

SUSTAINABLE BIOGAS PRODUCTION FROM SWEET POTATO PROCESSING WASTE

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ABSTRACT

Escalating global energy crisis coupled with pressing environmental concerns has accelerated the transition towards sustainable, eco-friendly and economically viable energy sources. This study evaluated the potentials of sweet potato peels, a widely available agricultural residue as a substrate for biogas generation using a laboratory scale batch anaerobic digester under mesophilic conditions. Prior to digestion, the substrate was pre-treated and co-digested with cow dung at a 1:2 ratio over a 25-day retention period, to enhance microbial activity and process stability. Biogas yield, pH and temperature were recorded daily to assess digester performance. To improve the biogas quality, the raw biogas was upgraded through sequential treatment using an iron sponge for H₂S removal and water scrubbing for CO₂ removal. Gas production commenced within 48 hours, indicating quick substrate degradability. Comparative biogas analysis before and after purification revealed a substantial enrichment in methane content from 57.21 % to 84.32%, CO₂ and H₂S were significantly reduced from 30.2% to 1.9% and from 1,93ppm to 0.04ppm respectively. These findings demonstrate that pretreated sweet potato peels co-digested with cow dung can deliver high quality biogas within a relatively short retention time, supporting their viability as a sustainable energy feedstock. The purification process effectively removed noncombustible and toxic constituents, thereby enhancing its quality. Trace contaminants including carbon monoxide (0.03 ppm), nitrogen oxides (NO = 1.36 ppm, NO₂ = 0.82 ppm, NO_x = 2.18 ppm), and volatile organic compounds (8.55 ppm), were present at minimal concentrations that can be useful for domestic use. The slight elevated oxygen level detected was attributed to sampling contamination and did not compromise the methane concentration. Collectively the results confirmed that sweet potato peels are viable substrate for biogas production and upgrading the biogas further increase the methane content to level suitable for domestic and small-scale applications. These findings suggest that sweet potato peels can serve as a sustainable waste to energy resource for decentralized biogas systems for rural energy security, sustainability and waste management.

Keywords: sustainable, biogas, sweet potato peels, digester, scrubbing, purification

INTRODUCTION

In recent times, the world's demand for energy and challenges of climate change has posed significant challenges globally, with predictions of possible energy shortage in the future (Oluwatoyin, 2023). Experts warn that natural gas reserves may be depleted within 50 years, while crude oil reserves could be exhausted within 40-70 years, this could lead to a global temperature increase of 1.8-6.4°C by 2100 (Sunarso *et al*, 2012). According to World Population Prospects (2017), the world's population is expected to reach 8.6 billion by 2030, 9.8 billion by 2050, and 11.2 billion by 2100, putting more demand on resources and energy. This growth has sparked interest in renewables energy and biogas is presumed as sustainable solution. Biogas is produced through anaerobic digestion of organic materials such as sewage sludge, animal waste, agricultural waste and municipal solid waste (MSW), offering a promising alternative (Valijanjan *et al*, 2018). Sweet potato peels are parts of agricultural wastes that are rich in starch, as well as cellulose, hemicellulose and protein with small

amounts of lignin. These components provide the carbon compounds needed during anaerobic digestion to facilitate microbial activity (Jabeen *et al.*, 2000).

As a sustainable and environmentally friendly energy source, biogas plays a vital role in generating heat and electricity, it is also recognized as one of the most promising renewable energy options globally (Tufaner and Demirci, 2020). Biogas is generated using anaerobic digestion of organic matter, such as manure, municipal solid waste, sewage sludge, biodegradable waste, and agricultural slurry under anaerobic conditions with the assistance of microorganisms (Dong *et al*, 2020). The process is divided into four sequential steps, performed by different anaerobic microorganisms in microbial community: hydrolysis, acidogenesis, acetogenesis and methanogenesis (Labatut and Pronto 2018).

