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Study on Co-Digestion of Palm Oil Mill Effluent and Empty Fruit Bunches to Improve Biogas Production in Palm Oil Mill

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ABSTRACT

Utilization of empty fruit bunches (EFB) to increase biogas production could be developed through co-digestion of palm oil mill effluent (POME). Pre-treatment of EFB (shredding, grinding, and soaking) before it is utilized as a feedstock for biogas production is important to increase the biodegradability of EFB. The evaluation of the impact of EFB utilization on biogas production should be investigated to determine the optimum process conditions for biogas production from EFB and POME. This research consists of three steps: 1) Optimization of size of EFB and ratio of EFB-POME, 2) Optimization of hydrolysis and acidification retention time, and 3) Optimization of biogas production. The research result shows that co-digestion of EFB and POME increases biogas and methane production. Compared to POME only, co-digestion using POME and EFB (shredded 10%, shredded 15%, crushed 10%, and crushed 15%) is increasing biogas production in batch systems by 54.1%, 54.1%, 45.5%, and 75.2%, respectively. The research result also shows that in a continuous system with HRT for 25 days and similar feedstock, biogas production increased by 43.3%, 41.6%, 35.6%, and 62.6%, respectively, with methane concentrations maintained at about 60%. Co-digestion of EFB-POME with 15% crushed EFB is recommended to be applied in palm oil mills to increase biogas production.

Keywords: biogas, co-digestion, empty fruit bunches, palm oil.

INTRODUCTION

Palm oil mill effluent (POME) utilization as a feedstock of biogas production is quite common currently. In palm oil mills, biogas was utilized as fuel to produce steam and electricity, which was then exported to power grids. Upgrading biogas to bio-methane with methane content of more than 95% also growing. These kinds of conversions not only produce energy but also have been successfully to reduce greenhouse gases (GHGs) emission. Maximization and stabilization of biogas production is one issue that is important in biogas power plant from POME, but it is not easy to achieve. Fluctuation on reel production capacity in POME will have effect on POME production, it will be giving direct impact on energy (biogas and electricity) production. Additional feedstock is needed to increase and stabilize biogas production in palm oil mill even though POME production is unstable. The available organic matter in palm oil mill is empty fruit bunches (EFB). About 20–23% of the fresh fruit bunches (FFB) processed in the palm oil mill have the potential to be produced as EFB.

Currently, EFB is used as a mulch in oil palm plantations to retain organic carbon in the soil, but the duration of EFB degradation in the field is determined by weather and climate. Utilization of EFB to increase biogas production could be developed through co-digestion of EFB and POME. Co-digestion is a process that is increasingly being used for the simultaneous treatment of multiple solid and liquid organic wastes (Bouallagui et al., 2009). Due to its comparatively high organic content, EFB has the ability to act as a carbon source and offset POME's low nitrogen content during the co-digestion process. (Hosseini and Wahid, 2013). Pre-treatment of EFB before it is utilized as a feedstock for biogas production is important to increase the biodegradability of EFB. The evaluation of the impact of EFB utilization on biogas production should be investigated to determine the optimum process conditions for biogas production from EFB and POME. The separation process stage between hydrolysis, acidification, and methanation processes should also be considered to achieve optimum conditions for each process. The evaluation of the best pre-treatment process for EFB (shredded and crushed EFB) before using it as a feedstock for co-digestion of EFB-POME has never been carried out. EFB has a high ash content and mineral content, especially potassium and silica, so it can produce low heat energy. Minerals from EFB can be removed up to 74% using hot water leaching treatment and up to 92% when followed by water leaching. The lowest ash content is obtained by washing with large amounts of water (Prismantoko, 2017), but this can cause new problems in the form of increasing the amount of liquid waste produced by industry, so the EFB-POME co-digestion process is expected to be able to overcome this problem. The objectives of this research are to find out the best pre-treatment process for EFB before utilizing it as a feedstock for co-digestion EFB-POME and to evaluate the impact of co-digestion EFB-POME on biogas production.

MATERIALS AND METHODS

Materials and equipment's

The main materials used in this study are empty fruit bunches, palm oil mill effluent, sludge, and chemicals for laboratory analyses such as NaOH (JT Baker), H_2SO_4 (Supelco), COD reagent (HANNA HI 93754C-25 COD Reagent High Range), etc. The POME used in the research has characteristics of a pH 4.69–4.71, total solids 2.49–2.60 mg/L, S-COD 18510–21110 mg/L, and total volatile acids 5760–6504 mg/L. The EFB used in the research has characteristics of a water content 26.1% (shredder) and 31.4% (crusher) and an ash content 6.6% (shredder) and 6.0% (crusher). The equipment used is a crusher, oven (Mammert UN 55), furnace (Isuzu EPTR-13K), gas chromatography (Shimadzu GC-2014 serial no. C11484301828) with Shincarbon ST50 Coulmn and TCD Detector, COD reactor DRB 200, multiparameter photometer HI83399 with COD HI833999, pH meter (Hi 2550pH/ORP, vortx (Maxi Mix II Type 37600 Mixer), hot plate magnetic stirrer (Cimarec + Thermo Scientific), and other laboratory equipment.

Research procedure

This research was conducted in Agro-industrial Waste Management Laboratory, Faculty of Agriculture, University of Lampung from September to October 2023. This research consist of three steps: 1) Optimization of size of EFB and ratio of EFB-POME (Figure 1, Figure 2) Optimization of hydrolysis and acidification retention time (Figure 2 and Figure 3) Optimization of biogas production (Figure 3). Parameter to be analyzed consist of pH value, total volatile acid (TVA), soluble-chemical oxygen demand (S-COD), and total solid (TS).

