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(RESEARCH ARTICLE)

Assessment of biogas production potentials of palm oil mill effluent and cow dung substrates in anaerobic digester

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Abstract

The biogas production potentials of palm oil mill effluent (POME) and cow manure (CM) substrates were evaluated using anaerobic digester. The first two digesters (D1 and D2) were charged with POME and CM for mono-digestion respectively. However, co-substrates digestion was done in digesters D3 (60/40 % POME-CM), D4 (70/30 % POME-CM), and D5 (80/20 % POME-CM) and all the digestion lasted for 21 days. The biogas yield of the digesters and performance of the digestions were measured by the analysis of moisture content, pH, total suspended solids (TSS), total solids (TS), volatile solid (VS), chemical oxygen demand (COD), biochemical oxygen demand (BOD) and total organic carbon (TOC) using standard analytical methods. The results showed that D4 (70/30 % POME-CM) has the highest biogas yield (1875±0.11 mL) while D2 (100 % CM) gave the lowest biogas yield (443±0.15 mL). The BOD of D3, D4 and D5 were not detected. The concentrations of COD, TS, TSS and TOC showed a significant ($p<0.05$) decrease in D1, D3, D4 and D5 compared to D2. While D2, D3, D4 and D5 showed a significant ($p<0.05$) decrease in moisture content compared to D1. However, D1, D3, D4 and D5 showed increasing level of alkalinity compared to acidic level of D2. Therefore, this study suggests that co-substrates anaerobic digestion of palm oil mill effluent and CM are suitable for biogas production.

Keywords: Biogas; Methane; Anaerobic digestion; Co-digestion; Palm oil mill and Cow manure.

1. Introduction

Oil palm, derived from the fresh palm fruit, is a perennial crop extensively cultivated in the tropical and subtropical regions of West Africa (1). Indonesia, Thailand, Colombia, and Nigeria have emerged as the world's largest producers of crude palm oil (2). Belonging to the genus Elaeis within the Palmae family (3), oil palm processing generates three waste streams: solid waste, liquid waste, and gaseous emissions.

Oil palm processing waste, particularly palm oil mill effluent (POME), serves as a significant feedstock for biomass energy production. Biomass energy can be harnessed for various biofuel types such as biogas, bioethanol, biodiesel, bio-methanol, bio-butanol, bio-oil, briquette, bio-hydrogen, and bioelectricity using diverse conversion technologies (4). Bioconversion involves the biological transformation of waste or the conversion of complex organic waste into valuable metabolites through biological processes, often employing bacteria, yeast, and fungi.

When POME is discharged into water bodies, it settles, decomposes slowly, consumes dissolved oxygen, causes turbidity, emits foul odors, and can harm aquatic ecosystems due to its prolonged decomposition process. Before discharge, POME must undergo treatment to meet waste quality standards set by environmental agencies (5). Treatment methods for POME include aerobic and anaerobic processes. Aerobic digestion involves oxygen utilization,

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exhibiting a high microbial growth rate, potentially leading to shorter retention times during biogas production. In contrast, anaerobic treatment occurs without oxygen and features slower microbial growth, resulting in longer retention times compared to aerobic processes.

During anaerobic treatment, organic components of POME degrade, releasing methane (CH_4), carbon dioxide (CO_2), oxygen (O_2), and hydrogen sulfide (H_2S). This degradation process occurs in four stages: hydrolysis and acidogenesis, fermentation, acetogenesis, and methanogenesis, ultimately producing biogas commonly referred to as biomethanation (6). Biogas typically contains 40 % to 70 % methane (CH_4) and poses a greenhouse gas (GHG) potential compared to carbon dioxide (CO_2) if released into the atmosphere, contributing to global warming. Purifying biogas into biomethane enables its use in transportation, potentially reducing GHG emissions at palm oil mills and nearby petrol stations (7, 8).

In large mills, POME primarily originates from sterilization condensate, separator sludge (from classification), and hydroclone processes during oil palm milling. Conversely, smaller quantities of POME primarily result from sterilization condensate and clarification, with hydroclone contributing less (5, 9) . POME comprises complex vegetative matter, colloidal slurry (a suspension of water, oil, and total solids), and nutrients such as nitrogen, potassium, magnesium, calcium, cadmium, copper, chromium, and iron (10, 11).