The process leverages microorganisms to break down organic matter in the substrates, offering a cleaner, environmentally friendly alternative to traditional energy

sources. Biogas composed primarily of methane (45-75%) and carbon dioxide (25-55%), with smaller amounts of hydrogen sulfide, water, and other trace gases (Ayoub 2002). Its industrial-scale production has surged due to its perceived potentials as fuel and energy source; it also plays a positive role in reducing greenhouse gas emissions when captured and utilized as fuel.

Biogas requires purification when the intent of its application is for energy generation. Purification of raw biogas will increase the methane content thereby increase the energy value of the sample. Carbon dioxide, makeup 30-45 % of biogas, which is not desirable, because it doused methane efficiency and reduce engine performance. Hydrogen sulfide can also cause wear and tear on machine parts, because of its ability to form corrosive sulfur dioxide when combusted. Removing these impurities became crucial to optimize biogas performance as a fuel. When carbon dioxide is removed from biogas, methane content increases, resulting into a higher power output. However, iron filling can effectively remove hydrogen sulfide that constituted 0.1 % (1000 ppm) or more as the case may be, to avert engine damage. Applying simple water scrubbing techniques can

effectively remove carbon dioxide to enhance its quality when use for either heat or electricity generation.

METHODOLOGY

Substrate Collection and Preparation: The sweet potato peels used was obtained from local agricultural processing centers in Bida, Niger state, Nigeria. The peel was sun-dried for 2 days, 8 hours daily. Then, the dried peel was grounded with electric vegetable grinder to finer particles. Fresh Cow dung obtained from nearby cattle farm was used as inoculum to provide initial microbial consortium to the system due to high population of methanogenic bacteria present in the cow dung (Weiland, 2010). The mixing ratio of the substrate to inoculum was 1:2 on a weight-to-weight basis (w/w), as suggested by (Surendra et al., 2014)

Digester Setup and Operation: The anaerobic digester used was a plastic container with a working volume of 2 liters. Inlet pipe and outlet pipe were incorporated into it. The outlet was connected to gas sampling bags and then passed to purification units.

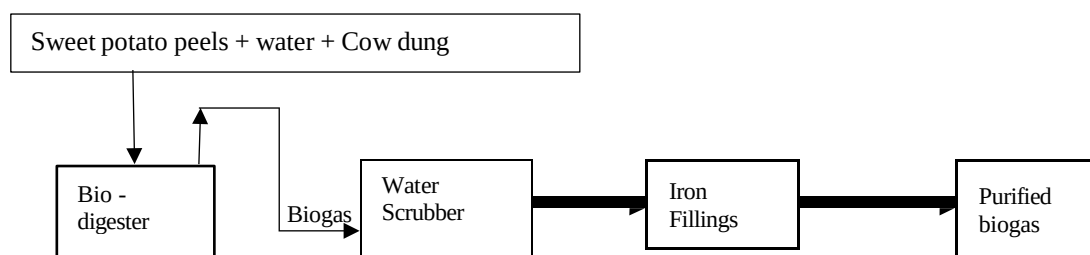


Figure 1: Block diagram of biogas production and purification

Digester/Substrate Loading: The digester was loaded with 150 g of potato peels, 300 g cow dung and 450 ml of water. The mixture was thoroughly mixed and pH of the mixed slurry was measured. The digester was then air tight and operated anaerobically for 25 days under mesophilic conditions. Daily gas production was monitored, measured and recorded. After each measurement the digester slurry were shaken and mixed thoroughly before the next reading was taken to promote uniform microbial activity. The pH and temperature were also monitored on daily basis.

Biogas Purification Procedure: The biogas produced underwent through a sequential purification step of

desulfurization and carbon dioxide scrubbing in order to enhance the quality of the biogas produced.

Desulfurization: The raw biogas was passed through an iron sponge scrubber to remove hydrogen sulfide (H_2S) to limit the corrosiveness and toxicity of the biogas. Iron oxide in the sponge reacts chemically with H_2S , converting it to iron sulfide and water. The iron sponges enclosed in an air tight container through which the biogas flows to the top is called the dry box method. The gas flows through the ferrous bed from the bottom and leaves the container at the top, where the Sulphur component in the biogas reacted with iron bed to give output gas with minimal or free of H_2S . The absorbing material was

regenerated by treating the sulphurated absorbent with atmospheric oxygen, thereby, returned it to its active oxide form required for further purification of gas.