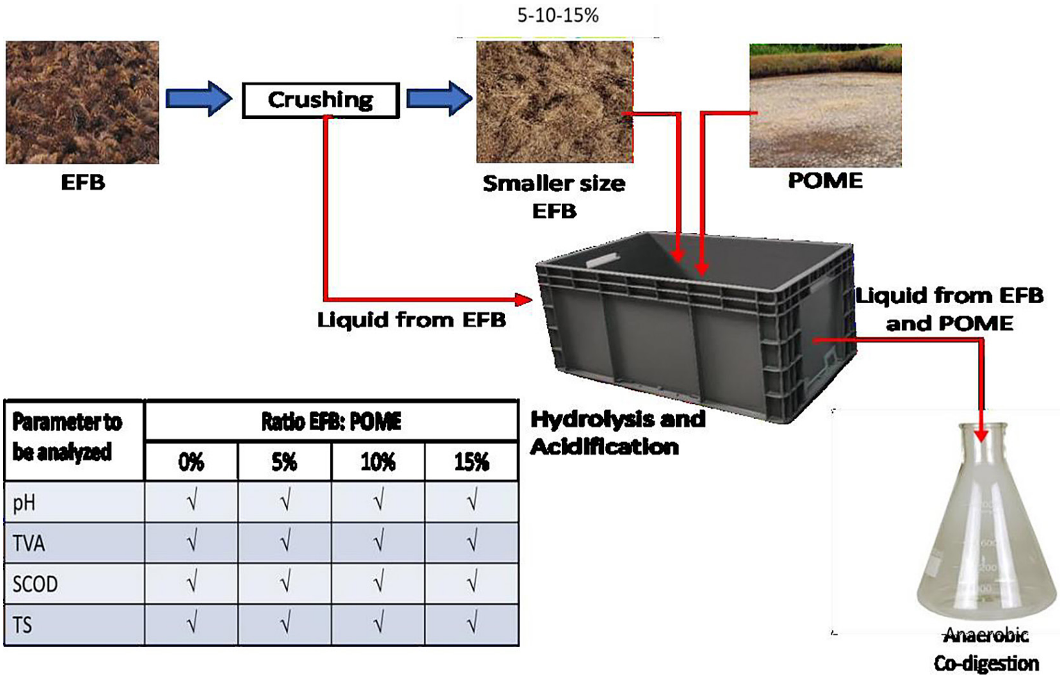
RESULT AND DISCUSSION

Step 1 and Step 2

In Step 1 and Step 2, shredded and crushed EFB was used to evaluate the increasing organic matters in liquid phase after these EFB was soaked in POME. Figure 4 shows the shredded and crushed EFB soaked in POME. The amount of EFB was varied as 5, 10, and 15% (w/v) and time of soaking was varied as 1, 2, and 3 days. After were soaked in POME with 1 to 3 days retention time, these EFB were pressed using manual presser to separate liquid and solid phase. The liquid phase was analyzed to know the changes of POME characteristics. Figure 5 shows liquid phase (POME) after mixed with shredded and crushed EFB.

pH value

The pH value is expressed as the reciprocal of the hydrogen ion concentration expressed in gmol equivalents per liter of solution (gmol). The pH value determines the alkalinity or acidity of anaerobic digestion. pH is important because microorganisms will decompose at pH values that are too high or too low. pH can be a good indicator of methanogenic activity, because a decrease in pH can indicate a conversion to VFA for methanogenic bacteria (Aldrich Piolo et al.,



Parameter to be analyzed	Ratio EFB: POME			
	0%	5%	10%	15%
pH	√	√	√	√
TVA	√	√	√	√
SCOD	√	√	√	√
TS	√	√	√	√

Figure 1. Pre-treatment of EFB and POME before anaerobic co-digestion

Parameter to be analyzed	Hydrolysis-Acidification HRT (days)			
	0 (POME)	1	2	3
pH	√	√	√	√
TVA	√	√	√	√
SCOD	√	√	√	√
TS	√	√	√	√

Figure 2. Pre-treatment hydrolysis and acidification before anaerobic co-digestion

2022). The results of the pH analysis on EFB-POME co-digestion can be seen in Figure 6. The research results show that the pH value with the addition of EFB to POME has increased. The more EFB added, the pH value also increases. This is because EFB contains organic and mineral materials in the form of potassium, calcium, and magnesium, which can decompose together with organic materials during the fermentation process. The process of decomposing minerals will release alkaline compounds, which are basic in nature, so that they can increase the pH of the solution (Fitriani et al., 2021).

The study's findings also demonstrate that adding HRT raises the pH value, albeit not significantly. The pH value increased from 4.91–4.98 to the interval 4.69–5.07. This is inline with earlier research by Nurliyana et al. (2015),

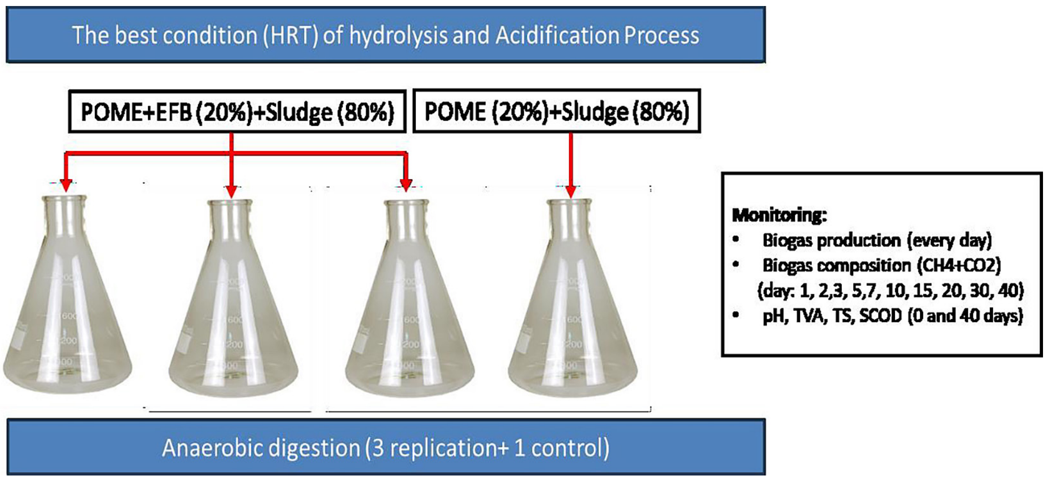


Figure 3. Optimization of anaerobic co-digestion using EFB-POME

Figure 4. Soaking shredded (a) and crushed (b) EFB in POME

Figure 5. POME after mixing with shredded (a) and crushed (b) EFB in POME

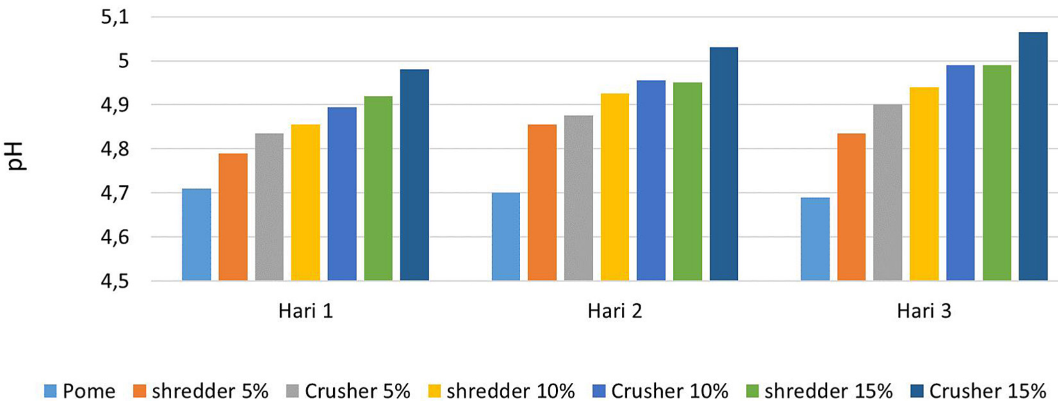


Figure 6. The results of pH analysis on EFB-POME co-digestion pre-treatment

which shows the pH value has increased from 4.8–5.7 to 7.8–8.2 after the digestion process takes place. This happens because microbes that eat organic debris high in protein produce alkalinity. The results of the research also show that EFB carried out by the crusher process has a relatively higher pH when compared to EFB used by the crusher. This is because the EFB that is crushed has a smaller size, so the organic material degradation process to produce alkaline components is easier. The smaller size of EFB provides a larger surface area to be exposed to biodegradation.

