

PAPER 126 – Production of Biogas from Anaerobic Co-Digestion of Pineapple Crown and Cattle Dung in A Batch Digester

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ABSTRACT

Biogas production from agricultural waste is gaining more attention from researchers in the biofuel industry. However, many of the findings from biogas production have not been implemented, especially in the rural area where the agricultural waste is mostly available. This study was aimed at the determination of the influence of biochar (BC) on biogas yield from anaerobic co-digestion of pineapple crown (PC) and cattle dung (CD) using a domestic batch digester. The feeds were characterized to determine moisture content, ash yield, total solid, volatile solid, fixed solid content, and pH. The nanoparticle size of biochar was determined using Dynamic Light Scattering (DLS) instrument. In the first experimental setup, biogas was produced from anaerobic co-digestion of PC and CD in the fabricated batch digester, while biogas was also produced in the anaerobic co-digestion of PC and CD in the presence of BC. Biogas was collected at 30- and 45-days hydraulic retention time (HRT). The gas analyzer revealed the major composition of the incombustible biogas from PCCD at 30 days HRT to be CH₄ (50.38 %), while PCCDBC has CH₄ (40.38 %). At forty-five days HRT, a combustible biogas was produced from PCCD with 59.42 % CH₄ and 54.2 % CH₄ as major gas composition in PCCDBC. Forty-five days HRT is more suitable for the production of combustible biogas from both PCCD and PCCDBC using locally fabricated batch domestic digester. The biogas produced in this study is suitable for domestic cooking.

KEYWORDS: Agricultural wastes, Biochar, Biogas, Cattle dung, Co-digestion, Pineapple crown

32. 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; Cavali *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 (Cavali *et al.*, 2022). In an attempt to providing 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 as a country is blessed with about 1.42 million metric tonnes per year of pineapple production (Efunwoye *et al.*, 2019; Baidhe *et al.*, 2021). The pineapple crown has continued to constitute a serious environmental problem which includes landfilling and blockage of the drainage. This pineapple crown can be used for biogas synthesis (Efunwoye *et al.*, 2019). With an estimated 20.7 million cattle herds in Nigeria, the country has been ranked 5th in cattle population in Africa. By the year 2050, the Nigerian cattle population is expected to be about 53.6 million (Ripples Nigeria, 2021). 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 use of Pineapple crowns and cow dung for biogas production could be a big opportunity for Nigeria to be enlisted among the biogas producer in the world. Considering the huge waste generation from both pineapple crowns and cow dung in Nigeria, this study was therefore aimed at the fabrication of an anaerobic co-digester for biogas synthesis from these wastes.

33. MATERIALS AND METHODS

2.1 Materials

Pineapple crown was sourced from Lapi Market, Niger State, Nigeria and it was ground with locally fabricated grinding machine to particle size ≤ 0.425 mm. Cow dung was collected from Mandate Market, Ilorin, Nigeria and it was ground with locally fabricated grinding machine to particle size of ≤ 0.425 mm. Bio-char was obtained from Mechanical Engineering Department, Kwara State University, Ilorin, Nigeria.

2.2 Methods

2.2.1 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 tap, 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.

2.2.2. Anaerobic Co-Digestion Mechanisms

The digesters were incubated at mesophilic (25–35 °C) conditions for a certain period of time. 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).

2.2.3. Biogas production setup

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

2.2.3.1 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 (XI). 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.

2.2.3.2 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).



Plate XIV: Experimental Setup for Biogas production by Co-digestion Process

2.2.4 Sample Characterization

The determination of moisture content, total solid, volatile solids, fixed solids, ash content, pH were done according to the reported methods by Jeppu *et al.* (2022). The average size of the biochar was determined according to the method described by Guo *et al.* (2020). The biogas composition was determined using gas analyzer.

34. RESULTS AND DISCUSSION

3.1 Characterization of Feedstocks for Biogas Generation

The result of the analysis for both pineapple and cow dung are presented in Table 1.

Table 1: 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.

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 low total solid content shows that there is 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 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 vapour 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 80 % volatile solid in this study is in total agreement with the report by Hamilton and Zhang (2023) that fresh manure is 80 % volatile. 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

Bio-char is 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 4.1, while the other data generated is presented in Appendix. The Z-Average of 75.68 nm represent the average particle size of the bio-char. Nanoparticle are particle with size ranging from 1-100 nm, this gives an indication that the bio-char 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 soybean 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 material are more suitable for adoption of larger molecules such as dyes (Kumar and Jena *et al.*, 2016).

3.2 Characterization of Biogas from PCCD AND PCCDBC

The biogas collected from the co-digestion of pineapple and cow dung as well as the one from the co-digestion of pineapple, cow dung, and bio-char in this study is categorized into combustible and non-combustible biogas.