Carbon Dioxide Removal: The biogas produced was passed through a water scrubbing column, where CO₂ dissolves in water, to increase the methane concentration in the biogas. Here, CO₂ is dissolved in water as the biogas passed upward through a packed column of downward-flowing water. This improves the methane concentration in the biogas.

Analysis of the biogas: The measurement and characterization of biogas are essential to evaluate the efficiency of the anaerobic digestion process. Several analytical methods were used in this study to determine the volume, composition, and operating parameters of the digester system. These methods are vital for understanding the suitability of the substrate in biogas production.

Daily Gas Yield: The biogas produced was collected through a gas outlet hose into a gas collection bag. The weight of the gas was measured daily by the use of weighing balance. The difference in mass of the collection container before and after gas collection. The cumulative gas yield was calculated over time.

Determination of Biogas Composition : The sample of the gas produced was analyzed using Gas Chromatography (GC) to ascertain the quantity of methane (CH₄), carbon dioxide (CO₂), hydrogen sulfide (H₂S) and impurities that are present at the end of retention times. Gas chromatography is an instrument use to identify and quantify of each component of the biogas produced. In this method, a small sample of biogas is injected into the chromatograph, where it passes through a stationary phase in a column. Each component (CH₄, CO₂, H₂S, etc.) moves at a different speed and exits the column at a different time, called the retention time. A thermal conductivity detector (TCD) or flame ionization detector (FID) measures the concentration of each component.

The pH of Digester Slurry: The slurry's pH was measured using a calibrated digital pH meter, before each measurement, the meter was calibrated using standard buffer solutions (pH 4.0, 7.0, and 10.0). Samples were

stirred and readings were taken after stabilization (about 30 seconds). pH was recorded every day throughout digestion period to monitor acidity or alkalinity of the medium.

RESULTS AND DISCUSSION

The result of this study showed that, the cumulative biogas yield from sweet potato peel was 2.31 liters after the retention period of 25 days. Figure 1 showed the gas yield as a function of time.

Gas Yield as Function of Time: From figure 1, the daily biogas yield from potato peels showed a progressive growth from the 3rd day after the lag period of 2 days, when the initial volume of biogas was recorded. As the gas production commenced on the 3rd day with a total yield of 0.0434 liters. The yield was observed to increase steadily to a maximum value of 0.2609 liter on the 9th day of retention, which correspond to the highest methanogenic activity seen throughout the digestion period. This increase attested to the readily available components that are soluble within potato as substrate. The other lignocellulosic part of the substrate was slowly degraded for microbial consumption thereby led to the decrease in biogas production for the subsequent days of retention. It was after the 9th day that, the gas production showed a gradual decline to 0.2174 liters and continued to decline until near-zero on the 23rd day of digestion. A clear prove to the fact that, most of the easily hydrolysable component of the substrates are consumed within the first nine days and transition to slower degradation, signifies that, there are more resistant components within the digester slurry or more harmful chemical are produced in the system that was capable of retarding the digestion. This trend is typical for most of the batch mesophilic digestion systems, where substrate availability determined the rate at which the subsequent stage of digestion will be geared towards (Bouallagui *et al.*, 2005). At the end, sweet potato peels demonstrated quick onset of biogas yield and attained peak in a minimal retention period when compared to lignocellulosic materials that typically exhibit a lag phase of 2 – 5 days before digestion due to slow hydrolysis (Matheri *et al.*, 2016), while sweet potato peels produced biogas within 48 hours. The decrease observed in gas yield after day 18 of digestion, may be attributed to limited biodegradable organic matter left within the system or possibly acid accumulation in the digester.

