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# Optimization of Biogas production by Co-Digestion of Sawdust and Piggery Dung

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## ABSTRACT

The Co-digestion of Sawdust (SD) with Pig Dung (PD) to produce biogas was studied. The objective of this paper is to increase biogas yield by comparing combinations of sawdust and piggery dung at different mixing ratios. The study also investigated the effect of Total Solids (TS) and microwave pre-treatment on biogas yield. Different mixing ratios of sawdust and piggery dung were combined and investigated for potential biogas production at Initial total solid (TS) of 5% and 10% in the co-digestion experiments. Results show that a maximum cumulative gas yield (CGY) of 33.75 L/kg of biogas was obtained in 60 days for a SD-PD ratio of 1:2. Similarly, the CGY of 29.33L/kg was obtained for experiments carried out with 5% TS. Experiments carried out at SD-PD ratio of 1:1 showed lower biogas yields when compared to experiments at SD-P 1:2 with 10% TS for SD-PD 1:1 giving a maximum biogas yield of 27 L/kg and 5% TS giving 22.5 L/kg. The results obtained also show that microwave pretreatment of sawdust improved biogas yields by 13.1-16.7%.

**Keywords**: Anaerobic Co-digestion, Biofuels, Biogas, Lignocellulose, Sawdust

## INTRODUCTION

Lignocellulose materials have been known for many years as alternative source of raw materials to produce environmentally benign biofuels (Huber *et al.*, 2006). These materials can be used to make solid fuels like briquettes, liquid fuels like bioethanol and gases like biogas. A lot of focus has been on utilizing agricultural residues, municipal solid waste, food waste and energy crops to produce biofuels (Hendriks and Zeeman 2009; Li *et al.*, 2015). However, the timber industry is one of those underutilized waste materials that can be harnessed. The forest industry in Nigeria is made up of the saw mill, wood based panels and the furniture industry. These sectors generate massive wood waste products from sawing, planning, routing, drilling, sanding operations, furniture manufacturing and joinery. This waste stream consists of small discontinuous chips (shavings) or simple fine particles of wood called sawdust (Kumar *et al.*, 2014; Tilak *et al.*, 2018). Reports have shown enormous increase in sawdust resources from an estimated 1.8 million tonnes in 2009 to 5.2 million tonnes in 2014 in Nigeria (Sambo 2009; Oluoti *et al.*, 2014,; Onochie *et al.*, 2018). These enormous sawdust resources are grossly underutilized and considered waste that require disposal. The disposal options of sawdust includes open dumping, open burning or as landfills dumping causing several environmental problems. Therefore, there is a need to convert sawdust into valuables products to reduce or eliminate disposal costs. The anaerobic digestion of sawdust to produce biogas is an alternative renewable energy option. Sawdust as a lignocellulose material can be combined with animal waste in a process called co-digestion to produce biogas (Milkue-Yobe, 2019; Kok *et al.*, 2020). Anaerobic Co-digestion is the process of transforming two or more organic waste into biogas by a synergy of microorganisms in the absence of oxygen (Shitophyta *et al.*, 2015). The four steps in the process of Anaerobic Digestion are hydrolysis, acidogenesis, acetogenesis, and methanogenesis (Meegoda *et al.*, 2018). The need to utilize the abundance of animal waste also provides use for them as co-digestion substrates. Several studies have been carried out on the anaerobic digestion of sawdust with different biogas yields ranging from low to high final cumulative gas yields. Sawdust has been co-digested with the chicken manure (Kok *et al.*, 2020), Africa dwarf goat dung (Milkue-Yobe, 2019), sewage sludge (Ahmed *et al.*, 2019). Cow dung (Madu and Onwuamaeze, 2018; Otaraku and Ogedengbe, 2013; Azmy *et al.*, 1991). There is no information in literature on the co-digestion of sawdust with piggery dung. This study will focus on investigating effects of different substrate mixing ratios, total solids concentration and microwave pretreatment on biogas yields. The goal is to enhance biogas yields from the co-digestion of sawdust with piggery dung.