3.2.1 Incombustible Biogas from the Co-digestion of PCCD and PCCDBC

Biogas collection was first carried out on the fifteenth day of co-digestion. The collected biogas was ignited, but it does not support combustion. Another biogas collection was done on the thirtieth day of co-digestion but it does not still support combustion. Analysis of the biogas from 30 days of co-digestion by Bio Portable Gas Analyzer revealed the composition of the biogas produced as shown in Table 2. Ten different gases were identified from both PCCD and PCCDBC co-digestion systems. Gases such as carbon monoxide (CO), nitrogen oxide (NO), nitrogen dioxide (NO₂), sulphur dioxide (SO₂), and hydrogen sulphide (H₂S) are considered to be impurities. However, the gases may not result in any serious environmental pollution as their presence is only in trace amounts. The addition of the bio-char was to minimize the formation of H₂S, however, there was no positive contribution of the bio-char to the biogas composition within the first thirty days of the gas production.

Table 2: Biogas Composition for 30 days Co-digestion from PCCD and PCCDBC

| S/N | Gas | PCCD (%) | PCCDBC (%) |
|-----|------------------|----------|------------|
| 1 | O ₂ | 1.621 | 1.213 |
| 2 | CO | 0.0037 | 0.00427 |
| 4 | CO ₂ | 2.100 | 3.200 |
| 5 | NO | 0.00116 | 0.00132 |
| 6 | NO ₂ | 0.00033 | 0.00037 |
| 7 | NOX | 0.00149 | 0.00169 |
| 8 | SO ₂ | 0.00006 | 0.00003 |
| 9 | CH ₄ | 50.38 | 40.38 |
| 10 | H ₂ S | 0.00015 | 0.001827 |

Figure 1 present the plot of the results of the major biogas composition which are methane (CH₄), carbon dioxide (CO₂), and oxygen (O₂). Oxygen is a combustible gas but its presence is low in biogas. There is not much significant difference in the oxygen content of the biogas from both the PCCD (1.621 % O₂) and PCCDBC (1.213 % O₂). CO₂ is a non-combustible gas, hence its presence might further be a setback to the combustion of the biogas produced. The CO₂ content of 2.1 % recorded in PCCD is lower than 3.2 % in PCCDBC. PCCD has a higher methane (CH₄) content of 50.38 % compared with the 40.38 % from the PCCDBC process route. This might be due to higher carbon content that might likely result from the addition of bio-char, thereby causing an imbalance in the carbon-to-nitrogen ratio (Omondi *et al.*, 2019). The non-combustibility of the biogas from both PCCD and PCCDBC at 30-day co-digestion is in agreement with the report by Agunwamba (2001) that for any biogas mixture to be combustible, the methane content must be more than 50 %.

In another study by Omondi *et al.* (2019) on biogas production from the co-digestion of water hyacinth (WH) and ruminal slaughterhouse waste (RSW), biogas production was collected for 60 days HRT. Co-digestion of WH with RSW at 1:4 and 1:5 RSW: WH ratio improved the startup rate above that for both biomass. At the 1:4 of RSW to WH ratio and 60 days residence time, there was an increase in biogas production from 87 % to 90 %. However, the percentage methane content of the biogas was not reported and it was not also documented that the biogas combusted.

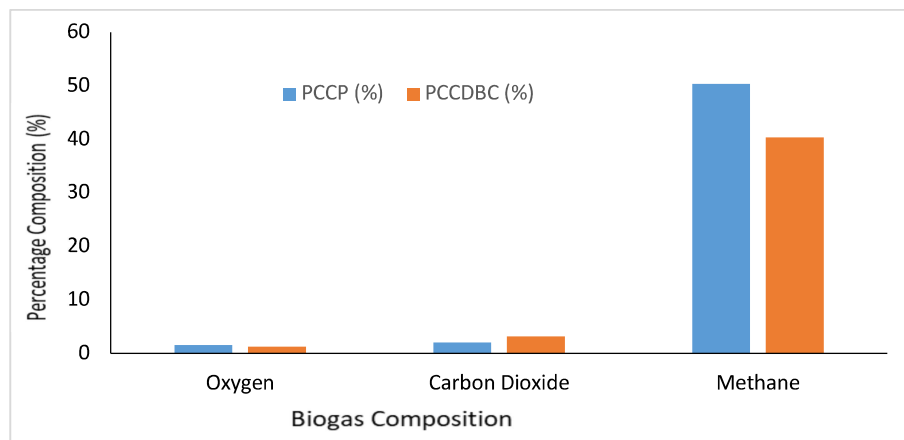


Fig 1: Biogas Composition from PCCD and PCCDBC after 30 Days of Co-digestion

3.2.2 Combustible Biogas from the Co-digestion of PCCD and PCCDBC

The third biogas collection was carried out at the forty-fifth day of co-digestion. The biogas collected from PCCDBC (Plate II) and PCCD (Plate III) combusted on espouse to fire. The biogas from PCCDBC burns with almost complete blue flame while that of PCCD burns blue and traces of yellow flames.



