BIOGAS PRODUCTION THROUGH ANAEROBIC CO-DIGESTION OF PALM OIL MILL EFFLUENT WITH CATTLE MANURE

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Abstract

One of the greatest alternatives to produce biogas is combining palm oil mill effluent (POME) with cattle manure (CM). The operation was carried out at a mesophilic (37°C) temperature and semi-continuously mixed with the stirrer in this study. The electrical energy was utilised at mixing ratios of POME and CM of 25:75, 40:60, 50:50, 60:40 and 75:25. This operation produced a maximum of 1,567 mL of biogas, with a methane content of 64.13 %. The best-preferred method for obtaining biogas was a 50:50 mixing ratio of POME and CM at a mesophilic temperature (37°C). A successful economic effect study of a biogas plant has also been anticipated. Since this technology is widely used, the planned biogas facility looks to be economically viable, with a five-year payback period on the original expenditure. In conclusion, the current research presents a comprehensive technique for combining many factors in order to increase the biogas output.

Keywords Anaerobic Bioreactor, Anaerobic Co-digestion, Palm Oil Mill Effluent, Cattle Manure, Biogas Production.

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Introduction

Developing innovative and applicable ways to produce bioenergy with the ability to overcome challenges are necessary. Anaerobic Digestion (AD), a biological conversion process, is a carbon-based option for converting organic wastes into biogas and removing the environmental concerns of waste management (Liu et al., 2013; Zaied et al., 2020a). The anaerobic reactor system may provide a way to overcome the limitations of individual element activities (Ahmadi-Pirlou et al., 2017). The generation of biogas from the co-digestion of POME and CM enhances the efficiency of the system. Anaerobic co-digestion (ACoD) is an oxygen-free treatment method that enhances system efficiency by using several substrates (Zaied et al., 2020b). As a result, compared to single substrate digestion, it produces more energy and improves system stability (Thanarasu et al., 2018). POME, indeed, is a black liquid that may readily dissolve and get suspended, and following a chemical breakdown by bacteria, it generates smells. POME can eventually damage the environment if dumped directly into the rivers, since it has a higher biochemical and chemical oxygen requirement. On the other hand, a massive amount of manure is currently being produced at various animal farms, causing substantial environmental damage (Liu et al., 2013).

In fact, the POME has anti-alkanic properties and its breakdown is difficult. CM element analysis, nevertheless, reveals a significant quantity of oxygenated compounds, possibly due to the type of feed the cattle consume. The AD is accomplished through bacterial groups and is largely influenced by variables such as pH, retention period, temperature and bacterial existence, and the process is rather sluggish. In the AD, cationic elements like sodium, potassium and others are required for waste microbial development. Nevertheless, these elements presence in excessive concentrations can suppress microbial activity (Pérez-Fortes and Tzimas, 2016). Because of its low proportion, it is favourably impacted by the presence of metal components. It enhances biogas generation through the ACoD process. Nevertheless, as an extraordinary inoculant in the co-digestion operation, CM has a high buffer balancing function, an abundance of anaerobic microbes and a broad variety of necessary nutrients for microbial growth (Liu et al., 2013; Zaied et al., 2020c).

At present, POME and CM co-digestion suffer from the following drawbacks: (a) a long set-up period and sluggish reaction time, which necessitate a lengthier hydraulic retention time in an anaerobic reactor; (b) no prior mix proportion in POME and CM co-digestion to enhance biogas yield; and (c) methanogenesis is severely hampered by system constancy failure caused by an unexpected pH drop. The use of co-digestion of POME and CM has been explored in this study to achieve, which will evaluate the best mix proportion of these two substrates, increased biogas production with maximum biogas yield, and minimise Carbon Oxygen Demand (COD) and Volatile Solid (VS). This research also studies economic and environmental impact assessments to understand better how to construct a biogas plant on a big scale.

Methodology

Feedstock Collection and Preparation

POME was collected in a 100L sample collecting container from the LKPP Corporation Sdn. Bhd., No.45/4, Jalan Teluk Sisek, 25000 Kuantan, Pahang, Malaysia's anaerobic pond. A total of 100 kg of partly digested CM was obtained from a medium-sized farm in Gambang, Malaysia. The POME sample will go through a basic filtration process to remove any coarse components. It will then be filtered again using a filter medium made up of insignificant stones with an average size of 0.6 cm. The screened deposit will be filtered through another bed of minor stones and sand (average diameter/dia. 300–600 mm) at a ratio of 1:2. The rest will be filtered on the surface with Whatman No. 41 filter paper (20–25 m). A 1:25 dilution of CM in water will be prepared and filtered via a screen (20 m) to eliminate coarse components.

