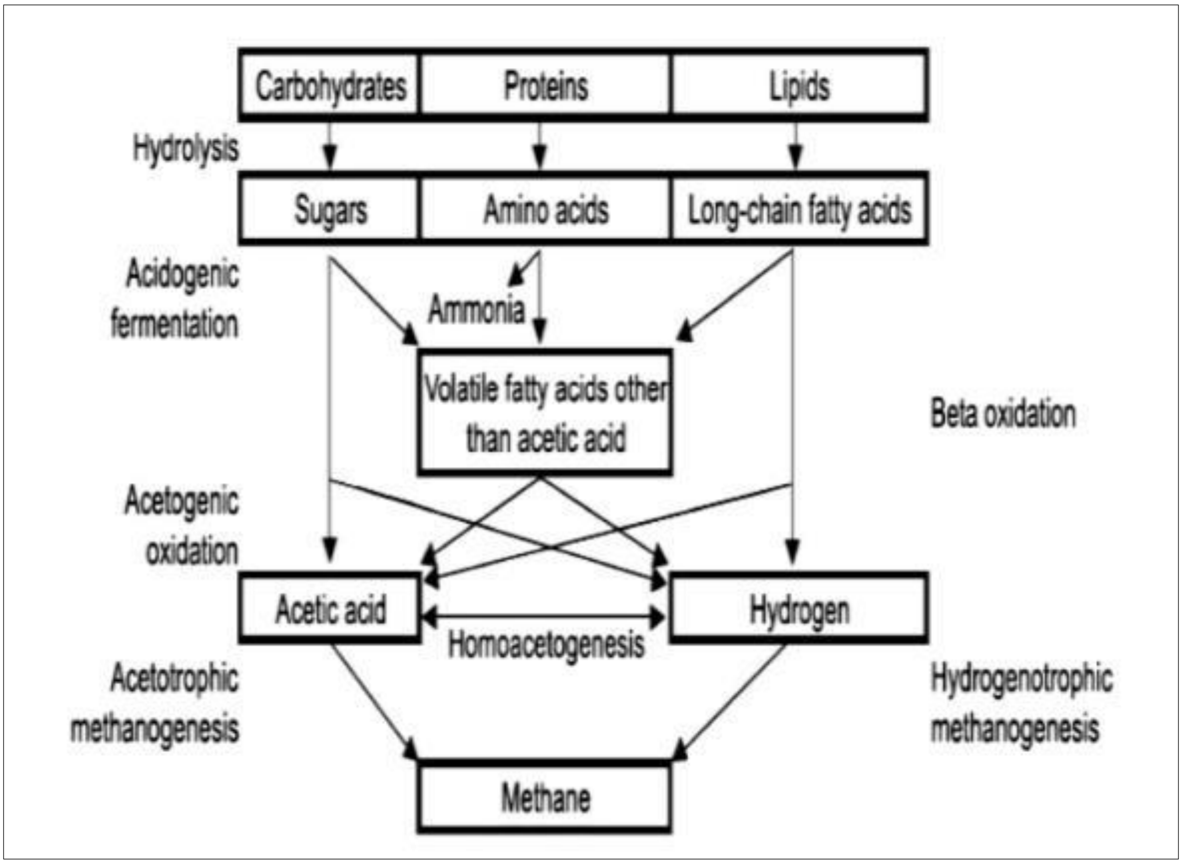

Figure 13 Anaerobic Digestion Process for the Production of Biogas (Al-Kanmun and Torii, 2015)

2.7.2. Biogas production setup

The biogas production setup in this study is divided into two stages:

First Stage Digestion (A)

Modification of the method described by Hamzah *et al.* (2020) was used for the biogas production in this study. Both the dry cow dung and dry pineapple crown were moisturized by adding water by weight of 17.1 kg and 7 kg respectively. The digester was first washed and allowed to dry. 12 % pineapple crown slurry was prepared by measuring 1.4 kg of ground pineapple crown into 10.2665 kg of water in the digester and mixed with the help of the stirrer (X). 5.833 kg of cow dung was measured into the digester and also mixed with the help of the stirrer, the mixing ratio of pineapple slurry to cow dung is 1:2. The pH of the content in the digester was monitored using a Universal pH paper. The digester was covered and the co-digestion process was allowed to continue for 21 days. The temperature of the digester was monitored with the aid of the digital thermometer while the pressure of both the digester and the gas storage tank was monitored with a pressure gauge. The biogas produced was pumped into the storage tank with the aid of the evacuation pump. The whole experimental setup is shown in (XI) below.