Plate II: Combustion of biogas from PCCDBC

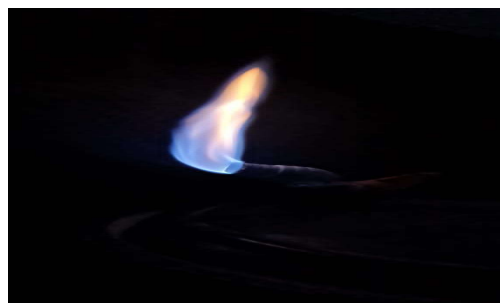


Plate III: Combustion of biogas from PCCD

Analysis of the biogas from 45 days of co-digestion by Bio Portable Gas Analyzer revealed the composition of the biogas produced as shown in Table 3. Four different gases were identified from both PCCP and PCCDBC co-digestion systems. The percentage composition of H₂S in PCCD (0.000242 %) and PCCDBC (0.000246 %) is relatively small. Hence there will be minimal environmental pollution from H₂S during the usage of the biogas. The O₂ from both PCC (0.00022 %) and in PCCDBC (0.000229 %) is considerably low, this does not constitute any challenge to the biogas combustion as sufficient O₂ from the air will combine with the biogas during its usage.

Table 3: Biogas Composition for 45 days Co-digestion from PCCD and PCCDBC

| Gas | PCCD (%) | PCCDBC (%) |
|------------------|----------|------------|
| H ₂ S | 0.000242 | 0.000246 |
| O ₂ | 0.00022 | 0.000229 |
| CO ₂ | 35.94 | 41.15 |
| CH ₄ | 59.42 | 54.2 |

Figure 2 present the plot of the results of the major biogas composition at 45 days of co-digestion which are methane (CH₄) and carbon dioxide (CO₂). The amount of CO₂ in both PCCD (35.94 %) and PCCDBC (41.15 %) is considerably high. It could therefore be inferred that a longer period of co-digestion enhances the biochemical conversion of the carbon content of the substrate into the CO₂. The presence of biochar in PCCDBC indicates higher carbon content which might also be converted to CO₂ during the co-digestion, thereby accounting for higher CO₂ in PCCDBC compared to PCCD. The CH₄ content in PCCD (59.42 %) is slightly higher than in PCCBC (54.2 %). The presence of CH₄ in both PCCD and PCCDBC is more than the required amount of >50 % CH₄ for any biogas to combust. This is the main reason for the combustibility of the synthesized biogas after 45 days.

The methane content in this study is slightly lower than the 69.89 % methane content reported by Al-Mamun and Torrii (2019) for the co-digestion of cafeteria, vegetable and fruit wastes, at mixing ratio of 1.5:0.5:1.0 and 21 days of HRT. The higher methane content by Al-Mamun and Torrii (2019) could be attributed to difference in substrate composition.

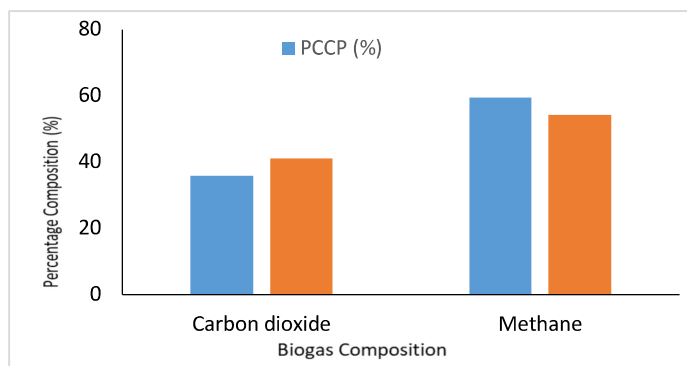


Fig 2: Biogas Composition from PCCD and PCCDBC after 45 Days of Co-digestion

The addition of bio-char did not show any significant effect on the methane content, this could be because the nanoparticle is mesoporous which is more suitable for the adsorption of bigger molecular substances (Kumar and Jena *et al.*, 2016). It is also possible that the bio-char was in excess (Torri and Fabbri, 2014).

In a study by Torri and Fabbri (2014), biochar made from maize was added to an anaerobic digestion system. The results showed that the addition of bio-char not only significantly boosted the cumulative methane yield but also enhanced the reaction rate. Similar to this, it was discovered that 10.0 g L⁻¹ of biochar was the ideal quantity and that higher levels decreased the methane output. This was primarily because moderate bio-char addition effectively reduced VFA buildup, leading to increased levels of methanogenic activity, whereas higher biochar concentrations caused more propionic acid to collect in the digester, decreasing the stability of the anaerobic digestion process.

35. 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 crown are suitable for biogas production. The major composition of biogas produced at 30 days hydraulic retention time for PCCD is 2.1 % CO₂ and 50.38 % CH₄, while that of PCCDBC are 3.2 % CO₂ and 40.38 % CH₄. At 30 days of hydraulic retention time, an incombustible gas was produced. The major composition of biogas produced at 45 days hydraulic retention time for PCCD is 35.94 % CO₂ and 59.42 % CH₄, while that of PCCDBC is 41.15 % CO₂ and 54.2 % CH₄. At 45 days of hydraulic retention time, a combustible gas was produced which is suitable for domestic uses.

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