Total solid

The amount of solids still present in the organic material in a solution after pretreatment is called total solids (TS). According to the conducted research, TS is a solid that is produced when heating at a temperature between 103 and 105 °C. The TS value indicates the rate of destruction or decay of organic waste solid material (Saragih, 2010). The results of TS analysis can be seen in Figure 7. The research results show that the TS value increases when EFB is added. This is in line with research by Saelor et al (2017), which

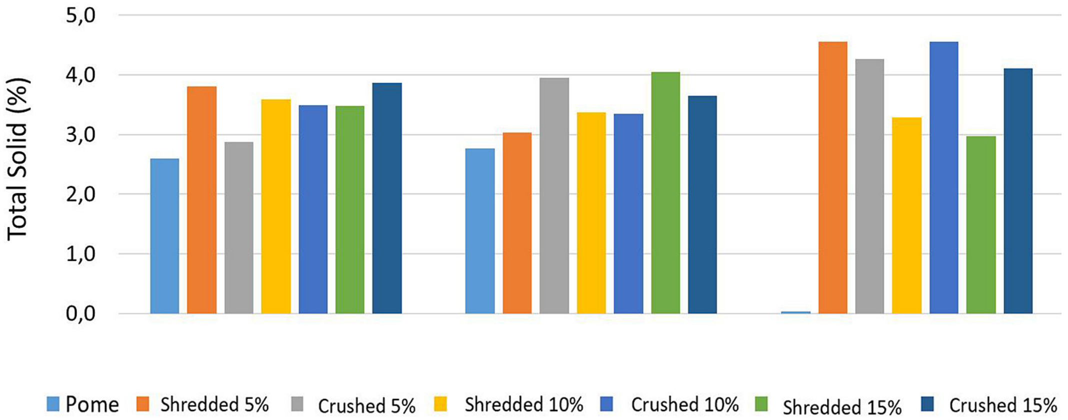


Figure 7. Total solid of EFB-POME co-digestion pre-treatment

states that the addition of EFB can affect the TS values because TS values for EFB and POME are 99.70% and 4.93%, respectively, so the addition of EFB to the research causes an increase in the TS value. According to Suksong et al. (2016), EFB is made up of cellulose (41.3%), hemicellulose (24.2%), lignin (20.5%), and extractives (8.9%) (proteins, fatty acids, carbohydrates, phenol, etc). The research results also showed that the TS value of the EFB-POME co-digestion pretreatment fluctuated along prolongation of HRT. Anwar et al (2021), states that the TS value can be influenced by the length of the fermentation process.

Total volatile acid

Total volatile acid (TVA) is an intermediate compound that will be converted into volatile acid at the acidogenesis stage. During the fermentation process, carbohydrates will be converted into VFAs. The VFAs value indicates the activity of acidogenic microorganisms (Strazzera et al., 2021). Because TVA is thought to be more sensitive to changes in conditions that occur during the anaerobic fermentation process, it is one of the process conditions that is utilized as an indicator for tracking stability in anaerobic processes. The results of the TVA analysis on EFB-POME co-digestion can be seen in Figure 8. The research results show that the addition of EFB to POME can increase the value of TVA. This is also in line with research by Sarwono et al (2016), which states that TKKS with a pre-treatment process will provide better glucose. This glucose will be converted into organic acids at the acidogenesis stage so that it will help increase the TVA value. The higher the TVA value, the more carbohydrates are converted into organic acids by microorganisms (Anwar et al., 2021). EFB contains several types of carbohydrates, such as 43.30% cellulose, 26.20% hemicellulose, and 30.50% lignin (Saelor et al., 2017). These compounds will be converted into organic acids during the fermentation process. The TVA value is correlated with the TS

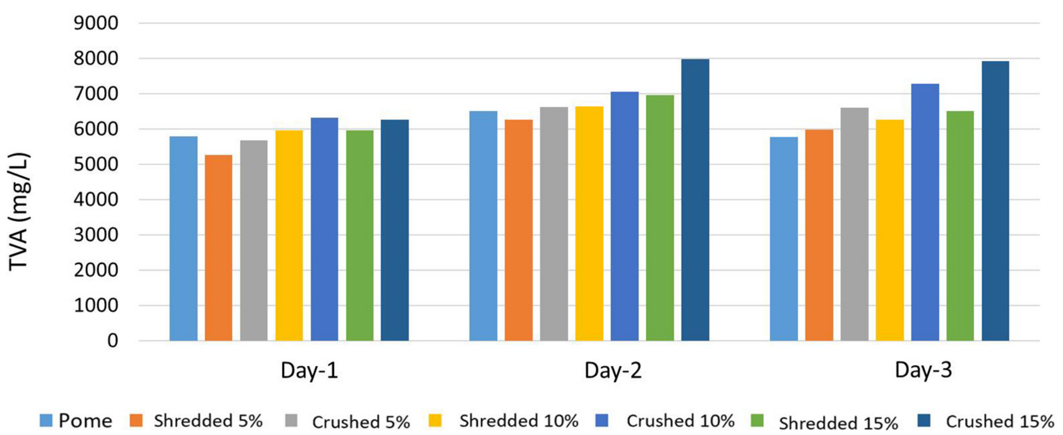


Figure 8. Total volatile acid analysis on EFB-POME co-digestion pre-treatment

value. The higher the TS content, the more TVAs are accumulated (Ibro et al., 2022).

The research results also showed that the TVA value tended to increase along prolongation of HRT. Longer HRT improves VFA production efficiency because bacteria have a longer reaction period (Lv et al., 2022). HRT also played an important role in controlling VFA production due to its ability to determine the reaction time of microorganisms. Maharaj and Elefsiniotis, (2001) state that increasing the synthesis of VFA requires control of HRT in order to aid in the multiplication of the hydrolysis and acidogenesis microorganisms (Fang, H. H., and Yu, 2000). In acidogenic fermentation, VFA production could substantially grow over the first 10 days and subsequently attain a steady-state production level (Jiang et al., 2013). The research results also show that EFB processed with a crusher has a higher TVA value. This is because the size of the EFB being crushed is smaller. The reactivity of the process rises as the particle size decreases because smaller particles have a larger surface area to volume ratio than similar large-sized particles. The hydrolysis reaction rate constant increases with decreasing particle size. Hydrolyzed monosaccharides contained in EFB are then utilized by acidogens and acetogens to produce VFA. The results of the TVA analysis have a correlation with the results of pH measurements in the research, where the higher the pH value, the higher the TVA value. According to certain studies, an alkaline pH may encourage the synthesis of more VFA than an acidic pH (Cai et al., 2009; Garcia-Aguirre et al., 2017; Jie et al., 2014).