Reactor Design and Fabrication

The traditional reactor is not capable of preserving the pH as well as the temperature. To attain excellent control over the system, pH and temperature controllers are added. A DC-AC converter will transform the two-unit battery cell into electrical power. The reactor has a total volume of 5.0 L, with a working volume of 3.5 L. The cylindrical global configuration system is used to construct the reactor. Glass and stainless steel make up the primary reactor. It is securely fastened by a steel body topping and four bolts. The agitator is permanently attached to the reactor. The stirrer includes a speed control mechanism that ranges from 0-450 revolutions per minute. Water jacket is also used to maintain the necessary temperature for bacteria destruction. Two feeding injectors are also employed to pour the POME and CM inside the digester. A gas collecting bag was used to collect the produced gas. Figure 1 illustrates the experimental diagram.

Figure 1: Experimental set-up for the Anaerobic Bioreactor (A: Battery, B: DC-AC Converter, C: Water Vapourisation, D: Stirrer Motor, E: Main Reactor).

Reactor Operation for Anaerobic Digestion

The bioreactor was maintained at 37°C for 24 working days, while being fed 437.5 mL of the same substrata in three days until it reached 3.5 L of operating volume for 24 days digesting. The mixing ratios of 25:75, 40:60, 50:50, 60:40 and 75:25 were investigated. Direct motors driven by electrical energy and connected to propellers spinning at 60 rpm produced the mixing. Meanwhile, anaerobic microbes devour organic molecules in the sludge as a source of carbon and create anaerobic conditions conducive to the growth of firm anaerobes. The characteristics of feed wastewater were tested three times a week, with the exception of pH, which was tested daily. Throughout the co-digestion period, a pH of 7.0±0.1 will be maintained using 1N NaOH. The outcomes of reactor operation will be the impacts of co-digestion on biodegradation, biogas production and system stability. The combination of POME and CM was gradually increased, since the microorganisms required time to adjust to the new habitat.

Economic Study

The payback time (PBT) was assessed from the capital cost divided by the annual cost based on Equation (1).

$$Payback\ period = \frac{Capital\ cost}{Annual\ cost} \tag{1}$$

The following Equation (2) was applied to calculate the net present value (NPV):

$$NPV = \sum_{t=1}^{n} CF/(1+k)^t - I \tag{2}$$

Where, CF = Cash flow at time (t), n = number of years considered, k = interest and I = Initial investment.

It is necessary to set the NPV to zero and execute computations to obtain the discount rate in order to calculate the IRR (k). In practice, IRR cannot be calculated rationally, necessitating the use of trial-and-error approaches and, in certain cases, software programs based on Equation (3).

$$IRR = NPV = \sum_{t=1}^{n} \quad CF/(1+k)^t - I = 0 \quad (3)$$

Analytical and Statistical Methods

At a constant temperature and pressure, biogas production was determined using the water displacement method (Wang et al., 2014). A gas chromatography (GC) instrument from Agilent was used to determine biogas output and methane composition. The carrier gas was helium, with a flow rate of about 30 ml/min. Temperatures of 70°C, 120°C and 200°C were maintained in the oven, intake and detector, respectively (Liu et al., 2013). Standard water and wastewater examination procedures were used to determine the total solids (TS), volatile solids (VS), total nitrogen (TN), total phosphate (TP), chemical oxygen demand (COD), biochemical oxygen demand (BOD), volatile fatty acids (VFA) and pH (Association et al., 1915). Microsoft Excel 2016 was used to analyse the data for three replicates. This program will generate essential statistical data. OriginPro 9.1 will compute the mean, standard deviation and standard error from replicates, and apply them to each figure and table data.

Results and discussion

Characterisation of Substrates

Prior to co-digestion, the physicochemical properties of POME and CM are shown in Table 1. POME's TS and VS values are respectively 39,750 mg/L and 32,560 mg/L. This high presence indicates that microorganisms in the substrate are readily available. The POME is largely made up of cellulose, hemicellulose, carbohydrates, glucose and lignin, whereas the CM is mostly made up of considerable buffering capacity, a huge number of anaerobic bacteria and a wide variety of necessary nutrients for bacterial development (Ahmadi-Pirlou et al., 2017; Liu et al., 2013). The pH of POME was reported to be 4.6, whereas the pH of the co-substrate, CM, was reported to be 5.4. The POME's COD value was determined to be 28,340 mg/L. In comparison to other excess components, dung animals had a high nitrogen concentration. The ammonia produced by CM throughout the digesting phase helped to maintain the advanced process's stability. Another crucial element in the anaerobic digestion process is the Carbon to Nitrogen ratio (Ivana et al., 2016).

