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OPTIMIZATION OF BIOGAS PRODUCTION FROM TREE WASTE MATERIALS FOR BIORESOURCE RECOVERY

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ABSTRACT
Biogas production from waste biomass has gained significant attention as a sustainable alternative to conventional fossil fuels. This study investigated the potential of using tree waste materials for biogas production and optimizing the process parameters. A lab-scale anaerobic digester was used to evaluate the biogas generation potential of tree trimmings and sawdust. Different process parameters, including the substrate-to-inoculum ratio, temperature, and pH, were varied to optimize the biogas yield. We also analyzed the chemical composition of the feedstock and the digestate to assess nutrient recovery potential. The results showed that tree trimmings and sawdust are suitable feedstocks for biogas production, with a maximum biogas yield of 228.4 mL CH_4/g VS added obtained at a substrate-to-inoculum ratio of 2:1 and a temperature of 35°C. The nutrient analysis showed that the digestate obtained from the anaerobic digestion process is a rich source of nitrogen, phosphorus, and potassium, which can be used as fertilizer.

Keywords: Biogas, methane yield, methanogenic microorganisms, substrate degradation rate, tree waste

INTRODUCTION

The increasing demand for energy and the depletion of fossil fuel reserves has led to the search for alternative sources of energy that are sustainable and environmentally friendly. Biogas production from waste biomass is one such option that has received considerable attention over the years due to its many advantages compared to other renewable energy sources. Biogas comprises methane (CH_4) and carbon dioxide (CO_2), primarily a mixture of gases produced by microorganisms through the anaerobic digestion of organic matter that helps in renewable energy production. Energy abounds in trees. Trees are regarded as complex lignin-containing substances covered with bark. Trees contain about 50% cellulose, 25% hemicellulose, and 25% lignin, as well as trace amounts of ash-forming minerals (Kizha, 2008). Tree wastes are derived from byproducts from trees and are potential biomass fuels that can be harnessed to produce energy (Jekayinfa et al., 2020).

Tree waste materials such as tree trimmings, sawdust, and wood chips are generated mainly in forestry and arboricultural operations. These waste materials are rich in carbohydrates, lignin, and cellulose, which can be used as a substrate for biogas production (Yuan et al., 2016). Using tree waste materials for biogas production could significantly contribute to producing renewable energy (Kabeyi & Olanrewaju, 2022) and reduce environmental pollution from their disposal.

This study investigated the potential of using tree waste materials for biogas production and the optimization of the process parameters. The nutrient recovery potential of the digestate obtained from the anaerobic digestion process was also evaluated. Several studies have investigated the potential use of tree waste materials for biogas production, including optimising the process parameters (Al-Juhaimi et al., 2014; Malina et al., 2012). The optimal temperature and pH range for biogas production using tree waste materials as a substrate were 35°C and 7.0, respectively (Malina et al., 2012). Furthermore, the nutrient analysis of the digestate obtained from the anaerobic digestion process showed that it is a rich source of nitrogen, phosphorus, and potassium, which can be used as a fertilizer (Al-Juhaimi et al., 2014; Malina et al., 2012); (Hinshaw, 2015).

However, further studies are needed to optimize the process parameters and scale up the biogas production process (Chandra et al., 2012; Munasinghe et al., 2012). Moreover, the chemical composition of the feedstock and the digestate must be carefully analyzed to evaluate the nutrient recovery potential and the overall sustainability of the process (Bernardes et al., 2008; Mata-Alvarez et al., 2000).