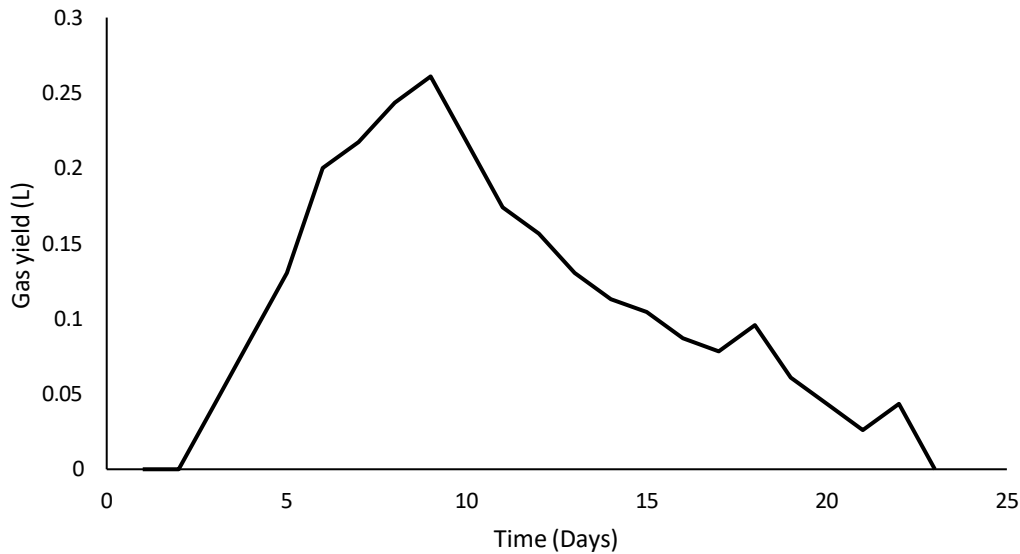


Figure 1: Biogas yield with time

Effect of Temperature on the Gas Yield

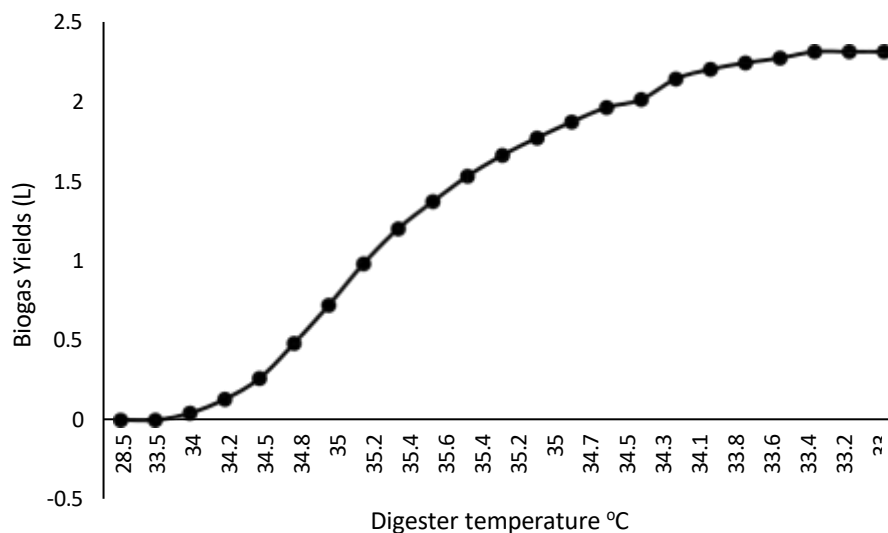


Figure 2: Effect of Temperature on Biogas Yield

There is a positive correlation between the temperature and gas production rate as observed in Figure 2. During the active phase of digestion, the quantity of biogas produced increases as the digester temperature increases from 33.5 °C to 35.6 °C that was observed between the 6th and 10th day of digestion. The peak yield of 0.2609 liters of biogas occurred on day 9 at 35.4 °C, aligning with the 35 – 37 °C optimal temperature range for digestion reported by Gerardi, (2003) and Appels *et al.*, (2008). This peak performance at 34°C can be attributed to enhanced microbial activity within the mesophilic range.