Palm oil mill effluent poses environmental risks, including oxygen depletion, soil and aquatic ecosystem pollution, and disruption of clean water access for human use, leading to land and ecosystem contamination. However, employing environmentally friendly biotechnology can convert POME into a valuable resource (12). Researchers have explored co-digestion of wastes for biogas production, including olive-oil mill wastewater, poultry manure, and food waste. Effective management of cow dung, which harbors high pathogen concentrations, is essential to minimize environmental pollution and public health hazards (13, 14).

The utilization of CM as a "carrier" substrate during the co-digesting of POME with CM in this study has been recognized as a novel alternative strategy for raising the reactor's efficiency and yield of biogas. Because manure has a high quantity of nutrients, micronutrients, and other trace elements that promote optimal bacterial growth, combined with a high buffering capacity that maintains the reactor's ideal pH, it can be employed as a "carrier" substrate (15, 16).

2. Materials and methods

2.1. Collection and preparation of Materials

The following materials were used for the construction of the bio-digester:

A 220-litre tank served as the container for holding the substrate material, facilitating decomposition and biogas production while PVC pipes of various diameters were utilized at different sections of the digester, including the slurry outlet, slurry inlet, and gas holder. Furthermore, corks were employed to seal openings, ensuring airtight conditions to maintain the anaerobic environment within the bio-digester. In addition, approximately 900 elbows were utilized for seamless connections between components, ensuring proper assembly of the bio-digester. Meanwhile, control valves were installed at various points to regulate air inlet and prevent the entry of air into the bio-digester. A ¼ inch rubber hose was used to collect the gas generated by the bio-digester and direct it to the measuring cylinder for measurement purposes.

2.1.1. Digestion Substrates

The materials utilized in this investigation comprised POME and CM as substrates. The POME was sourced from a nearby palm oil mill located in the Unwana community of Ebonyi State, Nigeria, while cow dung was obtained from the animal farm within the Department of Horticulture, Akanu Ibiam Federal Polytechnic, Unwana, Ebonyi State, Nigeria. Five digesters were assembled specifically for this research endeavor. Similarly, both POME and CM were subjected to individual digestion as well as co-digestion processes.

2.1.2. Feedstock Preparation

The stored POME and CM were retrieved from the cold room and allowed to thaw until reaching room temperature, typically between 28°C to 34°C. For the CM, its volume was measured using a measuring cylinder. Once measured, then transferred into a beaker. POME was gradually added to the beaker until the desired volume of the mixture was achieved. Prior to adding POME into the beaker, the POME solution was stirred for a minute to ensure homogeneity. Subsequently, the mixture of cow manure and POME was thoroughly stirred again using a glass rod to enhance their blending. Following this, the mixed solution was transferred into anaerobic digester bottles using a conical funnel.

2.2. Methods

2.2.1. Operation Startup

Five improvised batch digesters (designated as D1, D2, D3, D4, and D5), each with a capacity of 1.5 L and a working volume of 1.25 L, were employed in this study. U-tubing with an internal diameter of 9 mm and valves with a ¼ inch internal diameter were affixed to the caps of each batch digester, with silicon sealant applied to prevent air entrapment. Biogas collection was facilitated using plastic gas bags. Prior to loading the digesters with substrates, the U-tubing was filled with tap water up to a marked level. The experiments were conducted at ambient temperatures ranging between 28 °C and 34 °C.

The first two digesters (D1 and D2) were charged solely with POME and cow manure, respectively, for mono-digestion. The remaining three digesters (D3, D4, and D5) were charged with varying mixtures of POME and cow manure: 60 % POME + 40 % cow manure, 70 % POME + 30 % CM, and 80 % POME + 20 % CM for co-digestion, respectively. Initial pH levels were recorded as neutral before the onset of anaerobic digestion (AD). Nitrogen gas was purged through the digesters to eliminate oxygen and establish anaerobic conditions in the headspace, following the method described by Hassan et al. (2004). Subsequently, the digesters were connected to gas bags for biogas collection. The volume of gas generated was measured daily using the water displacement method, whereby the volume of water displaced in the U-tubing equated to the volume of gas produced.