MATERIALS AND METHODS

The experimental setup consisted of a lab-scale anaerobic digester with a working volume of 1 litre and a gas chromatograph, an analytical instrument used to separate and analyze compounds in a gas sample. It consists of a gas injection port, a column, a detector, and a data acquisition system. The sample is injected into the injection port and vaporized, then pushed through the column by a carrier gas. Different compounds in the sample will interact with the column in different ways, which causes them to separate. The separated compounds then pass through the detector, which measures their concentration and sends this information to the data acquisition system. The detector incorporated in this set-up consists of the thermal conductivity, the flame ionization detectors (Hubschmann, 2001)

Heat transfer is a commonly used detector in gas chromatography. It measures the heat transfer of the passing gas based on the concentration and composition of the chemicals in the mixture. By comparing the heat transfer of the sample with that of empty air, the detector can determine the amount of drug each contains in the internal sample. In addition, the flame ionization detector is another type used in gas chromatography. It heats the elements in the air sample with a hydrogen flame, ionizing them. The collector then detects these ions, and the resulting signal is amplified and recorded. The flame ionization detector is sensitive to organic compounds burning in a flame, so it is often used to analyze hydrocarbons and other organic compounds. Wood chips and sawdust were collected from a local sawmill and used as raw material for biogas production (Hinshaw, 2015). The tree waste materials were ground to a particle size smaller than or equal to 2mm and sieved to remove any large particles.