Soluble chemical oxygen demand

To identify the specific, sequential water-soluble chemical components and the organic content that bacteria would consume to produce methane, soluble chemical oxygen demand (S-COD) analysis is necessary. In order to help boost the production of biogas, S-COD analysis is performed to identify the potential of organic materials that can be transformed into volatile acids and subsequently broken down into methane. The S-COD value in the research carried out represents the dissolved organic content. The results of the S-COD analysis on EFB-POME co-digestion can be seen in Figure 9.

The results of the research show that there was an increase in the S-COD value along with the addition of EFB as a substrate. The increase in the S-COD value indicates that there has been a process of hydrolysis of complex organic contents into simpler dissolved compounds that can be measured as S-COD values. This increase was caused by additional S-COD input due to the hydrolysis of complex organic content and continued to occur during the experiment. The research results also show that the EFB size reduction treatment has an effect on the S-COD value. The research results of Wadchasit et al. (2020), show that the composition of EFB cellulose increased after size reduction from 41.3–45.0% to 61.47%. The results of this study also showed that the hemicellulose content after size reduction decreased from 25.3–33.8% to 13.15%. The research results also show that crushed EFB tends to have a higher S-COD value when compared to shredded EFB. The EFB that was crushed in the study had a size of around 5 cm, while the EFB that was crushed had a size of around 10–15 cm. The organic material content is related to the

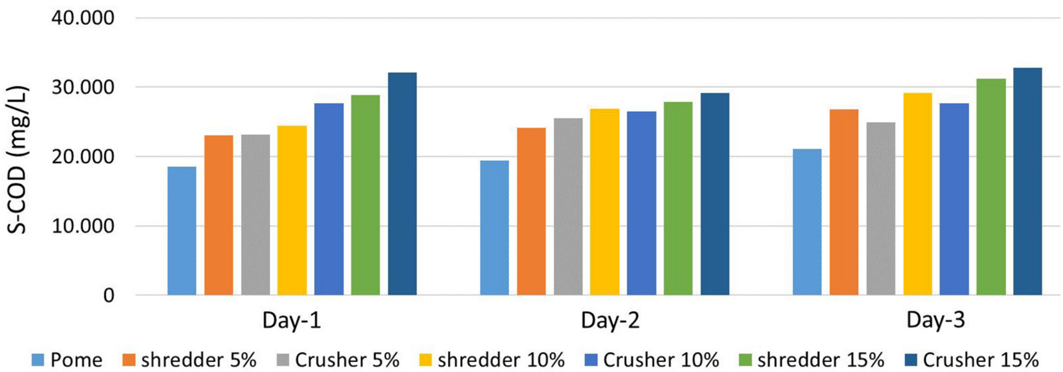


Figure 9. S-COD on EFB-POME co-digestion pre-treatment

particle size. Smaller particle sizes cause more organic matter to dissolve in the system.

Sludge acclimatization in anaerobic digester

One factor in the success of the anaerobic degradation process is the start-up time. The start-up time is the initial stage of the growth process of anaerobic bacteria until it produces steady-state conditions. In this research, sludge of anaerobic bacteria was collected from commercial biogas plant with utilized tapioca wastewater as a feedstock. Tapioca wastewater has a high carbohydrate content, namely around 13,970 mg/L, total solids around 19,370 mg/L, and volatile solids around 16,910 mg/L (Chaiprasert et al., 2017). Because of POME has different characteristics with tapioca wastewater, acclimatization using POME is very important. About 40 liter of sludge was used as starter and 10 liter of POME was used as substrate. This process was conducted in 50 liter of stirrer tank anaerobic batch reactor. Figure 10 shows the addition of sludge and POME in stirrer tank anaerobic reactor which the acclimatization was conducted.

Shortening the start-up time is an important factor in increasing the efficiency of anaerobic degradation systems because the growth time of anaerobic bacteria tends to be slow. One method that can be used in this regard is by adding secondary substrate, microbial starter seeds, or sludge. The anaerobic digestion process depends on the microbial starter seeds employed, which determine how the organic waste is broken down, how much biogas is produced, and other factors. A crucial element in guaranteeing the successful operation of anaerobic digestion is the selection of suitable microbial starting seeds. Biogas production and methane composition were evaluated during acclimatization process. Figure 11 and 12 show daily and cumulative biogas production during acclimatization. The gas chromatography GC-2014, equipped with a thermal conductivity detector (TCD) and a Shyn-Carbon coulomb, was used to measure the amounts of methane. The result of methane

Figure 10. Sludge (a) and POME (b) added in Stirrer tank anaerobic reactor (c)