2.2.2. Analytical Methods

The following parameters were measured before and after the experiment according to the standard method of American Public Health Association (APHA, 2005). The parameters measured were; pH, total suspended solids (TSS), total solids (TS), volatile solid (VS), chemical oxygen demand (COD), biochemical oxygen demand (BOD) and total organic carbon (TOC). The purpose of measuring the parameters mentioned above was to know their effects on the performance of anaerobic digestion process and biogas production.

2.2.3. Statistical Analysis

The results of the analysis were obtained in triplicate and analyzed using using (IBM SPSS software 25.0) one-way ANOVA to obtain the descriptive and multiple comparisons, LSD (Post Hoc Test). The mean difference was taken to be significant at $p<0.05$.

3. Results

3.1. Characteristics of Substrates

The fresh POME and CM were analyzed with respect to volatile solids (VS), total solids (TS), total suspended solids (TSS), chemical oxygen demand (COD), biochemical oxygen demand (BOD) and total organic carbon (TOC) content as well as pH.

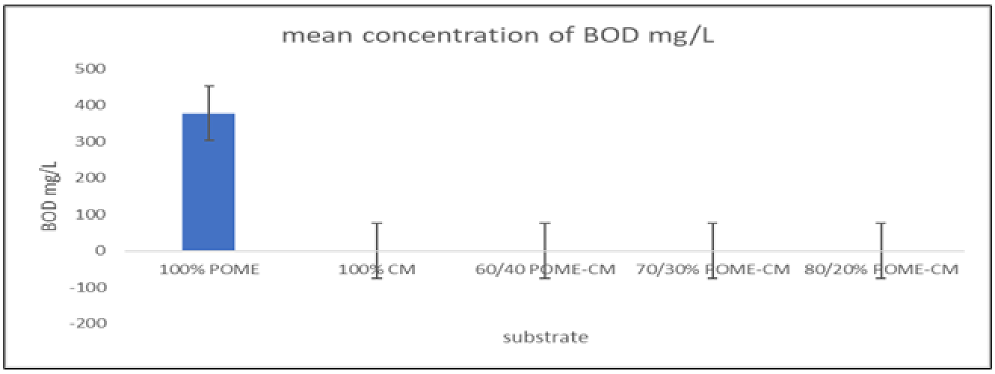

Figure 1 Effects of biodigestion of substrates on BOD concentration.

The BOD concentration in 100% CM, 60/40% POME-CM, 70/30%POME-CM and 80/20% POME-CM substrates were not detected in the substrate. However, 100% POME showed an increase in BOD level as shown in Figure 1 above.

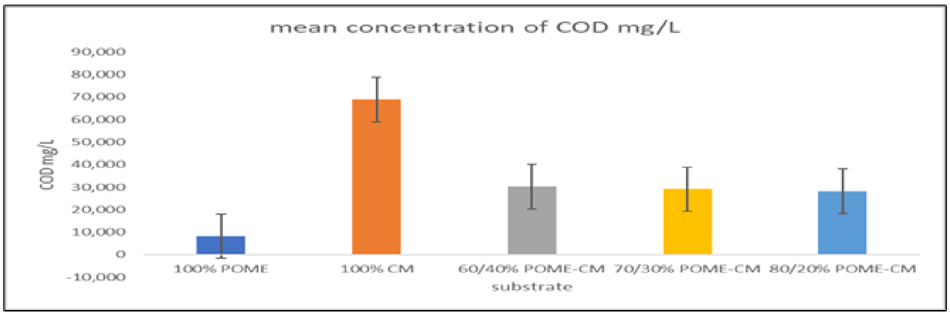

Figure 2 Effects of Biodigestion of substrates on COD concentration

The substrate with 100 % CM showed a significant (*p*<0.05) increase in COD concentration compared to other substrate. There were no significant difference in substrate 60/40 % POME-CM, 70/30 % POME-CM and 80/20 % POME-CM. while substrate 100 % POME gave the lowest concentration of COD.