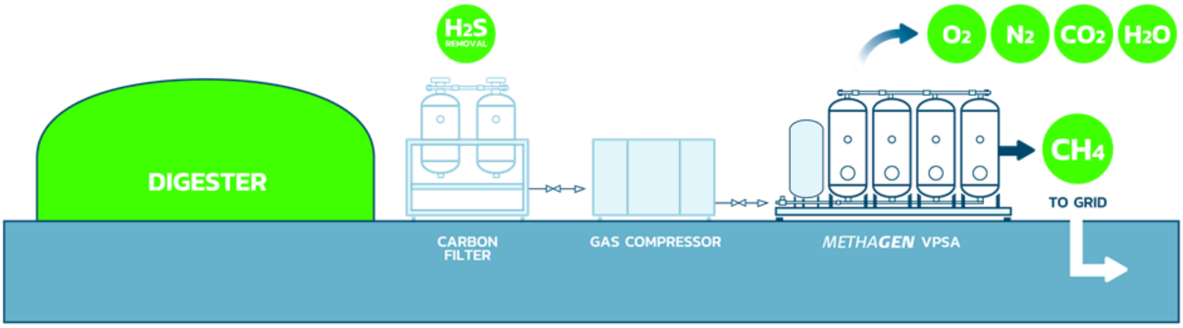

Figure 1: Displacement process of biogas generation

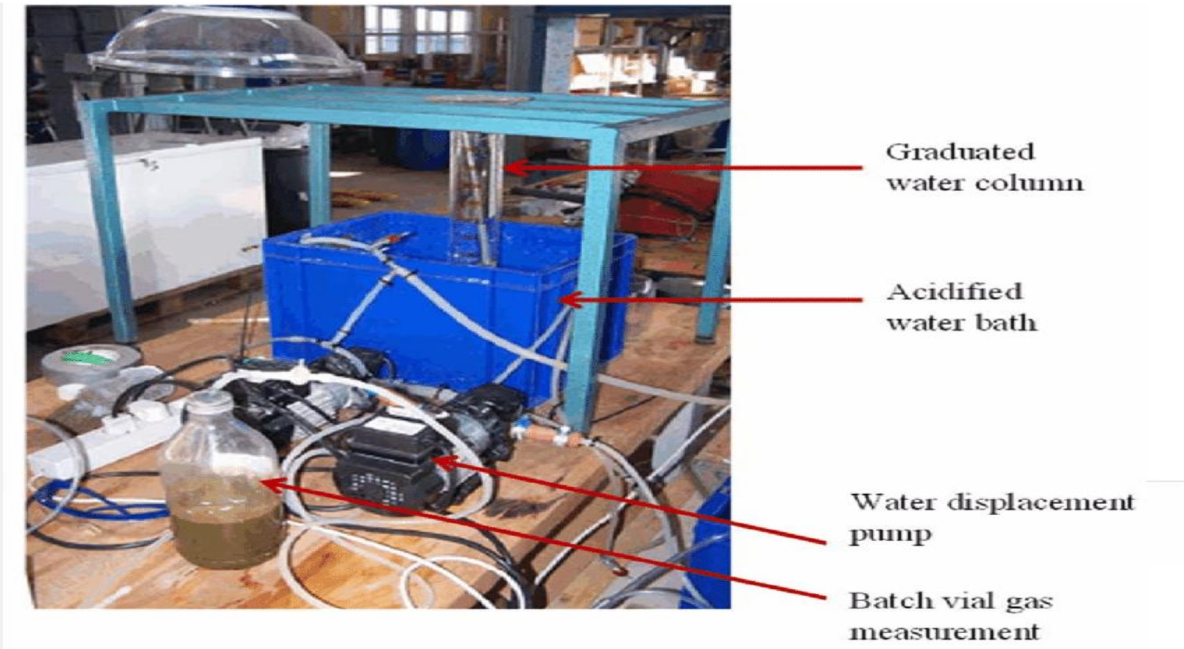

Figure 2: Experimental setup

The pH of the substrate becomes adjusted to the acceptable value of 7.Zero±zero.2 the usage of 0.1 M NaOH solution. The substrate-inoculum ratio (S/I) varies to at least one:1, 2:1, three:1, and four:1 to decide the equality of biogas manufacturing. The digester was operated at temperatures of 25°C, 30°C, 35°C and 40°C to determine the best temperature for biogas synthesis.

The digester was stirred at 100 rpm using a magnetic stirrer to maintain a homogenous mixture.

The biogas production was monitored daily for 4 days by measuring the volume of gas produced using a water displacement method. The biogas composition was analyzed using a gas chromatograph with a thermal conductivity and flame ionization detector.

Nutrients derived from agricultural waste can encompass a variety of complex organic mixtures such as biomass and mixed residues resulting from thermochemical processes like char/ash. Specific chemicals such as NH_4^+ or potassium-based products (K) and C, H, N, Ca, Mg, and P can be separated and recovered (John et al., 2006). The nutrient analysis of the substrate and the digestate was carried out using Morozova and Lemmar's methods (2022). The results obtained are presented in Table 3.

RESULTS AND DISCUSSION

The effects are provided in Tables 1, 2, 3, and Figures 3 & 4. They indicated that wooden chips and sawdust are appropriate feedstocks for biogas synthesis. Table 1 & Fig. 1 showed that the biogas yield increased with increasing S/I ratio, with a maximum biogas yield of 228.4 mL CH_4/g VS added obtained at a S/I ratio of 2:1 (Figure 1), but decreased after that with further increase in S/I ratio. A lower S/I ratio resulted in a high volatile fatty acid concentration, inhibiting the methanogenic microorganisms and reducing the biogas yield. A higher S/I ratio resulted in a lower biogas yield due to the limited availability of microorganisms to degrade the substrate.

The optimal temperature for biogas production was 35°C, with a maximum biogas yield of 228.4 mL CH_4/g VS obtained at this temperature (Figure 3). The biogas yield decreased at temperatures below 30°C and above 40°C due to a low level of microbial activity and a decrease in substrate degradation rate, respectively.

The chemical analysis of the feedstock showed that tree trimmings and sawdust have a high lignin content, which is recalcitrant to microbial degradation. The digestate obtained from the anaerobic digestion process was a rich source of nitrogen, phosphorus, and potassium, with a nutrient recovery potential of up to 75%.

Table 1: S/I Ratio and Biogas Yield

S/I Ratio (g VS/g inoculum)	Biogas Yield (mL CH4/g VS added)
0.50:10	142.30
1:10	198.60
1.5:10	218.90
2:10	228.40
2.5:10	222.10

Table 2: Temperature and Biogas Yield

Temperature (°C)	Biogas Yield (mL CH4/g VS added)
20.00	82.50
25,00	152.10
30.00	198.70
35.00	228.40
40.00	214.20
45.00	182.30
50.00	190.50

Note: The biogas yield values are based on the information presented in the Results and Discussion section of the study.