## MATERIALS AND METHODS

Piggery Dung (PD) was collected from a local farm in Makurdi Benue State Nigeria while sawdust (SD) produced from mahogany hardwood was collected from a Saw Mill located in New GRA Makurdi, Benue State. The sawdust was air dried and then pounded with a mortar and pestle to reduce particle size. Moisture content of the mixture of SD and PD were determined using standard analytical protocols (APHA, 1998). A 25L drum type digester system was designed and fabricated locally as reported in our previous work. It has three main parts, the inlet chamber, the body and the outlet chamber and inserted with a thermometer and pH metre. A thermometer was inserted through a drilled hole at the top of the drum to measure the temperature (Ona *et al.*, 2019, Ona *et al.,* 2021). Sawdust pretreated by microwave was subjected to microwave irradiation of 1000 W in a Hisense Digital Microwave oven for a total of 5 minutes after which the samples were then stored in a dry place and used when required.

The measuring cylinder inverted with water was used for volume measurement of gas through a process called upward delivery and downward displacement. A series of batch experiments were carried out at ambient temperatures at different total solid concentrations. The biomass weight was suspended in 20 Litres of water making different total solid suspensions of 5% and 10%. Different mixing ratios of Sawdust (SD) and piggery dung (PD) were used for the experiments as shown in Table 1.

Table 1: Table showing different substrate mixing ratios of Sawdust and Cow Dung (SD-PD 1:1 and SD-pd 1:2) at different Total Solid Concentrations of 5% TS and 10% TS.

| | **SD-PD 1:2** | | **SD-PD 1:1** | |
|---|---|---|---|---|
| | **SD(Kg)** | **PD (Kg)** | **SD(Kg)** | **PD (Kg)** |
| **5% TS** | 0.333 | 0.667 | 0.500 | 0.500 |
| **10% TS** | 0.666 | 1.334 | 1.000 | 1.000 |

The substrate was thoroughly mixed in the digesters. Each digester was manually agitated daily to avoid stratification. The input slot was properly sealed with wax and hose clips to prevent leakage. The daily biogas production was recorded by measurement of displaced water both in the mornings and afternoons. This is done by noting the quantity of water displaced from the gas collected in the measuring cylinder. The ambient temperature, digester temperatures and pH were measured at least twice a day both in the mornings and afternoons. Biogas production yields were given as Cumulative Gas Yields (CGY) expressed per gram TS loaded (L/kg TS).

Collection of biogas for analysis was done by collecting it in a balloon for storage The composition of the biogas was determined with a gas chromatograph (Chemito GC-8610 model) using a thermal conductivity detector with oven at temperature of $50^0$C and injector temperature of $200^0$C. Calibration curve was used to determine concentration of methane and $CO_2$ (Gunaseelan, 2009).

## RESULTS AND DISCUSSION

The moisture content of the two mixtures SD-PD 1:1 and SD-PD 1:2 were analyzed and results showed moisture content to be 7.98%±2.10 and 15.12±1.5%. This gives a total solid of 92.02% for SD-PD 1:1 and 84.88% for SD-PD 1:2.The variation observed for moisture content is expected because of the increase in animal waste in the SD-PD 1:2. Biogas yields are expressed in litres of biogas produced per total solids (TS). The Biogas yield presented here is expressed as Cumulative Gas Yield (CGY) measured in L/kg TS.

### Effect of Substrate Mixing Ratios and Total Solid (TS) Concentration

Biogas production is expected to be affected by different substrate mixing ratios as different combinations of the substrate will provide differing composition of protein, carbohydrates and other nutrients needed for microbial metabolism. An increase in animal waste is expected to provide more microbes and proteins and so it is important to study effects of mixing ratios and total solids. The substrates used for these experiments were not subjected to any pretreatments.

