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Methane Production from Anaerobic Co-digestion of Sewage Sludge and Decanter Cake

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Abstract
Increased production of sewage sludge from wastewater treatment and decanter cake from palm oil mill industry results in the generation of large quantities of waste that ends up difficulty to find the effective method of disposal. In this study, an anaerobic co-digestion has been considered to convert these organic pollutants into methane gas. Anaerobic co-digestion of sewage sludge and decanter cake was studied in 125mL serum bottles with 100mL working volume. The effect of different inoculum to substrate ratios (I/S) on biogas production was investigated. The batch study was conducted at the ratio I/S of 1:0.5, ratio 1:1 and ratio 1:2 and sewage sludge alone as control at ratio 1:0. Daily biogas collection for the ratio of 1:2 had resulted the highest cumulative biogas production of 247 mL. The highest methane yield was obtained at mixing ratio of 1:0.5 with 165.6 L CH4 / g VS. As a comparison, all co-digestion ratios produced more biogas than the sewage sludge alone. This proved that anaerobic co-digestion of sewage sludge and decanter cake can improve the production of biogas.

Keywords: Anaerobic co-digestion, Sewage sludge, Decanter cake, Lignocellulosic, Batch fermentation

Introduction

In Malaysia, palm oil industry gives the most sources of agricultural waste since palm oil is the largest producer.
More than 5.39 million hectares of land and 16.3% of the total land area were cultivated for oil palm in Malaysia in the year 2014 (Awalludin et al., 2015). It shows an increment from 11% of the total land area cultivated for oil palm in year 2003 (Hansen, 2005). Apart from crude palm oil (CPO) that produced from fresh fruit bunch (FFB), fibre, shell, decanter cake and empty fruit bunch (EFB) were also produced for 30, 6, 3 and 28.5% from the FFB respectively. It is estimated that about 26.7 million tonnes of solid biomass were generated from 381 palm oil mills in Malaysia in 2004 (Yacob et al. 2005). Abundance of this waste needs sustainable management to deal with to decrease the environmental pollution issues.
Decanter cake (DC) is one of the solid wastes from palm oil mill and produced from three-phase of CPO purification process in oil palm mill plant. It is about 3-5wt% of rate of DC production from FFB and estimated about 3.6 million tonnes of DC generated by palm oil mill in year 2012. DC becomes fire hazard to the mill when it is dried and increase the amount of suspended particles (Dewayanto et al., 2014). Decanter cake mostly used as animal feed that made in grade pellets (Chavalparit et al., 2006) and as digestate which is used as fertilizer (Holm-Nielsen et al., 2009). Currently DC has been utilized as feedstock for production of cellulose and polylose, bio-surfactant, bio-butanol and bio-diesel (Dewayanto et al., 2014). DC has also been used as a substrate in anaerobic digestion (Kanchanasuta & Sillaparassamee, 2017).
The decanter cake, composed of high biodegradable organic content and nutrient-rich composition, is ideal feed-stock for the production of bioenergy such as methane via fermentation. However, decanter cake is also lignocellulosic biomass which slow hydrolysis rates due to high fat and lipid content. Therefore, co-digestion of decanter cake with sewage sludge is considered as an attractive substrate for anaerobic digestion due to its high organic content (mainly in the form of proteins and fats) and due to its high methane potential (Pitk et al., 2012). A study by Kanchanasuta and Sillaparassamee (2016) co-digested DC and crude glycerol. Their results show that co-digestion could improve the production of methane gas. Another study by Kaosol and Sohgrathok (2014) co-digested the DC with frozen seafood wastewater, has resulted positive impact on the production of methane gas at the different organic loading rate.
The benefits of anaerobic co-digestion include improving the nutrient balance, increasing digestion rate, increasing load of biodegradable organic matter and producing better biogas yield (Sosnowski et al., 2003). The anaerobic co-digestion also may improve the biogas production due to carbon, nitrogen and nutrient balance (Yen and Brune, 2007).
Lignocellulosic biomass is mostly practiced in solid-state anaerobic digestion (SS-AD) rather than liquid anaerobic digestion L-AD, however, there are few challenges including low methane yield, potential instability and low values of end-product (Yang et al., 2015). Liquid anaerobic digestion (L-AD) operated with less than 15% of total solid (TS) content, while, solid-state anaerobic digestion (SS-AD) can operated with more than 15% of TS content (Yang et al., 2015). The advantages of SS-AD over L-AD are SS-AD can operated in small reactor volume, low demand of energy for heating, high production of

volumetric methane, minimal material handling and low of total parasitic energy loss. L-AD always regarded with floating and stratification of fibrous material problems and these can be solved with SS-AD (Li et al., 2011; Yang et al., 2015).Therefore, the aim of this study is to determine the methane yield of anaerobic co-digestion from sewage sludge and decanter cake by SS-AD approach. The methane yield was measured at different ratio of inoculum to substrate. The daily biogas composition was also analyzed to determine the biogas produced in anaerobic co-digestion of sewage sludge and decanter cake.

Materials and methods

Substrate and inoculum

Sewage sludge was obtained from wastewater treatment plant of Indah Water Konsortium. The decanter cake was collected from Yee Lee Palm Oil Industries Sdn. Bhd, Bidor, Perak. The sewage sludge and decanter cake were stored at 4°C for later use as the inoculum and substrate, respectively. The substrate and inoculum were characterized based on total solid (TS), volatile solid (VS), pH, carbon (C) and nitrogen (N) content, chemical oxygen demand (COD) and ammonia nitrogen (NH3). All analytical procedures were performed in accordance with standard method (APHA, 1998).