Figure 14 (a) Weighing of substrates and water

Figure 14 (b) Prepared Slurry **Figure 14** (c) Loading of Digester

2.7.3. Second Stage Digestion (B)

The whole procedure in the first stage of digestion was repeated with the addition of 349.99 g of biochar by 20 g/L reported by Rasapoor *et al.* (2020).

Figure 15 Experimental Setup for Biogas Production by Co-digestion Process

2.8. Characterization of Cattle Dung (CD) and pineapple crown (PC)

2.8.1. Total Solid

A known weight of cow dung was taken in a petri dish. The sample was dried at a temperature of 105 °C for 6 h. The final weight was noted, and the total solids (TS) % was taken as the percentage of the weight of the final sample/weight of the initial sample. The whole process was also used to determine the total solid in the pineapple crown and the residue left after digestion (Jeppu *et al.,* 2022).

Determination of Moisture Content

$$\text{Moisture (\%)} = \frac{w_1 - w_2}{w_3} \times 100$$

- w_2= Weight of the crucible and air-dried sample (g)
- w_1= Weight of the crucible and oven-dried sample (g)
- w_3= Weight of the air-dried sample (g)

Cow Dung (CD)

- w_1 = 43.84g
- w_2 = 43.78g
- w_3=1g

Moisture (%) = $\frac{43.84 - 43.78}{1} \times 100 = 6\%$

Pineapple Crown (PC)

- w_1 = 43.03g
- w_2 = 42.98g
- w_3=1g

$$\text{Moisture (\%)} = \frac{43.03-42.98}{1} \times 100 = 5\%$$

Determination of Total Solid (TS) (Jeppu et al., 2022).

$$Moisture\ content\ +\ TS\ =\ 100\%$$

$$TS\ =\ 100\%\ -\ Moisture\ Content$$

$$TS\ for\ CD\ =\ 100-6 = 94\%$$

$$TS\ for\ PC\ =\ 100-5 = 95\%$$

2.8.2. Volatile solids and fixed solids

To determine the volatile solids (VS) and fixed solids (FS) for CD and PC, about 1g of dried sample was ignited in a muffle furnace at 550°C for 1h. The sample was cooled in a desiccator and weighed. The ignition was repeated for 30 minutes cooled and weighed until the weight change was less than 4% (Omondi et al., 2019).

3.6.2.1 Determination of Volatile Solid and Fixed Solid

- A = mass of dry sample
- B = mass of dish
- C = weight of residue + dish after ignition

$$\text{Volatile Solid (\%)} = \left(\frac{A-C}{A-B}\right) \times 100$$

$$\text{Fixed Solid (\%)} = \left(\frac{C-B}{A-B}\right) \times 100$$

(Jeppu et al., 2022)

Cattle Dung

- A = 42.84g
- B = 41.84g
- C = 42.04g

$$\text{Volatile Solid (\%)} \left(\frac{42.84-42.04}{42.84-41.84}\right) \times 100 = \frac{0.8}{1} \times 100 = 80\%$$

$$\text{Fixed Solid (\%)} = \left(\frac{42.04-41.84}{42.84-41.84}\right) \times 100 = \frac{0.2}{1} \times 100 = 20\%$$

Pineapple Crown

- A = 42.8g
- B = 41.8g
- C = 41.91g

$$\text{Volatile Solid (\%)} = \left(\frac{42.8-41.91}{42.8-41.8}\right) \times 100 = \frac{0.89}{1} \times 100 = 89\%$$

$$\text{Fixed Solid (\%)} = \left(\frac{41.91-41.8}{42.8-41.8}\right) \times 100 = \frac{0.11}{1} \times 100 = 11\%$$

2.8.3. Ash Content

Apparatus and Procedure for the determination of Ash

Apparatus

- Muffle Furnace (figure 16)
- Porcelain Crucibles

Procedure

- Weigh the crucible and record weight to 2 decimal places.
- Weigh approximately 2g into the crucible.
- Record weight to 4 decimal places.
- Cool in a desiccator and weigh within 1h after reaching room temperature.
- Weigh the ashed sample and record weight to 2 decimal places
- Calculate % Ash and record the value with one decimal. (Jeppu *et al.,* 2022)