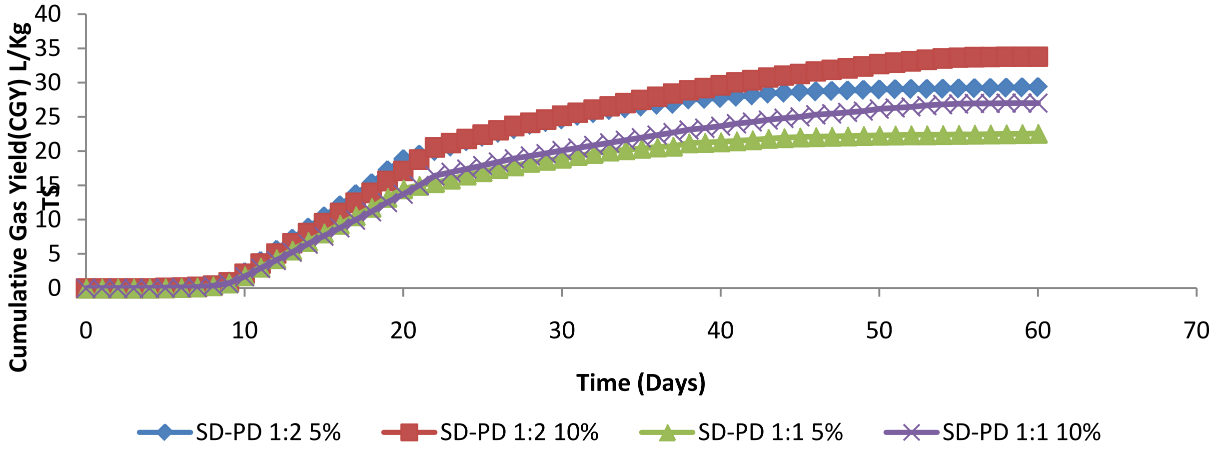


Figure 1: Progress curve showing the Cumulative Gas Yield (CGY) for the co-digestion of Sawdust (SD) with Piggery Dung (PD) at a mixing ratio of SD-PD 1:1 and SD-PD 1:2 at different Total Solid Concentrations and retention time of 60 days.

Results from Figure 1 shows experiments carried out when sawdust (SD) and piggery dung (PD) are combined as co-substrates with mixing ratios of SD-PD 1:1 and SD-PD 1:2. Results showed that experiments carried out with a substrate mixing ratio of SD-PD 1:2 showed higher biogas yield when compared with experiments at a mixing ratio of SD-PD 1:1 at both 5% and 10% TS. The maximum cumulative gas yield (CGY) of33.75 L/Kg TS was obtained for experiments with substrate concentration of 10% TS when compared to a CGY of 29.33 L/kg TS for experiments at 5% TS. For experiments at SD-PD 1:1, lower biogas yields for SD-PD 1:1 of 27 L/kg TS and 22.5 L/kg TS were observed for 10% TS and 5% TS respectively. A comparison of biogas yields at same TS show that experiments carried out at 5% TS with SD-PD 1:2 showed an increase in biogas yield of 23.29% over experiments with SD-PD 1:1. Similarly for experiments at 10% TS, SD-PD 1:2 showed an increase in biogas yield of 20% over experiments with SD-PD 1:1. The differences in yield are most likely due to the easier digestibility of piggery dung over the sawdust. The proteins and partially decomposed carbohydrate in animal waste is more likely to be amenable to be converted to biogas than sawdust. Sawdust is known to contain between 40-70% cellulose/hemicellulose and this might require a pretreatment for a breakdown to occur. A study by Bagudo *et al.*(2008) compared the biogas production potential of different substrates and observed that cow dung produced the highest amount of biogas when compared with rice husks, millet husk, sawdust and paper waste. Results from this study showed that sawdust produced 11% of the amount of biogas produced from cow dung. Rice husk and millet husk agric residues produced 76.14% and rice husk produced 16% of biogas produced from cow dung. This study shows that the recalcitrance of sawdust makes biogas production more difficult when compared with other agric residues. Another possible reason might be the increased C/N ratio that is expected for the substrate mixing ratio of SD-PD 1:2 when compared to SD-PD 1:1. SD-PD 1:2 will provide a higher Nitrogen content for the microorganisms involved in the breakdown. Biogas production is highly dependent on the carbon content as well as C/N ratios of the biomass utilized as substrates (Wang *et al*., 2006). A substrate mixing ratio of SD-PD 1:2 provide a better C: N ratio for the microbes involved in the digestion as the amount of protein is higher. Several studies that utilize sawdust as a co-substrate for production of biogas offer varying amounts of biogas yields. Ukonu (2011) produced biogas from sawdust and cow dung in a 1:1 ratio and reports a biogas yield of between 10.4 L/kg TS - 23.7 L/kg TS. However, pretreatment of the sawdust and addition of zeolite increased the biogas yield to 54.5% L/kg TS. A time lag of 10-15 days was also observed in this study. Another study carried out by Olusola and Omojola (2013) compared sawdust from both hardwood and softwood at different total solid concentration reports that when sawdust is combined with cow dung and cassava peels, biogas yields are reported between 6 L/kg TS and 33 L/kg TS. The highest yield was observed for mahogany sawdust combined with cow dung and cassava peels in a 0.5:0.25:0.25 ratios. The lowest yield was observed with Iroko Sawdust combined with cow dung and cassava peels at the same ratio. The study concluded that the specie of wood used to produce the sawdust is the one most important factor in improving biogas yield. This might be one of the reasons for the wide disparity in reviewed literature on biogas yields from sawdust ranging from very low yields of 0.045litres/TS (Otaraku and