Temperature in this range accelerate hydrolysis and methanogenesis to bring about increase in substrate breakdown and gas production rates. Beyond day 9 gradual decline in yield was observed. This could be attributed to depletion of readily degradable organic matter and the onset of rate-limiting hydrolysis of complex substrate. Therefore, maintaining reactor temperatures within the 35 – 37°C range is critical for optimizing biogas output. These findings support the feasibility of efficient biogas production under monitored mesophilic condition when use in similar agro-climatic region (Matheri *et al.*, 2016).

However, as the digestion progresses and the availability of consumable substrate reduces within the digester system, it affected the gas yield and brought about decline in gas production. Despite the fact that the temperatures still remain within the favorable mesophilic temperature there was a decline. This indicates that temperature was

supportive but isn't the limiting factor; substrate depletion became the dominant determinant of gas output. This trend aligns with the findings of Appels *et al.* (2008), who reported that under stable mesophilic conditions, substrate composition is the primary driver for methane yield in a digester.

Effect of pH on Biogas Yield

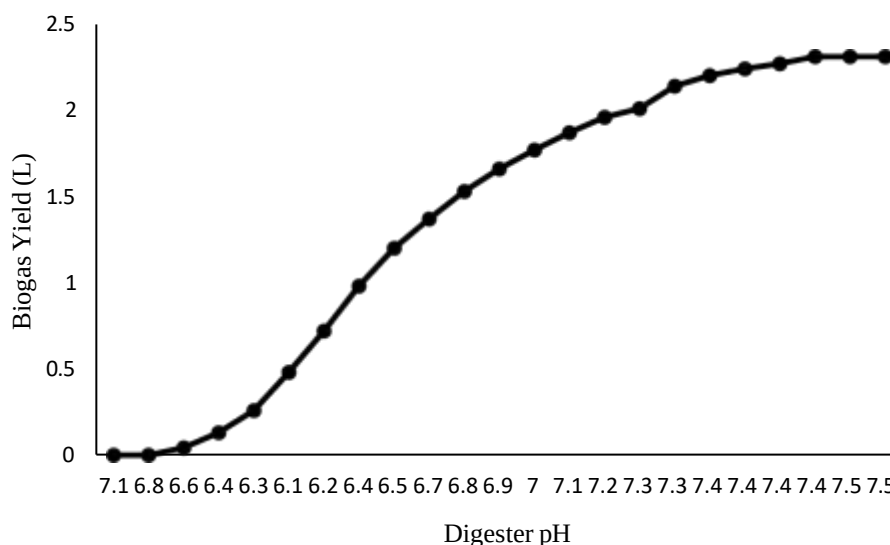


Figure 2: pH against biogas yield from sweet potato peels

The initial increase in biogas volume despite the decline in pH profile for sweet potato peels from 7.1 to 6.1 in the first 6 days was attributed to the rapid activity of acidogenic bacteria, which produce CO_2 and H_2 during hydrolysis of starch. The concurrent accumulation of volatile fatty acids lowered the pH. Subsequent consumption of these acids by methanogens lead to more methane production after 3 days and pH recovery to 7.2 – 7.4. At this stage the fermentative bacteria convert carbohydrates into volatile fatty acids, causing a decline in pH (Yadvika *et al.*, 2004; Appels *et al.*, 2008). That it is despite the decline in pH, gas production was improved significantly during this period, indicating a healthy progression toward methanogenesis. As digestion continued, the pH gradually increases to 6.7–7.3, corresponding with stable pH required for higher gas production.

As shown in figure 3, peak biogas yield coincides with pH values ranging from 6.5 to 7.2 which aligned with the optimal pH range reported for methanogenic archaea

(Gerardi, 2003). The gradual increase in pH to above 7.3 toward the end of digestion period suggested the accumulation of bicarbonate and ammonia as by-product of microbial metabolism. When nitrogen containing organic materials such as protein in the substrate is broken down, it releases ammonia NH_3 and ammonium NH_4^+ ions which contributed to the increase in alkalinity and helps increase pH of the slurry.