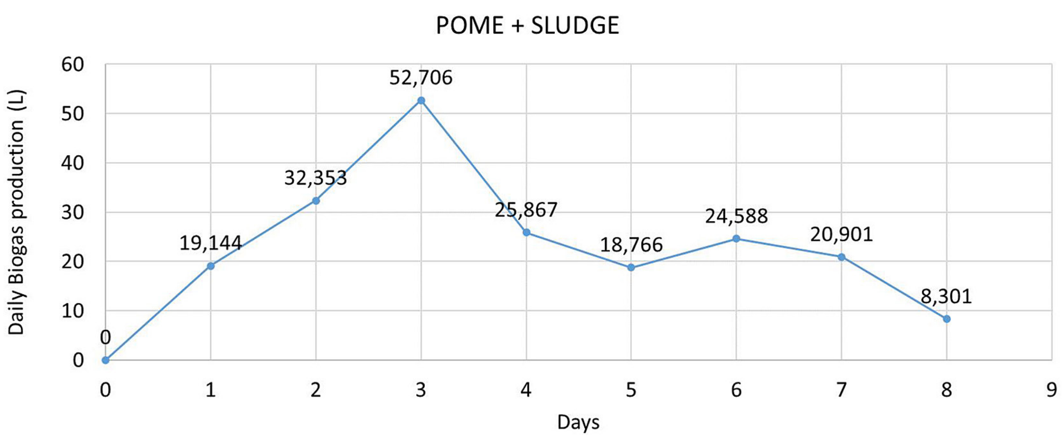


Figure 11. Daily biogas production during acclimatization

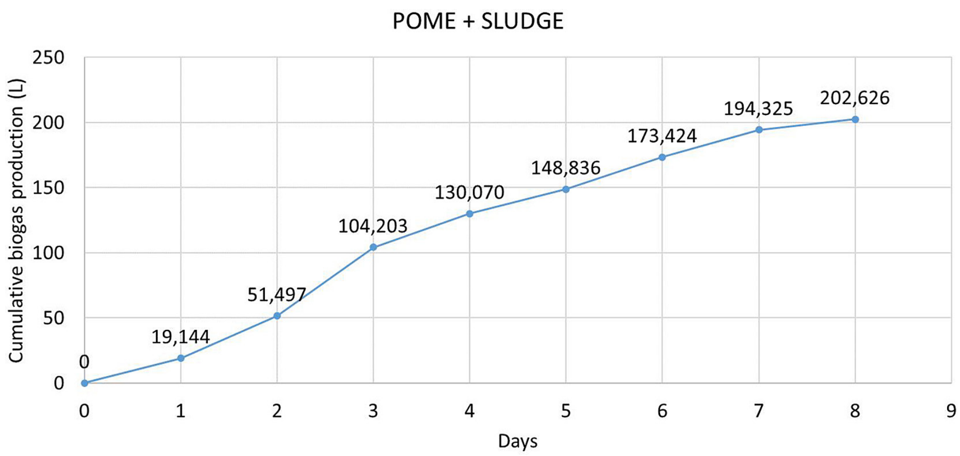


Figure 12. Cumulative biogas production during acclimatiazation

content analysis in the biogas is about 54 to 64 % (v/v). The biogas production after 8 days from about 10 liters of POME was more than 202 liters. It is means that more than 80% of organic matter in POME was converted to biogas. This indicates that acclimatization has successfully, and the sludge was ready to used for biogas production experiments.

Optimization of biogas production

A set of experiments was conducted to evaluate biogas production using co-digestion of EFB and POME. Figure 13 shows the experiment set-up for biogas production evaluation. Based on pre-treatment results, the shredded and crushed EFB were used as solid phase feedstock. The concentration of EFB was settled down as 10 and 15% with ratio sludge to substrate 4:1. A liter of Erlenmeyer flash anaerobic reactor was used for each variation of treatment. As a control was also used POME without EFB soaking treatment. The characteristics of sludge and POME were also evaluated as a condition of day 0 and day 25 (end of experiment).

pH value

In the process of anaerobic digestion, pH is crucial. The chemical equilibria of volatile fatty acids (VFAs), NH3, and H2S are all influenced by pH. Methanogenic bacteria's activity diminishes at higher or lower pH values, and methanogenesis is most effective at pH 6.5-8.2, which is the ideal pH 7.0 (Mao et al., 2015). The concentration of carbon dioxide in the gas phase and the concentration of carbonate ions in the liquid phase regulate the pH inside the reactor. The pH value of POME after pre-treatment with the sludge in the anaerobic digester can be seen in Table 1.

The research results show that the pH on 0-day was around 7.38–7.51. Mahajoeno (2008) stated that an initial substrate pH value of 7 can increase the rate of biogas production better than other pH treatments. The research results also

Figure 13. Co-digestion of EFB and POME; (a) Erlenmeyer flash reactor before added sludge, (b) Mixing sludge and POME after pre-treatment, (c) Erlenmeyer flash anaerobic reactor, (d) conventional biogas measurement

Table 1. pH of substrate in the anaerobic reactor

Sample	Day – 0		Day – 25	
	pH	Standard deviation	pH	Standard deviation
Control	7.61	0.02	7.94	0.18
Shredded 10%	7.55	0.01	8.11	0.03
Crushed 10%	7.38	0.07	8.13	0.00
Shredded 15%	7.44	0.08	8.24	0.02
Crushed 15%	7.45	0.08	8.27	0.02

showed that the pH value increased after the fermentation process was carried out for 25 days. The increase in pH is caused by the decomposition of proteins into ammonia (NH_3) by the activity of microorganisms. This is in line with research by Syaichurrozi (2015), which states that the increase in pH is caused by ammonia, which is produced during the protein decomposition process. The ammonium content increased afterwards due to the increased amount of soluble organic materials. The research results showed that the pH after 25 days of fermentation was still at the optimum pH for the methanogenesis process, namely around 7.94–8.27. The research results also show that the addition of EFB can increase the pH value.

Total volatile acid (TVA)

Total volatile acid (TVA) plays an important role in anaerobic processing. TVA concentrations and acetic acid equivalents are quite critical parameters for the anaerobic digestion process. TVA is a group of low-molecular-weight organic acids that are soluble in water and sludge. In the anaerobic digestion of waste activated sludge (WAS), complex organic materials are first hydrolyzed and fermented by rapidly growing and pH-insensitive acidogenic bacteria into TVA. After that, the TVA is oxidized by acetogenic bacteria that develop slowly to produce carbon dioxide, acetate (HAc), and molecular hydrogen—all of which make good substrates for the methanogenic bacteria. The TVA value are presented below (Table 2).

There has been a lot of discussion about the connection between TVA concentrations and anaerobic digester performance. When VFA concentrations in anaerobic digesters are high, they lower the pH of the system overall, which impacts the activity of methanogenic bacteria and eventually leads to instability in the digester's performance (Wang et al., 1999). The total range of VFA concentrations in bioreactors usually varies between 50 and 300 mg/L. The TVA value of POME after pre-treatment with the sludge in the anaerobic digester can be seen in Figure 15. The research results show that the TVA value after the 25-day fermentation process ranges from 79.29 to 80.33 mg/L. The research results show that the more EFB concentration added, the greater the TVA value. Prihartini et al. (2021) stated that the higher the fiber fraction, the higher the TVA value. The higher the cellulose and hemicellulose levels in the system, the higher the TVA value will also increase. The research results also showed that there was a decrease in the TVA value after the fermentation process was carried out for 25 days. The decrease in the TVA value is caused by conditions in the digester that are increasingly anaerobic, where organic material is starting to run out and acetogenic bacteria use H_2 to produce acetic acid and will compete with methanogenic bacteria, which are increasingly using H_2 to produce methane. A decrease in the TVA value

Table 2. TVA value of substrate in the anaerobic reactor

Sample	Day – 0		Day – 25	
	TVA	Standard deviation	TVA	Standard deviation
Control	1194	110	79.90	0.32
Shredded 10%	1338	8	80.00	0.47
Crushed 10%	1452	34	79.56	0.76
Shredded 15%	1560	136	79.29	0.20
Crushed 15%	1620	85	79.41	0.18

Table 3. S-COD value of substrate in the anaerobic reactor

Sample	Day – 0		Day – 25	
	S-COD	Standard deviation	S-COD	Standard deviation
Control	3780	127.28	945	28.99
Shredded 10%	4980	14.14	1113	17.68
Crushed 10%	5995	35.36	1124	138.59
Shredded 15%	5835	332.34	1212	37.48
Crushed 15%	6640	113.14	1248	55.86

also indicates that the system is already in the stationery phase or death phase (Marbun, 2018).