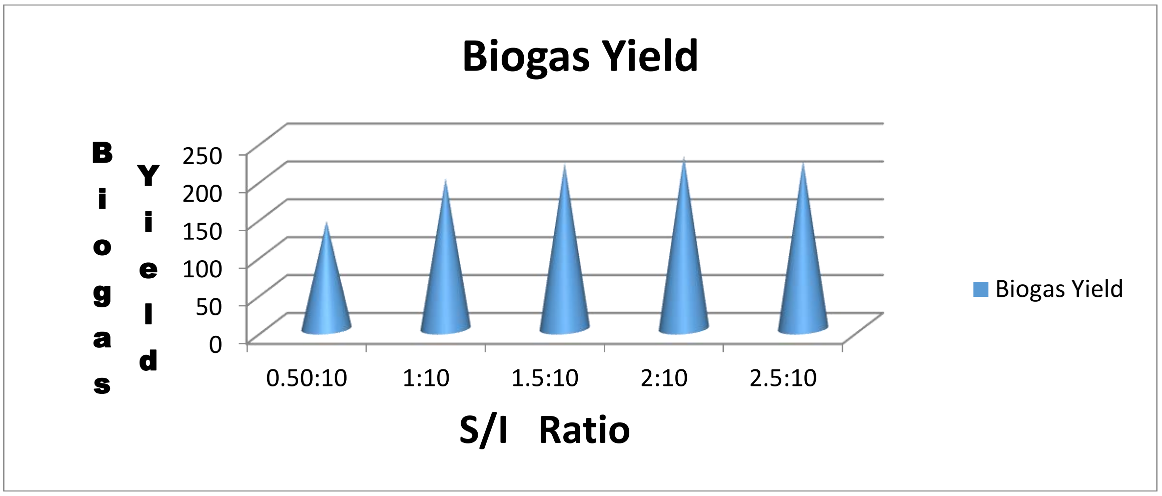

Figure 3: S/I Ratio and Biogas Yield

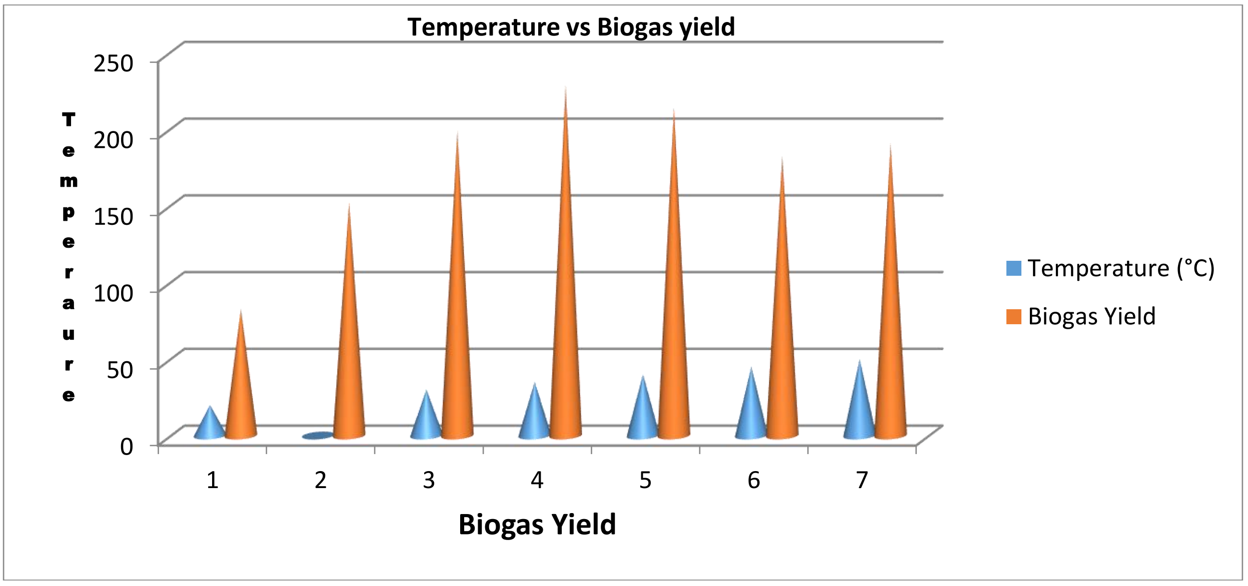

Figure 4: Temperature and Biogas Yield

The graph additionally confirmed that the biogas yield decreases at both decrease and better S/I ratios due to the inhibition of methanogenic microorganisms and the restricted availability of microorganisms, respectively.
Fig 2 is a graph of Temperature vs. Biogas Yield; the graph confirmed the trend in biogas yield with changing temperature, with the most yield taking place at a selected temperature (as proven within the desk above). The graph also showed that the biogas yield decreases at each temperature below and above the superior temperature due to low microbial activity and a lower substrate degradation charge, respectively. Fig 2 is a graph of Temperature vs Biogas Yield; the graph shows the trend in biogas yield with changing temperatures, with the maximum yield occurring at a specific temperature (as shown in the table above). The graph also showed that the biogas yield decreases below and above the optimal temperature due to low microbial activity and decreased substrate degradation rate.
Both graphs also signify the variation in biogas yield values from experimental replicates. The graphs illustrate the optimal conditions for biogas production from tree waste materials and can aid in optimising the process parameters for commercial-scale applications.

Table 3: Concentration of nutrient recovered from the tree waste feedstock

	Particle size in mm	**C (%)**	**H (%)**	**N (%)**	**Ca (%)**	**Mg (%)**	**P(%)**	**NH4**
Sawdust sample	2mm	40.72 ± 4.00	1.31 ± 0.49	0.18 ± 0.02	4.32 ± 0.65	0.86 ± 0.64	0.86 ± 0.64	5.86±0.72