2.9. Calculation of % Ash

- M_1 = crucible weight
- M_2 = crucible + sample weight
- M_3 = ash weight

$$\text{Ash (\%)} = \left(\frac{M3-M1}{M2-M1}\right) \times 100$$

Cattle Dung

- M_1 = 41.84g
- M_2 = 42.84g
- M_3 = 41.99g

$$\text{CD Ash (\%)} = \left(\frac{41.99-41.84}{42.84-41.84}\right) \times 100 = \frac{0.15}{1} \times 100 = 15\%$$

Pineapple Crown

- M_1 = 41.84g
- M_2 = 42.8g
- M_3 = 41.89g

$$\text{PC Ash (\%)} = \left(\frac{41.89-41.84}{42.8-41.84}\right) \times 100 = \frac{0.05}{0.96} \times 100 = 5.2\%$$

Figure 16 Muffle Furnace and Crucible

2.9.1. pH Determination

Distilled water of mass 51g was weighed and poured into a 250 mL beaker. The value of the pH was determined with a pH meter after 10 minutes and after 24 hours which resulted in a pH of 7.0. (Jeppu *et al.,* 2021) Cow dung of mass 28.5g was weighed and poured into a 250 mL beaker containing 85.5 ml of water and stirred. The value of the pH was determined with a pH meter after 10 minutes and after 24 hours which resulted in a pH of 8.1.

Pineapple crown of mass 7g which was weighed and poured into a 250 mL beaker containing 35 ml of water and stirred which resulted in a pH of 6.6.

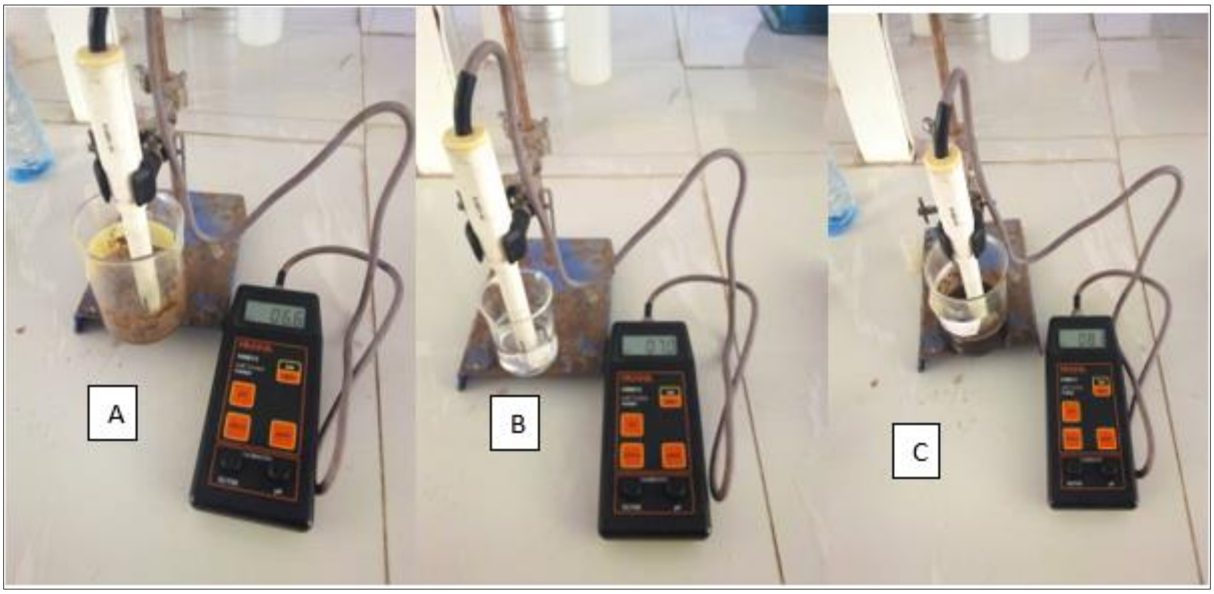

Figure 17 pH Determination of (A) Pineapple Crown (PC), (B) Water, and (C) Cattle Dung (CD)

The pH of the mixture (figure 17) of cow dung, pineapple crown and water in the digester was first measured after 10 minutes which resulted in a pH of 7.4.