Soluble chemicals oxygen demand

S-COD's value of POME after pre-treatment with the sludge in the anaerobic digester can be seen in Table 3. The research results showed that the S-COD value decreased after the fermentation process was carried out for 25 days. The decrease in COD values was caused by the breakdown of organic materials by microorganisms active in the anaerobic digester. The greater the decrease in the COD value, the greater the organic material that is degraded into organic acids. These organic acids are then converted into methane, meaning that if the decrease in COD is greater, the rate of formation of methane will also be greater. The decrease in COD values will also be followed by an increase in the accumulated volume of biogas. COD value will also be followed by an increase in accumulation biogas volume. The research results show that there is a correlation between COD and TVA. The higher the COD that is biodegraded, the higher the TVA concentration. This is consistent with the idea that more dissolved organic matter will be biodegraded into organic acids the higher the concentration of the reduced substrate. The next step is to turn this organic acid into methane. Therefore, if the decrease in COD is greater, the rate of methane formation will also be greater.

Total solid and total volatile solid

The production of biogas is significantly influenced by total solids (TS). Early on in the biogas production process, non-methanogenic microbes use total volatile solids (TVS) as a substrate, or food supply. According to Simeonov et al. (2012), VS is used to calculate the

Table 4. Total solid of substrate in the anaerobic reactor

Sample	Day – 0		Day – 25	
	TS	Standard deviation	TS	Standard deviation
Control	2.69	0.0882	2.54	0.0432
Shredded 10%	2.88	0.0125	2.48	0.0421
Crushed 10%	2.78	0.0870	2.50	0.0331
Shredded 15%	2.72	0.0121	2.52	0.0087
Crushed 15%	2.71	0.0192	2.51	0.0079

Table 5. Total volatile solid of substrate in the anaerobic reactor

Sample	Day – 0		Day – 25	
	TVS	Standard deviation	TVS	Standard deviation
Control	1.6007	0.0052	1.5376	0.0086
Shredded 10%	1.7374	0.0426	1.4994	0.0341
Crushed 10%	1.7143	0.0341	1.4836	0.0424
Shredded 15%	1.6301	0.0422	1.5169	0.0070
Crushed 15%	1.6370	0.0047	1.4801	0.0181

amount of organic matter present in the material, which the anaerobic process can convert to carbon dioxide and methane. The higher the TS and TVS values, the higher the biogas formation that occurs (Zarkadas et al., 2015). Value of TS and TVS are presented below (Table 4 and Table 5). The TS and TVS values of POME after pre-treatment with the sludge in the anaerobic digester can be seen in Figures 17 and 18. The research results show that the TS and TVS values decreased after the fermentation process was carried out for 25 days. The decrease in TS and TVS values shows that a greater amount of organic material is converted into biogas. High total solids systems have the capacity to create large amounts of methane (Duan et al., 2012). The decline in TVS indicates that organic compounds are being broken down in the biodigester by non-methanogenic bacteria (Ni'mah et al., 2014). In general, greater decrease of VS will make greater methane production rate.

Biogas production

Biogas is the most desired result of anaerobic carbon digestion. An essential reference metric for anaerobic digestion systems is the output of biogas. Figures 14 and 15 show the daily and total biogas generation from POME following pre-treatment with the sludge in the anaerobic digester. The study's findings indicated that during the course of the fermentation's 25 days, biogas output tended to rise. The increase in biogas production was very visible at the beginning of fermentation, but on the 10th or 11th days of fermentation, this increase was not very significant. This is because the longer the fermentation time, the less organic material is used by microorganisms to produce biogas. The longer the fermentation time, the more significant biogas production can occur, especially in the early stages of fermentation. The research result showed that compared to the POME only, Co-digestion using EFB shredded 10%, shredded 15%, crushed 10% and

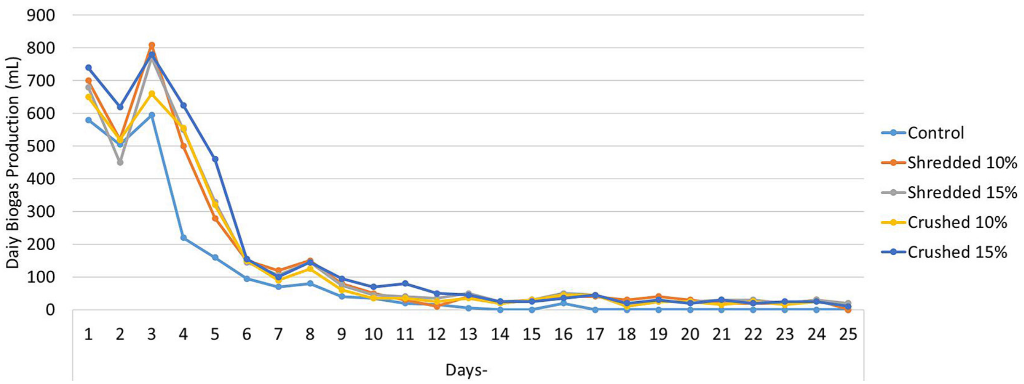


Figure 14. Daily biogas production

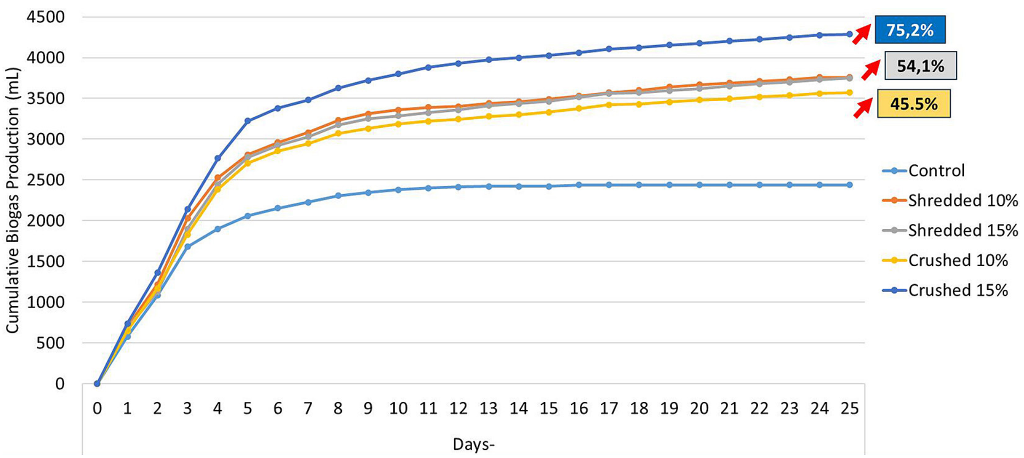


Figure 15. Cumulative biogas production

crushed 15% has successfully to increase biogas production in batch system by 54,1%, 54,1%, 45,5%, and 75,2%, respectively.