Ogedengbe 2013) and much higher yields observed in other studies (Kok *et al.*, 2020; Ali *et al.*, 2017).

Figure 1 also shows a lag time of nearly 10 days retention time for production of biogas. The lag time observed in this experiment is longer compared to previous experiments that involved the anaerobic co-digestion of rice straw or corn stalks with piggery, cow dung or poultry droppings (Ona *et al.*, 2019; Ona *et al.*, 2022). Those studies showed a lag time of between 4 and 5 days. It is possible that the recalcitrance of lignocellulose in sawdust is higher than observed for other agricultural residues. Muley *et al*., (2016) estimates the lignin content of sawdust to be 30% with cellulose/hemicellulose having 60%. Another study also estimates a cellulose content of 41% and a lignin content of 19% (Joshua *et al.*, 2016).

**Effect of microwave Pretreatment on Biogas Yield**

One option often used to improve biogas yield from lignocellulose materials is pretreatment. Figures 2 and 3 show results from experiments where microwave irradiation was used as a pretreatment option for sawdust.

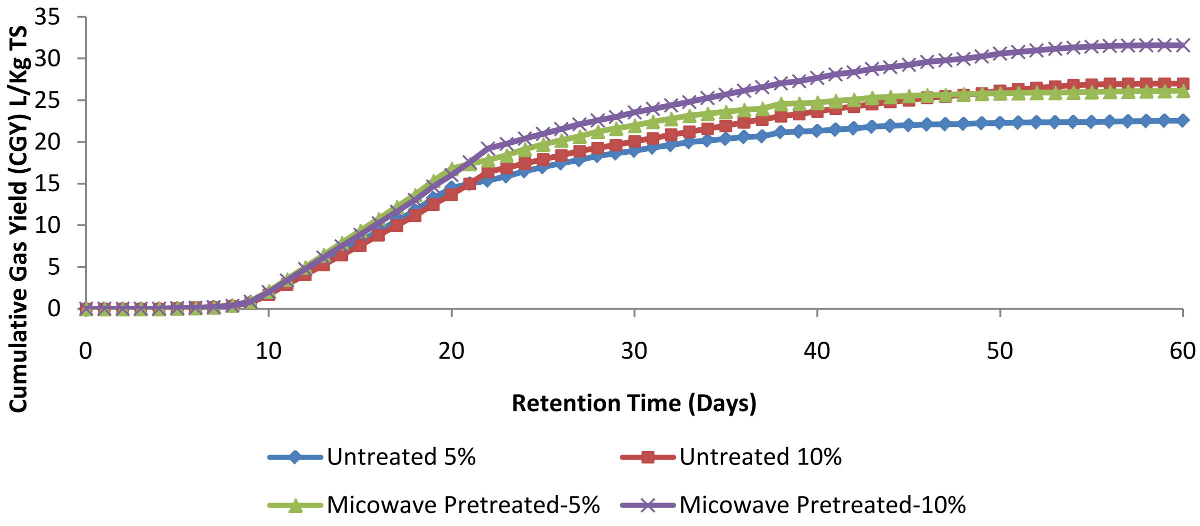


Figure 2: Progress curve showing the effect of microwave pretreated sawdust and untreated sawdust for the co-digestion of Sawdust (SD) with Piggery Dung (PD) at a mixing ratio of SD-PD 1:1 at different Total Solid Concentrations and retention time of 60 days.