The generated alkalinity provides buffering capacity that mitigates sudden pH fluctuations. Maintaining a consistent pH between 6.8 and 7.2 throughout methanogenesis is essential for process stability and efficient biogas production (Appels *et al.*, 2008; Ogunlabi and Ogunlabi, 2018).

Biogas Composition of Potato Peels:

The purified biogas sample was analyzed before and after purification as shown in table 1.

Table 1: Composition of Treated Biogas from Potato Peels

S/N	Parameters	Units	Before purification	After purification
1	Oxygen (O ₂)	%	2.1	0.80
2	Carbon Monoxide (CO)	ppm	0.03	0.0
3	Carbon Dioxide (CO ₂)	%	30.2	1.9
4	Nitric Oxide (NO)	ppm	1.73	1.36
5	Nitrogen Dioxide (NO ₂)	ppm	0.96	0.82
6	Ammonia (NH ₃)	ppm	2.5	2.18
7	Sulphur Dioxide (SO ₂)	ppm	0.07	0.03
8	Methane (CH ₄)	%	57.21	84.32
9	Hydrogen Sulphide (H ₂ S)	ppm	1.93	0.04
10	Volatile Organic Compounds (VOC)	ppm	3.27	8.55

Oxygen Content: Biogas should normally contain 0 – 1 % oxygen, for the fact that, oxygen is not produced during anaerobic digestion. The high value of 2.1% recorded in Table 1 did not originate from the digester; rather, it was as a result of air contamination during sampling or micro-aeration. Possible causes include:

1. Sampling the gas while the storage bag was not completely filled
2. Analyzer probe exposed to ambient air before testing
3. Minor leakage in tubing or fittings
4. Purification system introducing air during operation

Such contamination is commonly observed in biogas sampling. Arrhenius et al., (2019) reported that gas bag permeability, tube leakages, and improper purging can introduce atmospheric oxygen into the sample. Similarly, practical guidelines for biogas analysis recommend an air-tight sampling procedures to prevent such errors (Ohio Lumex, 2023). Although the measured oxygen does not affect the methane content obtained in this study, it emphasizes the need for careful sampling protocols to avoid dilution or contamination, in order to obtained accurate biogas characterization.

Carbon Monoxide Content: The CO level recorded in the treated biogas was low (0.03 ppm) as shown in Table 1, indicating that no incomplete combustion or pyrolysis occurred inside the digester. This aligns with expectations of properly operated anaerobic systems, where carbon monoxide is typically present only as a trace gas (Flotats and Bonmatí, 2006). According to International Energy Agency (IEA) (2020), values below 50 ppm are generally considered safe and do not pose any health or operational

risks. The low CO concentration confirms that the digestion process proceeded under strictly anaerobic and non-combustive conditions, and that the purification process did not introduce CO or other hazardous gases.

Carbon Dioxide Content: Raw biogas typically contains 25–45 % carbon dioxide, which lowers its calorific value. After treatment of the produced biogas, it was shown in Table 1 that CO₂ level was 1.9 % from initial value of 30.2 %, an indication that the purification method adopted achieved an excellent reduction of CO₂ from the raw biogas. This finding agrees with Ryckebosch & Vervaeren (2011), who reported that CO₂ can be reduced to below 5% using chemical absorption, water scrubbing, or pressure swing adsorption (PSA). The success in lowering the CO₂ content in the biogas contributed greatly to the increase in methane concentration recorded.

Nitrogen Oxides (NO, NO₂, NO_x): The nitrogen oxides recorded in the treated biogas were also in decrease (NO = 1.36 ppm, NO₂ = 0.82 ppm, NO_x = 2.18 ppm), indicating minimal contamination from external sources. Anaerobic digestion itself does not produce nitrogen oxides, as these gases are typically formed during combustion or high-temperature oxidation processes (Flotats et al., 2006). Their presence in the gas sample is therefore likely due to minor exposure to ambient air during sampling or handling, rather than being a product of microbial digestion. Such low concentrations are consistent with safe, high-quality biogas.