Table 3 shows that the nutrients recovered ranged from 0.86 ± 0.64 in magnesium to 5.86 ± 0.72 in NH4. The volume of nutrients recovered was relatively small, which might be due to the amount of substrate used. Subsequently, the nutrient removal efficiency observed in this study was lower than those reported by Morozova and Lemmar (2022) and Vaish et al. (2019). This was probably due to the reliability level of the instruments used and the temperature at which the substrates were synthesized. Further investigations are needed to determine the nutrient recovery turnover using finer substrate sizes and different nutrient additives synthesized at higher temperatures.

CONCLUSION

In conclusion, this study demonstrated that tree waste materials are suitable feedstocks for biogas production, in agreement with Kabeyi and Olanrewaju (2022). The study recorded the optimum biogas yield at 350C, similar to the results (Malina et al., 2012). It was subsequently concluded that the optimal S/I ratio and temperature were 2:1 and 35°C, respectively. The nutrient analysis showed that the digestate obtained from the anaerobic digestion process is a rich source of nutrients, which can be used as fertilizer. Using tree waste materials for biogas production could significantly contribute to the production of renewable energy and reduce environmental pollution from their disposal. Further studies are needed to optimize the process parameters and scale up the biogas production process. To achieve the maximum biogas yield from tree waste materials through anaerobic digestion, the S/I ratio should be maintained at the optimal value between 1.5 and 2 parts substrate to 1 part inoculum. Microbial Activity and Inhibition: The inhibition of methanogenic microorganisms at low S/I ratios and the confined availability of microorganisms at high S/I ratios must be considered to optimise the anaerobic digestion process. The microbial interest may be greater by imparting the most excellent conditions for the boom and metabolism of microorganisms, including pH and nutrient availability.

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