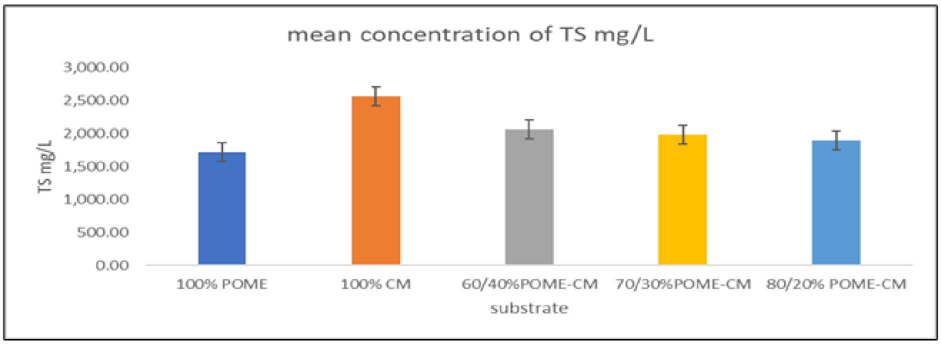

Figure 3 Effects of Biodigestion of substrates on TS concentration

The biodigestion of the substrate 100 % CM showed a non-significant (*p*> 0.05) increase in TS concentration compared to substrates 100 % POME, 60/40 % POME-CM, 70/30 % POME-CM and 80/20 % POME-CM. But no significant differences in TS concentration of 100 % POME, 60/40 % POME-CM, 70/30 % POME-CM and 80/20 % POME-CM (Figure 3).

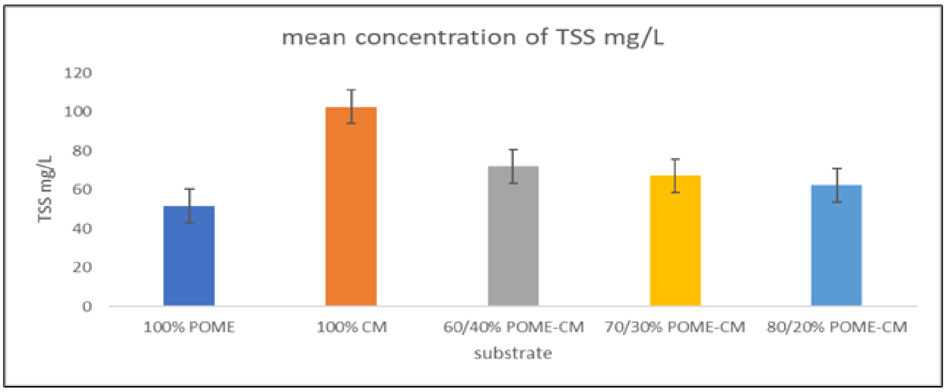

Figure 4 Effects of Biodigestion of substrates on TSS concentration.

The analysis of TSS concentration in the substrates showed that substrates 100 % POME, 60/40% POME-CM, 70/30 % POME-CM and 80/20 % POME-CM gave significant (*p*<0.05) decrease in TSS compared to 100 % CM (figure 4).

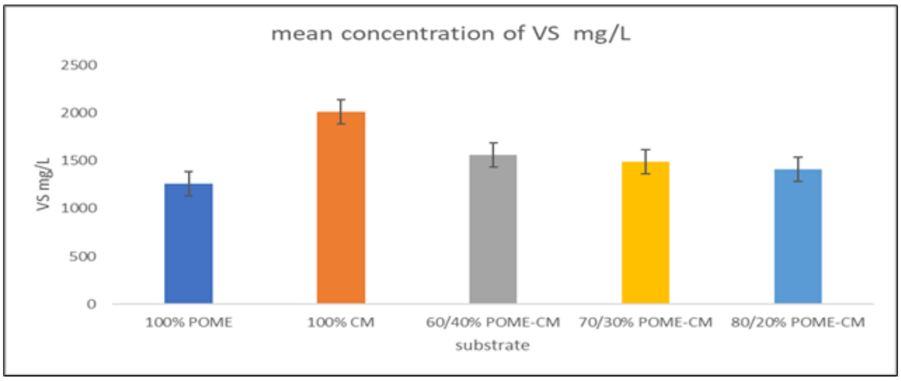

Figure 5 Effects of Biodigestion of substrates on TSS concentration.