Table 1: Compositions and Characteristics of Palm Oil Mill Effluent and Cattle Manure.

Parameter	POME	CM
pH	4.6	5.4
COD (mg/L)	28340	16720
BOD (mg/L)	15280	9280
TS (mg/L)	39750	2380.5
VS (mg/L)	32560	1167
VFA (mg/L)	3200	2800
TC (mg/L)	15689	2621.59
TN (mg/L)	725	317
TP (mg/L)	132	27.4

Biogas Production

Figure 2 depicts the total biogas production for five reactors. From the first day of reactor operation, reactors R2 (40 percent POME + 60 percent CM), R3 (50 percent POME + 50 percent CM), R4 (60 percent POME + 40 percent CM) and R5 (75 percent POME + 25 percent CM) produced biogas, whereas reactor R1 (25 percent POME + 75 percent CM) did not. The water displacement method was used to determine the volume of biogas generated on a daily and cumulative basis. The volume yield of biogas was measured in millilitres. Biogas was produced in proportion to the amount of water displaced. The total biogas generation from reactors R1, R2, R3, R4 and R5 after 24 days of operation was 637 mL, 782 mL, 1567 mL, 1,346 mL and 942 mL, respectively. According to the results of this study, co-digestion with a 50:50 mixing ratio is the best and may increase biogas production competency by 146 %, 100 %, 16 % and 43 %, respectively, compared to digestion of R1, R2, R4 and R5. The findings show that co-digestion with a 50:50 mixing ratio can increase biogas production by 15% to 150 %, depending on the functional state and substrates used.

The graph shows that during the 5th day, reactor R1 (25 % POME + 75 % CM) did not produce biogas. Two variables are thought to be at action, both of which might cause a delay in biogas production. As the cows have been fed primarily agricultural products, lignin, cellulose, and hemicellulose are plant materials that retain about 90% of their dry weight in an irregular way in the cattle manure. The presence of lignin in lignocelluloses provides a protective barrier that prevents bacteria and fungi from degrading plant cells for biogas generation, unless the course is prepared. Pretreatment methods can alter the physical and chemical composition of lignocellulosic biomass while also increasing hydrolysis rates. Furthermore, because of the low biodegradation of CM, it might promote VFA accumulation, resulting in a reduction in biogas output from the reactor. The restriction of biogas yield was overcame once the VFA were dispersed and production began. Despite the possibility of VFA build-up, the pH of reactor R1 (25 % POME + 75 % CM) was preserved between 6.5 and 7.5 due to the buffering ability of CM.

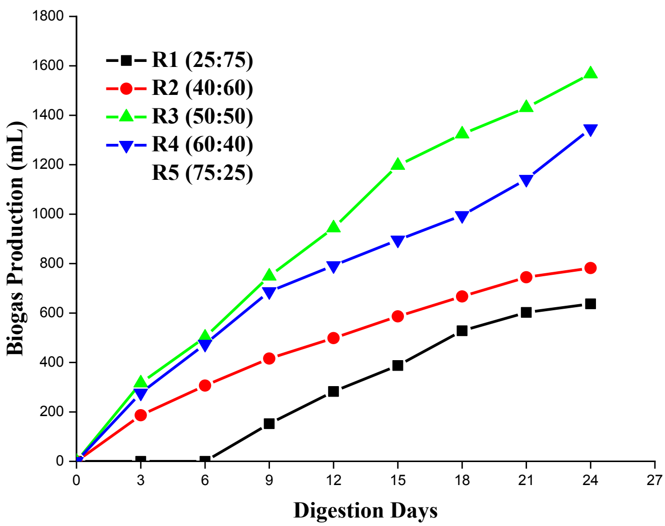

Figure 2: Total Biogas Production after 24 Days of Digestion.

Methane Composition

The most crucial and last component of the ACoD process is methanogenesis for biogas generation. The existence of a small number of methanogens will result in less biogas being produced. Figure 3 shows that reactor R3 (50 % POME + 50 % CM) produced the highest proportion of methane composition. The methane concentration reached was 64.13 %. In addition, R1 received 40.21 %, R2 received 45.72 %, R4 received 54.85 % and R5 received 49.37 %. The remaining proportions in produced biogas are hydrogen (H_2), oxygen (O_2), nitrogen (N_2), carbon dioxide (CO_2) and water (H_2O). In this investigation, the mixing ratio of 50:50 for POME and CM was determined to be the optimum for biogas generation and methane composition.