Biogas composition

Depending on the particular substrate and reactor operating parameters, the raw biogas from anaerobic digestion typically contains 50–70% methane (CH_4) and 30–50% carbon dioxide (CO_2). Methane and carbon dioxide (CO_2) are the primary constituents of biogas produced by anaerobic digestion. But biogas also includes moisture, particle matter (PMs), and other trace gases along with pollutants such ammonia, siloxanes, volatile organic compounds (VOCs), and sulfur compounds. Due to variations in feed content and anaerobic digester operating parameters, biogas composition can vary between plants and even within a single plant. Methane percentage in high-quality biogas ranges from 50 to 70 percent (Haryanto et al., 2019). Without purification, the CO_2 content of biogas typically varies from 25 to 45% (Kalsum et al., 2022). Methane is created when acetotrophic bacteria reduce carbon dioxide using acetate, and it is hydrogenotropic when hydrogen is used. Biogas composition (methane content and carbon dioxide content) in this research can be seen in Figures 16 and 17.

The research results show that the biogas produced from each treatment is of good quality

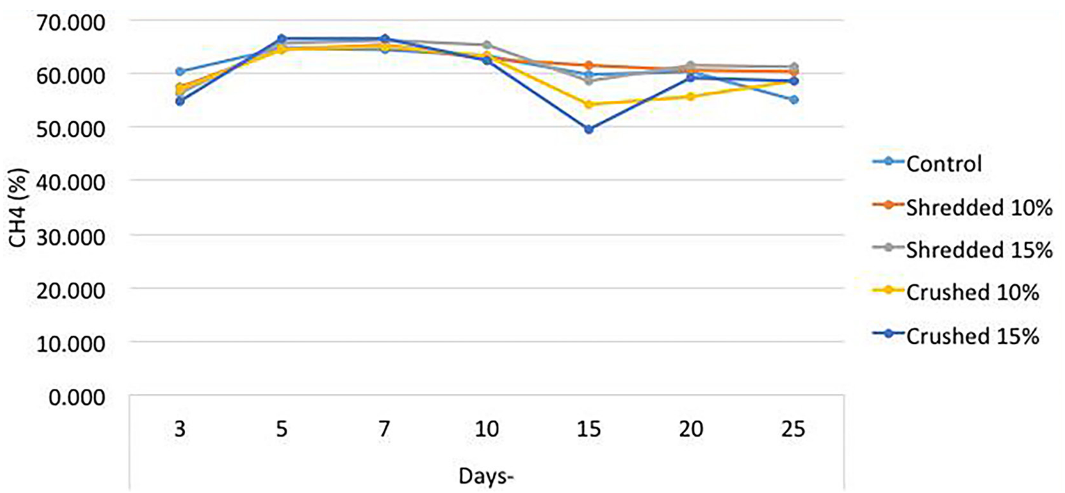


Figure 16. Methane content in the biogas from anaerobic reactor

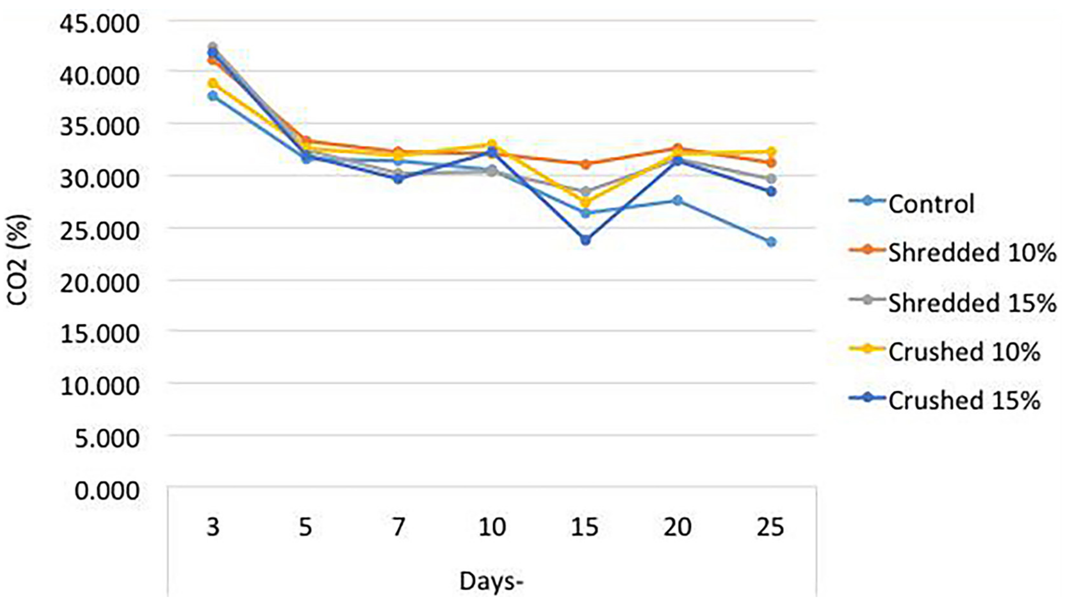


Figure 17. Carbon dioxide content in the biogas from anaerobic reactor

because it contains 50–70% methane. One crucial factor in the production of biogas is the duration of fermentation. That does not imply, however, that the amount of methane increases with fermentation time. There is an ideal moment to produce high methane content, according to the findings of multiple studies. The first five to seven days see the greatest amount of methane generation; after that, it dramatically slows down and enters a stagnant phase. According to Taherzadeh and Karimi (2008), this is caused by a slowing in the biodegradation process and a depletion of the biodegradable complex components. The research results also show that the addition of pre-treated EFB tends to increase the methane content, although not significantly. To increase the EFB's biodegradability and the digesting process's methane production, pretreatment is necessary. The pretreatment process, which involves shredding and crushing the material, reduces the constraints on heat and mass transport as well as well digestibility. As a result, the production of methane was enhanced because the hydrolytic bacteria and enzyme could readily access fermentable materials. Other than methane, the anaerobic digestion process also produces carbon dioxide. Gas fermentation can be used to create commercially viable goods using the carbon dioxide from biogas as raw material. Given that gas fermentation has the ability to convert carbon dioxide into chemicals that are commercially viable, CO_2 emissions can be reduced by creating valuable liquid product.