Analysis of 100 % CM showed a non-significant (*p*>0.05) increase in TSS compared to substrates 100 % POME, 60/40 % POME-CM, 70/30 % POME-CM and 80/20 % POME-CM (Figure 5).

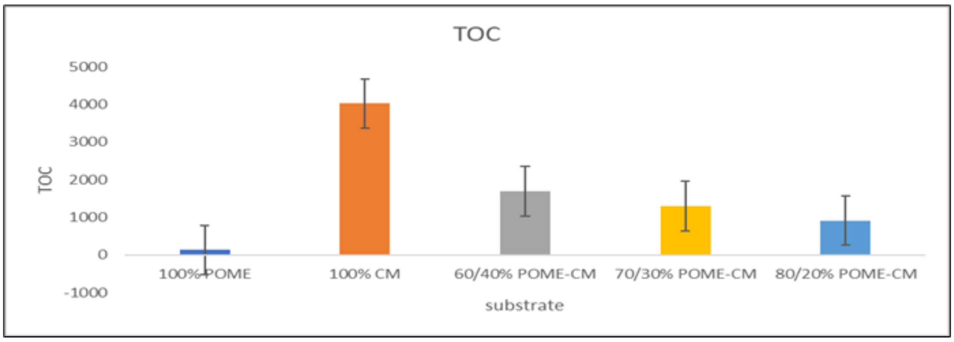

Figure 6 Effects of Biodigestion of substrates on TOC concentration.

The TOC level of substrates was analysed as shown in figure 6 and the result showed that 100 % CM significantly increased in TOC level compared to substrates 100 % POME, 60/40 % POME-CM, 70/30 % POME-CM and 80/20 % POME-CM.

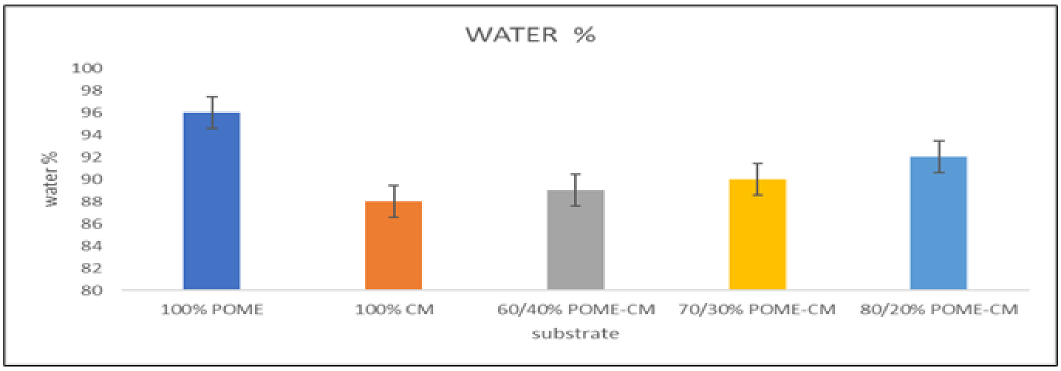

Figure 7 Effects of Biodigestion of substrates on water level.

Substrate 100 %POME showed the highest water level while 100 % CM was the least. The order of decreasing level of water as shown in figure 7 is 100%POME > 80/20% POME-CM > 70/30 % POME-CM > 60/40 % POME-CM > 100 %CM