Methane Content: Methane is the major energy-yielding component of biogas and it determines the fuel quality and flammability of the gas. As shown in Table 1, the purified

biogas produced from potato peels contained 84.32 % methane after purification. This is significantly higher than the normal range of 50–70% reported for raw biogas in some literatures (Drouillon and Vervaeren, 2011). This high value indicates that the purification method applied was effective in removing CO₂, H₂S, and other non-combustible gases. According to Angelidaki and Sanders (2004), purified biogas can reach methane levels of 82–98 %, which agrees with the value obtained in this study. Such quality of methane may be very suitable for cooking, heating, and electricity generation, and can serve as a substitute to upgraded natural gas.

Hydrogen Sulphide Content: Hydrogen sulphide is a corrosive and toxic gas that must be removed from biogas before use. Raw biogas often contains 50–10,000 ppm of H₂S depending on the substrate. Table 1 shows that there is a very low H₂S concentration of 0.04 ppm recorded in this study which indicates that almost all sulphur compounds are completely removed. Muñoz et al. (2015) recommended that H₂S levels below 100 ppm are safe for engines and burners; hence the value obtained is far below the safety threshold. This means the purified biogas will have minimal corrosion effect when in use or may produce less offensive odor.

Sulphur Dioxide Content: The Sulphur dioxide content of the treated biogas was 0.03 ppm, indicating that almost all Sulphur-bearing compounds were successfully removed during purification. Such a concentration confirms the high quality of the biogas and ensures that it will not cause corrosion in engines or release unpleasant odors during use. This aligns with best practices for biogas purification, where SO₂ levels are ideally kept below 100 ppm to ensure safety and usability (Muñoz et al., 2015; Drouillon, and Vervaeren, 2011).

Volatile Organic Compounds: The VOC content in the treated biogas was low at 8.3 ppm, indicating that only minor traces of organic vapors remained after purification. VOC levels below 10 ppm are typical for well-treated biogas and do not significantly affect its fuel quality or performance. This demonstrates that the purification process effectively removed volatile contaminants, contributing to clean, and high-quality biogas suitable for use in cooking, heating, or electricity generation (Ryckebosch, Drouillon, & Vervaeren, 2011).

CONCLUSION

This study demonstrates that biogas production from sweet potato peels is a temperature dependent substrate with the maximum yield achieved at 35.4°C on day 9. The result affirms the established literature identifying 35 -37°C as the optimum for mesophilic anaerobic digestion. The reduced retention time observed here could be attributed to preliminary steps of size reduction, soaking and co-digestion with cow dung. These measures enhance substrate bioavailability and inoculate the mixture with active methanogens needed in substrate conversion, which brings about accelerated hydrolysis step that possibly could be rate limiting step of the production.

Processing steps like size reduction, soaking and mixing with cow dung inoculum boosted microbial activity and sustained biogas production for 25 days. Optimal mesophilic temperatures and pH levels supported stable digestion and gas yield. The biogas from potato peels showed a high methane content (84.32%) after purification, with minimal contaminants, making it suitable for cooking and electricity generation. These findings highlight the potential of agricultural waste to energy solutions, supporting small scale biogas systems for rural communities and reducing environmental pollution. Simple purification methods also improved the biogas quality and system efficiency as well.

RECOMMENDATIONS

Based on the results and observations from this study, the following recommendations are made:

1. Different pretreatment method be tried on the substrate to compare the biodegradability efficiency and enhancement of methane yield.
2. Co-digestion of potato peels with another agricultural waste, to possibly achieve a more balanced C/N ratio is encouraged.
3. The use of continuous stirred-tank digester or semi-continuous system is recommended to maintain steady agitation, reduce stratification, and to enhance overall microbial activity.
4. Future work can incorporate additional purification stages, such as silica gel drying or activated carbon filters.
5. Government and community stakeholders should promote awareness programs that will encourage the adoption of biogas technology as a sustainable alternative to firewood and fossil fuels, thereby reducing deforestation and greenhouse gas emissions.

6. Long-term assessment should be conducted to evaluate environmental impacts such as reduction in waste accumulation, mitigation of methane emissions, and improvement in sanitation practices.

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