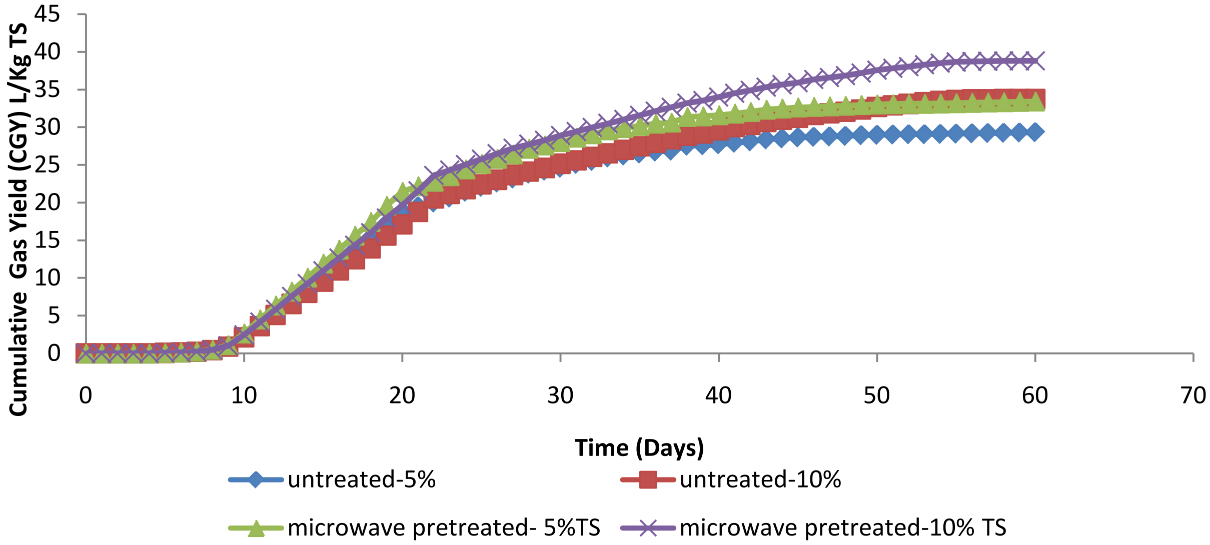


Figure 3: Progress curve showing the effect of microwave pretreated sawdust and untreated sawdust for the co-digestion of Sawdust (SD) with Piggery Dung (PD) at a mixing ratio of SD-PD 1:2 at different Total Solid Concentrations and retention time of 60 days.

From these results, experiments where microwave pretreated sawdust was used gave higher biogas yields when compared to experiments without microwave pretreatment. Figure 2 shows experimental results with SD-PD 1:1. Here, experiments with 5% TS showed a final CGY of 26.16 L/kg TS compared to 22.56 L/kg TS for the untreated substrate leading to 16.7% increase in biogas yield. Similarly, experiments with 10% TS showed a CGY 31.59 L/kg for microwave pretreated substrate when compared to a final CGY of 27 L/kg TS leading to increased biogas yield of 13.1% . A similar trend was also observed for experiments carried out at substrate mixing ratios of SD-PD 1:2 with microwave pretreated saw dust producing marginally higher biogas when compared to untreated biomass as shown in Figure 3. These results show a positive impact of microwave pretreatment. Several literatures have explored different pretreatment options with positive results in biogas yields. Ali *et al.*,(2017) used a 10 day consortium of lignocellulose degrading microbes to increased biogas yields of between 25%-75%. Ardhiansyah and Budiyono (2018), showed that different pretreatments including physical treatment (size reduction, extrusion, ultrasonic), chemical treatment (hot water, dilute acid, ionic liquid), biological treatment (fungal pretreatment, enzymatic pretreatment) has provided better results environmentally and economically. Some advantages that microwave has over other pretreatment options include shorter residence time, faster heat transfer, selective, instantaneous on and off operation, precise and controlled heating, rapid and efficient and it is environmental friendly (Yin, 2012). An analysis of the biogas produced also showed the composition of methane to be between 59%-70% as shown in Figure 4. Experiments with microwave pretreatment did not improve methane composition. A closer look at the results might suggest that experiments carried out at 5% with PD-SD 1-2 shows higher methane content when compared to the other experiments however this was not observed with PD-SD 1:2 at 10% TS. This might be due to random error. Further analysis would be needed to determine whether this is reproducible. Most studies in literature on biogas production did not carry out compositional analysis of the biogas. The composition of gas observed in these experiments agrees with the report by Ukonu(2011) which gives a range of 60-72% of composition for $CH_4$ and 20-30% $CO_2$.