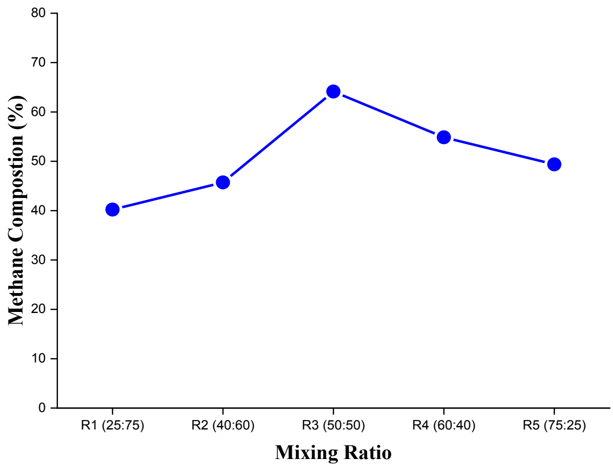

Figure 3: Cumulative Methane Composition (%) vs. Mixing Ratio after 24 Days of Digestion

COD Removal & VS Reduction

The greatest biogas output of 1,567 mL was obtained from reactor R3 (50 % POME + 50 % CM), according to the findings of this investigation. On the other hand, reactor R1 (25 % POME + 75 %

CM) produced the least biogas (637 mL). Reactor R1 generated biogas with a high degree of irregularity due to reduced COD removal, decreased VS, and the presence of less methanogens in a mixture of POME and CM. These data show that lowering COD levels and lowering VS levels enhance biogas production. The reason for this is because the methanogen functioned perfectly, resulting in the perfect breakdown of biological components (El-Mashad and Zhang, 2010). This implies that the microorganisms in reactor R3 are significantly more energetic than those in other combinations for biogas generation.

In this research, the efficacy of COD and VS removal was investigated for each reactor, and the findings are presented in Figure 4. In this case, reactor R3 achieved the highest COD removal percentages, 68 %, whereas reactor R1 achieved the lowest COD removal percentages, 15 %. COD elimination efficiency shows that bioreactor co-digestion is somewhat successful. Figure 4 depicts the percentage of COD elimination and percentage of VS reduction efficiency in the production of biogas. It also implies that VS is crucial for biodegradation, which indicates the metabolic condition of the AD system's biggest microbe group and process stability. The reactor's maximum VS removal effectiveness (63%) was achieved using R1.

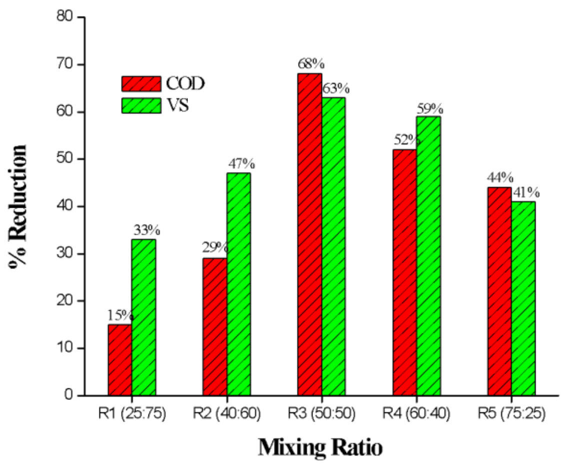

Figure 4: Effect of % COD Removal and % VS Reduction

Economical Impact Analysis

Since government administrations are always under pressure to handle wastewater effectively and distribute regulated investment, wastewater treatment is a key problem for developing countries. A financial study is necessary for the development of a large-scale biogas facility. An economic feasibility analysis for treating POME with an ACoD technique using CM as a co-substrate was done based on the findings of this research. After a 24-day digestion period, the mixed ratio (50:50) of substrates POMECM provided the best results in this study, with biogas production of 447.7 L/m3 of substrates and methane content of 64.13 %, resulting in 1.69 kWh of electric power generation. Table 2 shows the total cost, which includes investment expenses, transportation costs, earnings and development costs (manpower and operational maintenance). The overall cost of establishing a biogas plant with daily output capabilities of 18.65 L/m^3 is $1,961,500 USD. The Internal Rate of Return (IRR), Payback Time (PBT) and Net Present Value (NPV) are used to evaluate the system's performance (NPV). There are still certain challenges, such as plant building, transportation and personnel costs that might reduce its cost-effectiveness.