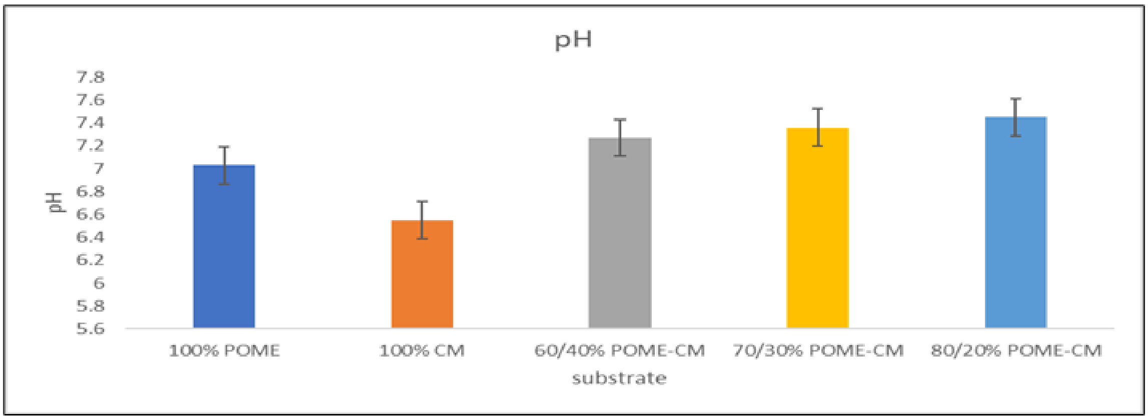

Figure 8 Effects of Biodigestion of substrates on pH level.

The pH level of the substrates showed 100 % CM as the most acidic while 80/20 % POME-CM was most alkaline. The order of decreasing acidity of the substrates is shown as 80/20 % POME-CM< 70/30 % POME-CM < 60/40 % POME-CM < 100 %POME < 100 % CM (figure 8).

3.2. Biogas Production

In the production of biogas, digester D2 (100 % CM) and D3 (60/40 % POME-CM) did not produce biogas on the first day of digestion, digesters D1 (100 % POME), D4 (70/30 % POME-CM), and D5 (80/20 % POME-CM) did. Daily biogas volume measurements and a cumulative volume calculation were performed using the water displacement method.

The production of biogas was represented by a volume yield (ml). The amount of biogas produced increases with the amount displaced. At 1atm, the biogas was collected at room temperature, which ranges from 28 to 34 degrees Celsius. Biogas production was not possible in digesters D2 (100 % CM) and D3 (60/40 % POME-CM) until the tenth and fifteenth days, respectively. There are two things that cause delays in the manufacturing of biogas..

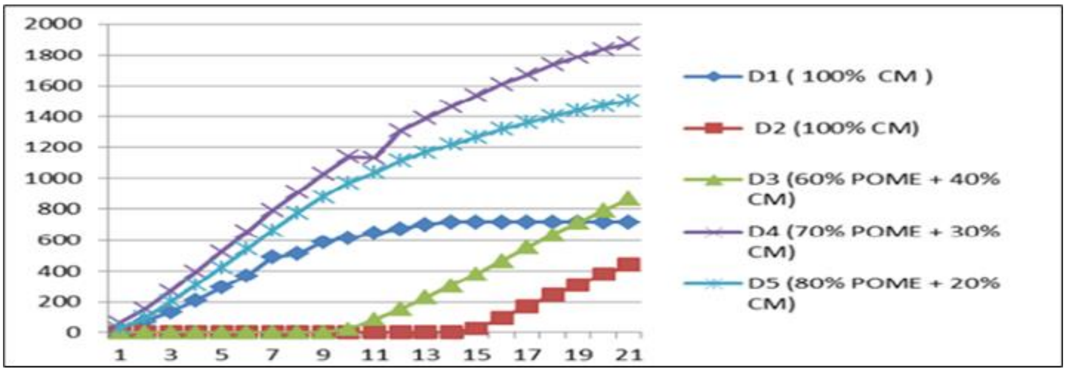

Figure 9 Mean volume of biodigester gas yield after 21 days

After 21 days, the digesters D1 (100 % POME), D2 (100 % CM), D3 (60/40 % POME-CM), D4 (70/30 % POME-CM), and D5 (80/20 % POME-CM) produced the following biogas yields: 717 ±0.05 mL, 443±0.15 mL, 864±0.16 mL, 1875±0.11 mL, and 1504±0.10 mL. Biodigester D4 (70/30 % POME-CM), showed a significant (p<0.05) increase in average gas yield compared to 100 % CM and 100 % POME. Combine substrate of POME and CM showed significant difference in gas output compared to single substrates (Figure 9).