The whole procedure was repeated with the addition of 2 g of bio-char which resulted in a pH of 7.6.

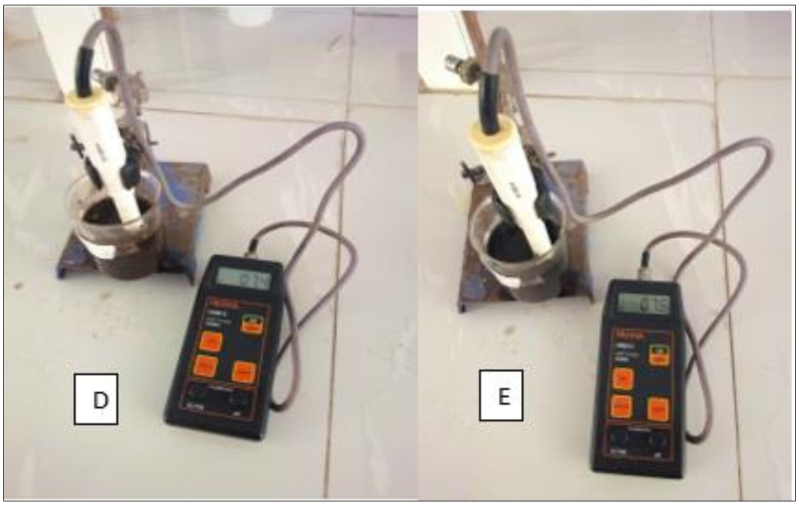

Figure 18 Experimental setup for pH of (D) PCCD and water (E) PCCDBC and water

2.9.2. Determination of Bio-Char Particle Size

The average size of the biochar was determined according to the method described by Guo *et al*. (2020). Biochar suspension was formed with water before subjecting it to dynamic light scattering (DLS, Malvern Nano-ZS).

3. Results and discussion

3.1. Characterization of feedstocks for biogas generation

The results of the analysis for both pineapple and cow dung are presented in Table 2

Table 2 Characterization of Cow Dung and Pineapple Crown

Parameter	Cow Dung	Pineapple Crown
Moisture (%)	6.00	5.00
Ash (%)	15.00	5.20
Total solid (%)	94	95
Volatile Solid (%)	80.00	89
Fixed Solid (%)	20.00	11.00
pH	8.1	6.6

3.1.1. Moisture Content

The moisture content provides relevant information on the amount of water that is present in semisolid or solid material. The knowledge of the moisture content serves as the basis for the amount of water that is required to prepare the substrate for the co-digestion process. The moisture content of cow dung (6 %) is higher than that of pineapple crown (5 %) The low moisture content indicates that the samples can be preserved over a long period without much deterioration (ref).

3.1.2. Ash Content

The ash content of any organic material is the inorganic or mineral component left after the material has been subjected to elevated temperature. The ash content of cow dung of 15 % in this study is higher than the 5.2 % of pineapple crown. The ash content of the cow dung in this study is within the 11.62 to 32.16 % reported by Maj *et al.,* 2021, while the ash content of pineapple crown in this study is close to the 4.5 % reported by Daud *et al.* (2014).

3.1.3. Total solid

A high total solid value indicates that there is a low water content in the sample, while a low total solid content shows that there is a high-water content. The 94 % total solid in cow dung is much higher than the 15.32 % reported by Anhuradha and Mullai (2010) but is slightly above the 81.86 % reported by Hamzah *et al.* (2020). The total solid of 95 % of removal of pineapple crown in this study is above 79.35 % for pineapple waste by Hamzah *et al.* (2020). The total solid in cow dung in this study is slightly above that of pineapple crown.

3.1.4. Volatile Solids (%)

Substances that can be easily converted directly from the solid phase to the vapor phase without passing through the liquid phase are referred to as volatile solids. The volatile solids of 89 % of pineapple crown and 80 % of cow dung in this study are considerably high, however, the volatile solids in pineapple are slightly higher than that of cow dung. The volatile solid of pineapple crown in this study is much higher than the 4.95 % for pineapple waste reported by Hamzah *et al.* (2020) but slightly lower than the 95.9 % for pineapple (Rani and Nand, 2004). The volatile solid of cow dung in this study is very close to the 77.5 % reported by Anhuradha and Mullai (2010), but is much higher than the 6.25 % for cow dung reported by Hamzah *et al.* (2020).