The research results show that the longer the fermentation time, the more carbon dioxide production drops. Based on biogas production and methane composition, the methane production could be estimate by multiplying biogas production with methane concentrations. Figures 18 and 19 describe daily and cumulative of methane production. Similar with biogas production profile, methane production also relatively high at the beginning of 10 days fermentation time. Using methane production profile, we can estimate that

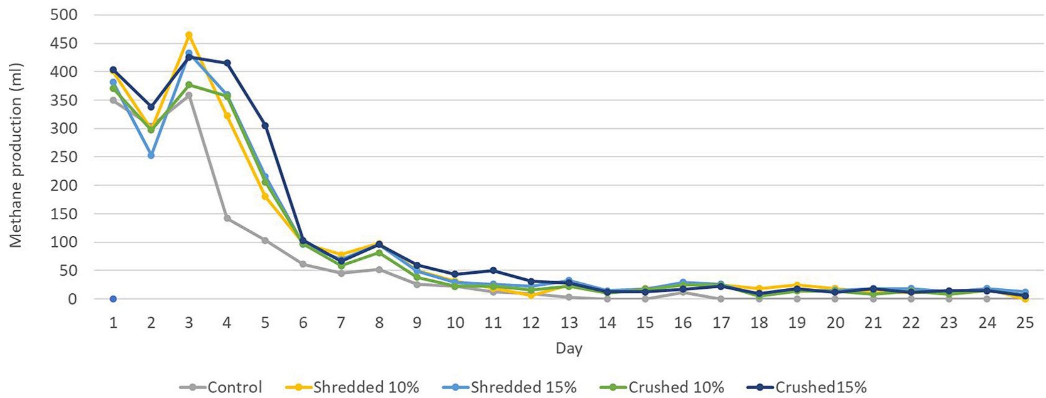


Figure 18. Daily methane production

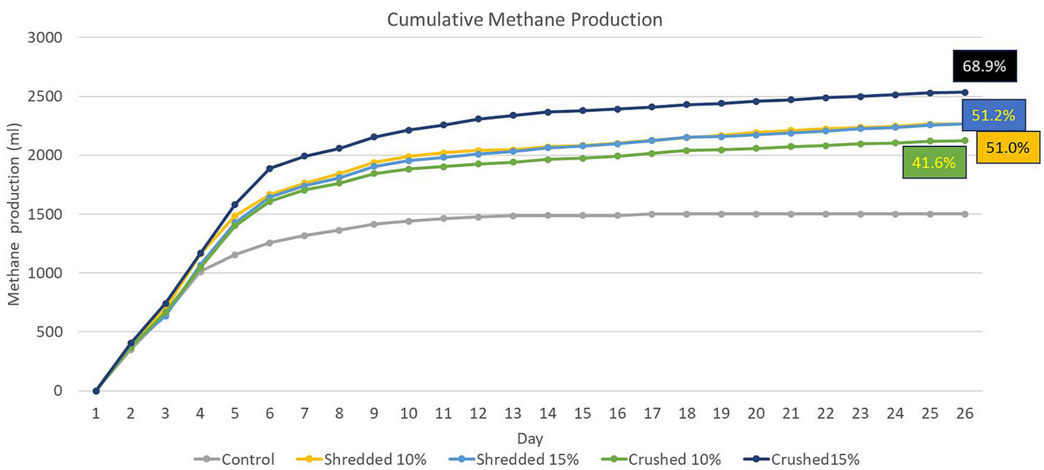


Figure 19. Cumulative methane production

Table 6. Increasing of Biogas Production in Continuous System (m^3/m^3 POME)

Sample	Biogas production in continuous system (m^3/m^3 POME); HRT 25 days	Increasing biogas production (%)
Control	275.95	0.00
Shredded 10%	395.35	43.3
Shredded 15%	390.65	41.6
Crushed 10%	374.10	35.6
Crushed 15%	448.73	62.6

Note: HRT = 25 days

	Day-1	Day-2	Day-3	Day-4	Day-5	Day-6	Day-7	Day-8	Day-9	Day-10	....	Day-25	Total (L)
1	580	505	595	220	160	95	70	80	40	35	…	0	2,44
2		580	505	595	220	160	95	70	80	40	…	0	2,44
3			580	505	595	220	160	95	70	80	…	0	2,44
4				580	505	595	220	160	95	70	…	0	2,44
5					580	505	595	220	160	95	…	0	2,44
6						580	505	595	220	160	…	0	2,44
7							580	505	595	220	…	0	2,44
8								580	505	595	…	0	2,44
9									580	505	…	0	2,44
10										580	…	0	2,42
…											…	0	…
25												0	0
CUMULATIVE													55,19

Control; HRT 25 days, POME loading rate 0,2 L per day

$$Vn = \sum_{t=0}^{n} \mathrm{Vt} + \sum_{t=0}^{n-1} \mathrm{Vt} + \sum_{t=0}^{n-2} \mathrm{Vt} + \cdots \sum_{t=0}^{n-(n-1)} \mathrm{Vt}$$

Figure 20. Matrix of estimation system for biogas production in continuous systems

co-digestion EFB-POME has successfully increased methane production about 51.0%, 51.2%, 41.6%, and 68.9%, by using EFB shredded 10%, shredded 15%, crushed 10% and crushed 15%, respectively. Based on daily biogas production, we can estimate biogas production in a continuous system. A matrix in Figure 20 could be used to estimate biogas production in continuous systems. The co-digestion EFB-POME has successfully increased biogas production biogas production in continuous system by 43.3%, 41.6%, 35.6%, and 62.6%, if utilized EFB shredded 10%, shredded 15%, crushed 10% and crushed 15%, respectively. Table 6 describes the estimation of increasing biogas production through co-digestion of EFB and POME. Since EFB has high content of organic matter, it can serve as a good carbon source for biogas production. EFB is a lignocellulosic biomass. The properties of lignocellulosic biomass render it resistant to biodegradation. Several structural and compositional properties were found to have impacts on the biodegradability of lignocellulosic biomass (Zheng et al., 2014). Due to the complexity and variability of biomass chemical structures, the optimal pre-treatment method and conditions depend on the types of lignocellulose present. Biomass pretreatment prior to anaerobic digestion is usually required to reduce structural and compositional impediments of lignocellulosic biomass and expose the polymer chains of cellulose and hemicellulose to microbial breakdown so as to increase the rate of biomass degradation and biogas yield. Pre-treatment EFB (crushed and shredded) is able to disrupt the matrix of poorly biodegradable lignin consisting in the lignocellulosic substrate effectively. Consequently, hydrolytic bacteria and enzymes could easily access fermentable matter, resulting in an enhancement of biogas production.

CONCLUSIONS

Co-digestion of EFB and POME increasing biogas and methane production. Compared to the POME only, Co-digestion using POME and EFB shredded 10%, shredded 15%, crushed 10% and crushed 15% are increasing biogas production in batch system by 54,1%, 54,1%, 45,5%, and 75,2%, respectively. In continuous system with HRT 25 days and similar feedstock, biogas production increase 43.3%, 41,6%, 35,6%, and

62,6%, respectively with methane concentration are maintained at about 60%. Co-digestion EFB-POME with 15% of crushed EFB is recommended to applied in palm oil mill to increase biogas production.

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