4. Discussion

The analysis of various characteristics of the substrates evaluated reflected the general performances and efficiencies of the biodigesters in biogas production. Biochemical and chemical oxygen demand of the substrates were significantly higher in 100 % POME and 100 % CM respectively compared to combined substrates. High BOD and COD is an indication of increasing accumulation of organic matters in the anaerobic digesters of these substrates.

Further, excessive organic loading can inhibit the activity of anaerobic organisms which can result in volatile fatty acid (VFA) accumulation, leading to a process instability and reduced biogas production. Certain organic compounds with high COD values, such as long-chain fatty acids, can be difficult to degrade anaerobically. Their accumulation can inhibit methanogenesis and decrease biogas yield (17).

High level of total solid, volatiles solid, total suspended solids, and Total organic carbon occurred mostly in D2 (100 % CM). The high total solids might have caused increased viscosity of the digester slurry, which might have hindered the mixing and mass transfer processes within the digester. This might have resulted in poor substrate availability to the microbial consortia, leading to reduced biogas production rates for D2 as shown.

Higher volatile solids and total organic carbon content generally indicate a higher potential for biogas production. However, efficient degradation of volatile solids and total organic carbon is crucial for microbial activity maximizing biogas yield. The combine substrates might have shown higher degradation efficiency even with low volatile solid level and total organic solid and this must have enhanced the increase gas yield seen in biodigesters D3 to D5. This agrees with Murto et al. (2004)(18) that co-digestion may increase biogas output by 50 - 200 %, depending on the operating environment and substrates utilized.

Although, the ratios of volatile solids to total solids in substrates D1 to D5 were marginally different, it is an important indicator of the digestibility of the organic matter. However, this finding is at variance with El-Mashad and Zhang, (2010) (19) that opined that higher volatile solid fraction typically correlates with higher biogas production potential. Another reason for low gas yield of D1 and D2 is the level of total suspended solids. High levels of total suspended solids can lead to the accumulation of particulate matter in the digester, which may inhibit microbial activity by limiting the contact between microorganisms and the organic substrate. This must have resulted in reduced biogas production rates and process inefficiency in D1 and D2.

The moisture level of the biodigesters showed that 100% POME in D1 has more moisture compared to others. This must is associated with the low gas production; the excess water must have caused substrate saturation and limited the gas diffusion, and reduce biogas production rates. Ibrahim et al. (1985) (20) states that the methanogenesis process of POME will be restricted by the anaerobic digesting process alone.

However, proper amount of water levels can help to create a suitable environment for gas formation and release, allowing for efficient biogas production. Inadequate water levels can lead to gas entrapment, foaming, or gas pockets, hindering gas removal and potentially causing process upsets (21, 22). The most alkaline substrate was 80/20 % POME-CM in digester D5, the alkaline pH range for these co-substrates were possibly the suitable range of the anaerobic microorganism to carry out the proper digestion and this correlates with high gas yielded by the co-substrates.

pH levels influence the activity and growth of microorganisms involved in the anaerobic digestion process. Different groups of bacteria and archaea thrive at specific pH ranges, with methanogenic bacteria typically preferring neutral to slightly alkaline conditions (pH 6.5-7.5) (23, 24). Maintaining the pH within the suitable range for methanogens (typically 6.5-7.5) is critical for maximizing methane yield and biogas production (25, 26) . pH deviations can lead to a shift in microbial populations and reduced methane output (27).

5. Conclusion

The potential use of POME and CM as single substrates subjected to anaerobic biodigestion for biogas production showed significant facts. The high level of chemical oxygen demand, total solids, and total suspended solids were significantly higher in cow manure (CM). These caused inefficient digestion even with high volatile solid and total organic carbon that were adequate and necessary for biogas yield. High BOD and excess moisture were some of the hindrances of 100% POME to sufficient gas production. However, The cosubstrates in D3 to D5 (60/40% POME-CM, 70/30%POME-CM, 80/20% POME-CM) provided adequate moisture, pH ranges, BOD, COD, TS, and TSS needed by the anaerobic organisms for proper and efficient digestion for high biogas production. Therefore, this study suggests that co-substrates anaerobic digestion of palm oil mill effluent and cow manure are suitable for biogas production.

Compliance with ethical standards

Disclosure of conflict of interest

Authors hereby declare that there was no conflict of interest

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