3.1.5. Fixed Solids (%)

Fixed solids, otherwise known as inorganic ash is the measure of solid matter that remains after the total dissolved solids have been evaporated (Omondi 2021). The 20 % fixed solids content of cow dung is in total agreement with the report by Hamilton and Zhang (2023) that fresh manure has 20 % fixed solids. However, the value of the fixed solids of cow dung is above 11 % for pineapple crowns.

3.1.6. pH

The methane-producing bacteria live best under neutral to slightly alkaline conditions, the required pH for anaerobic digestion ranges between 6.8 and 8.5. The pH values for cattle dung used in this experiment is 8.1 which is slightly alkaline and pineapple crown is 6.6 which is acidic. The pH of the mixture of PCCD is 7.4 and PCCDBC is 7.6 which is within the required pH for Biogas generation, with that the method of anaerobic co-digestion employed in this experiment was able to produce a more desired pH for biogas generation.

3.1.7. Particle size determination of Bio-Char using Dynamic Light Scattering

Biochar is a stable carbon-rich material (Guo *et al.,* 2020). The average particle size distribution by intensity was investigated by Dynamic Light Scattering (DLS) and the result is presented in Figure 19 while the other data generated is presented in Appendix. The Z-Average of 75.68 nm represents (represents)the average particle size of the biochar. Nanoparticles are particles with particle sizes ranging from 1-100 nm, this indicates that the biochar used for the co-digestion in this study is nanoparticle in size. The nanoparticle size in this study is much higher than the 4 nm and 5 nm for cattle manure and soybeans reported by Guo *et al.* (2020). Nanoparticle size between 2 nm and 50 nm is called mesopores and is considered Type IV isotherm (*Thommes et al.,* 2015). Highly developed mesoporous carbon materials are more suitable for the adoption of larger molecules such as dyes (Kumar and Jena *et al.,* 2016).

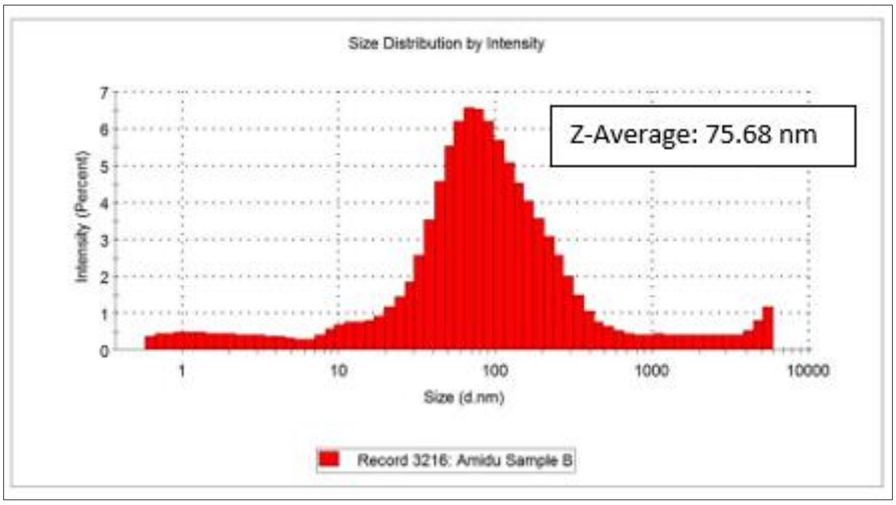

Figure 19 Bio-char Nanoparticle Distribution

4. Conclusion

It can be concluded in this study that the cow dung used in this study consists of 6 % moisture, 15 ash, 96 total solid, 80 % volatile solid, 8.1 pH, and 20 % fixed solid. The result of the characterization revealed 5 % moisture, 5.2 % ash, 95 % total solid, 89 % volatile solid, 6.6 pH, and 11 % fixed solid. The pH of the mixture of PCCD is 7.4 and PCCDBC is 7.6 which is an improvement to the individual pH of cattle dung and pineapple crown. Hence, both cow dung and pineapple crowns are suitable for biogas production.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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