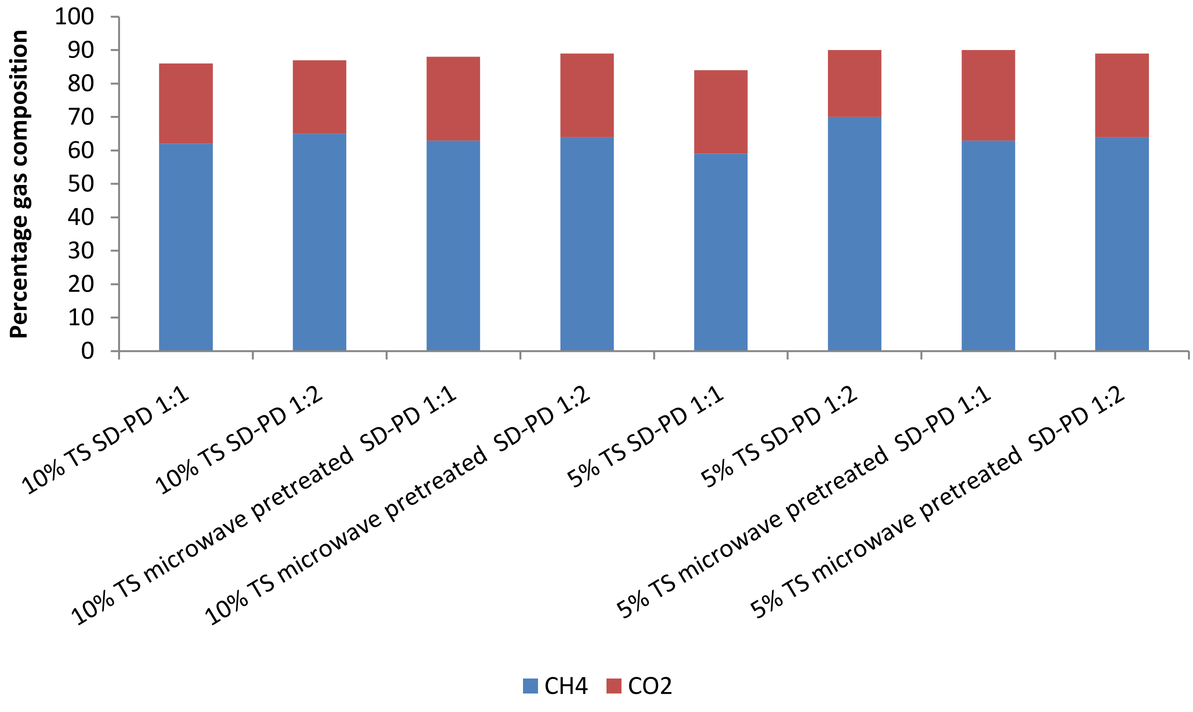


Figure 4: Composition of biogas produced from the co-digestion of sawdust and piggery dung at 5% TS and 10% TS

**CONCLUSION**

This paper shows that sawdust and piggery dung can be utilized to produce biogas. The study shows that a combination of sawdust and piggery dung at a substrate ratio of SD-PD 1:2 provides the highest cumulative gas yield. It was also observed that a Total Solid concentration of 10% gave marginally higher biogas yield when compared to 5% TS. Microwave pretreatment also increases the biogas yield.

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