Table 2. Economic Study for Large Scale Bioreactor Plant

Items	Description	Amount (USD)
Total Overhead Cost	Plant Construction Cost	1,760,300.00
	Motor & Pump Cost	78,500.00
	Reactor Cost	122,700.00
Yearly Operational & Maintenance Cost	Periodic Maintenance Cost	64,370.00
	Labour Cost	194,200.00
	Transport Cost	90,400.00
Yearly Income	Electricity Revenue	805,310.00
	Heat Revenue	11,760.00
	Fertiliser Revenue	34,680.00
Yearly Benefits	Yearly Profits	502,780.00

Items	Description	Amount (USD)
Economic Ratios	Net Present Value (NPV)	1,900,971.46
	Payback Time (PBT)	4.60
	Internal Rate of Return (IRR, %)	44.08

To create this quantity of energy, a biomethanization facility requires a stirred container reactor with an operating capacity of roughly 17,000 m^3, a height of 15 meters and a diameter of 15 metres, with a hydraulic retention time of 24 days. A biogas storage container with a capacity of 2,700 m^3 is required by the facility. The POME treatment will take place in a 350 m^3 stagnant horizontally flowing vessel with a width of 10 metres, a length of 28 metres and a height of 1.25 metres. The POME dedicated to ensuring thermal stability in the reactor at mesophilic temperature (37°C) is generally heated by the effectiveness of the container. The top crust of the reactor suffers 22 % losses on average, while pipelines and plant insulation suffer 5 % losses (Shafie et al., 2012). The biogas plant generates 437 kWh of energy each year as a result of this.

It is worth noting that 33 biogas-powered pumps have been chosen. These pumps have a nominal power of 50 kW and cost 2,378.8 USD each, bringing the total cost of motor pumps to 78,500 USD. The transportation area is estimated to be about 20 kilometres. The annual profit will also come from energy savings gained by employing motor pumps that run on biogas generated in this biogas plant rather than electric power (Carneiro and Ferreira, 2012). Economic factors including the internal rate of return (IRR), net present value (NPV) and payback time (PBT) study indicate 1,900,971.46 USD, 44.08 % and 4.6 years, respectively. This study shows why equipment costs and sizes have increased. As a result, the results presented in this paper may be deemed proven.

Environmental Impact Analysis

Because it recovers a higher amount of bioenergy, biogas generation and usage are the best ways to treat POME from an environmental standpoint. The primary benefits of bioenergy reclamation from POME and CM are reducing wastewater volume for high demand in the land, lowering waste transportation costs to long-distance landfills, and, most significantly, a net reduction in environmental contamination (Moreno et al., 2017). When biogas is converted to electricity using a combustion heat and power (CHP) unit, greenhouse gases are produced (GHG). If the digesting technique is not used to generate power from biogas, the annual GHG emissions will be around 22,700 m^3 (Thanarasu et al., 2018). If the waste-to-energy system performs as intended, GHG emissions will be reduced by 17,870 m3 per year (Akbulut, 2012). When vehicle fuel is biogas, the global warming potential (GWP) effect is reduced by around 80-130 CO2 eq/ton, resulting in larger environmental advantages than igniting (Pérez-Fortes and Tzimas, 2016). Because of the high proportion of inorganic nutrition present in solid wastes following the ACoD process, they may be utilised as composts (N, P and K). Another important benefit of using biogas as a car fuel is that it creates less pollution. A diesel-powered vehicle produces 11 particles per MJ of fuel, but biogas-powered vehicles emit only 0.02 particulates per MJ. (Patterson et al., 2011).

Conclusion

Currently, the anaerobic bioreactor is the most widely used method for treating a wide spectrum of wastewaters. It is a one-of-a-kind technology in terms of waste treatment applications and ease of installation. Despite these benefits, maintaining the required degradation efficiency, process stability and methane output is a key problem for the deployment of this technique. A key disadvantage of the anaerobic reactor is that it has less control over operating temperature and pH. The addition of digital temperature and pH control to the reactor system has improved the system. The greatest breakdown efficiency was achieved in a bioreactor by anaerobic co-digestion of POME with CM. In comparison to traditional treatment systems, co-digestion of POME and CM (50:50) has significantly increased biogas output and methane composition by 50-65 %. It is worth noting that mesophilic conditions (37°C) have been proved to be the best for speeding up methanogenesis. When compared to the control COD reduction; adding digital control of operating temperature and pH, as well as co-digestion of POME with CM, enhanced biogas output. This technique demonstrates a promising possibility to increase waste eminence. Furthermore, running costs can be lowered by using methane for heat or electricity energy generation in the facility. Models are also beneficial in the creation and design of bioreactors. Researchers should investigate the usefulness of the substantial model for evaluating the impacts of various substrate types, intake substrate concentrations, flow rates and biomass kinds on reactor performance. The microbial activity of anaerobic bioreactors in terms of methane production should be studied for enhanced biogas output.

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