Experimental setup

The batch fermentation was conducted in 125mL serum bottles enclosed with rubber stoppers at working volume of 100mL (Figure 1(a)). The samples were flushed with nitrogen gas for 2 min before seal to remove traces of oxygen and to ensure anaerobic condition. Batch fermentation was conducted in anaerobic mesophillic at 38±1°C temperature in a water bath (Memmert Waterbath WNB 45) for 30 days (Figure 1(b)).

Figure 1(a): The set up of sample in serum bottles

Figure 1(b): The serum bottles in waterbath

The digesters containing sewage sludge and decanter cake were mixed at inoculum to substrate (I/S) ratios of 1:0.5, 1:1 and 1:2 at 25% of total solid content. The sewage sludge alone at I/S ratio 1:0 was used as control and incubated in the same water bath. The pH samples were adjusted by using pH meter to 7±1.0 using sodium hydroxide (NaOH) to provide better growth conditions for methanogenic bacteria that can produce biogas and methane effectively at a pH value from 6.5 to 8.0 (Sibiya, 2014). The pH value was adjusted to the range of optimum pH value by using sodium hydroxide (NaOH).

The methane yield was expressed as the volume of methane produced based on the initial total VS of the feedstock. The parameters was analyzed at initial and final of the batch fermentation and the removal efficiency parameters such as TS, VS, COD and ammonia nitrogen was calculated. The biogas was collected daily and the cumulative biogas production was measured by water displacement method.

The biogas composition was measured by gas chromatoghraphy (GC) (Agilent 6890) with Thermal Conductivity Detector (TCD). The methane yield was expressed as the volume of methane produced based on the initial total VS of the feedstock and nitrogen and oxygen free basis.

Results and discussion

Biogas production from batch fermentation

The variations of inoculum to substrate ratio for co-digestion between sewage sludge and decanter cake was observed. There were I/S ratio of 1:0, 1:0.5, 1:1 and 1:2 with 25% of total solid content. Mesophilic temperature of 38°C was used in this study due to optimum condition for microorganism to grow. The pH value also one of the main factors which greatly affect to the digestion process. Different microorganism requires different optimal pH but in the anaerobic digestion, the most favorable range of pH value is 6.8 – 7.2 (Hagos et al., 2017).

The cumulative biogas production profile for all I/S ratios were shown as in Figure 2. Based on the results, ratio 1:2 produced the highest volume of biogas followed by ratio 1:1, 1:0.5 and 1:0 which are

247 mL, 211 mL, 150 mL and 39 mL respectively, in total of 30 days batch fermentation. At first stage, ratio 1:1 produced more biogas than other ratios till day 25. The fermentation process then becomes slower to the end of the batch fermentation. However, ratio 1:2 keep produced more biogas until the end of batch fermentation make it the highest ratio of biogas production. In this study, the ratio 1:1 and ratio 1:2 produce the lowest methane yield although both ratio generated high volume of biogas. High content of substrate makes the rate of fermentation process becomes slower due to low content of microorganism in the inoculum that inhibit the fermentation process to happen faster. Apart from that, all co-digestion ratios produced more biogas than the sewage sludge alone. This proved that anaerobic co-digestion can improve the production of biogas.

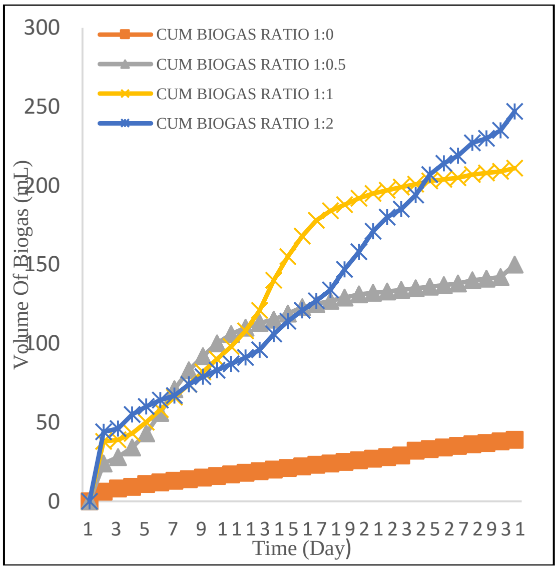

Figure 2: Cumulative biogas production for 30 days

Methane yield from batch fermentation

The methane yield in each biogas samples for each day were shown as in Figure 3. The result of the biogas production with the ratio 1:0.5 content has the highest methane yield. The fermentation shows faster rate of digestion process at early fermentation compared to other ratios. Although the methane yield production becomes lower till the end of 30 days of fermentation, the ratio of 1:0.5 still consistently produced the highest methane gas. In this study, ratio 1:1 and ratio 1:2 generated the lowest methane yield although both ratios produced high volume of biogas as compared to the others ratio.

The finding was in accordance with those reported by Suksong et al. (2015), who observed that methane yield of decanter cake and POME mixture decreased with increasing proportion of decanter cake in mesophilic conditions. It has also been reported by Suksong et al. (2015) that the lower methane yield could be due to difficulty of microorganism to degrade the decanter cake which has high amount of lignocellulose of 32.78%. Therefore, adding more lignocellulose material achieved longer acclimization period for methanogens.

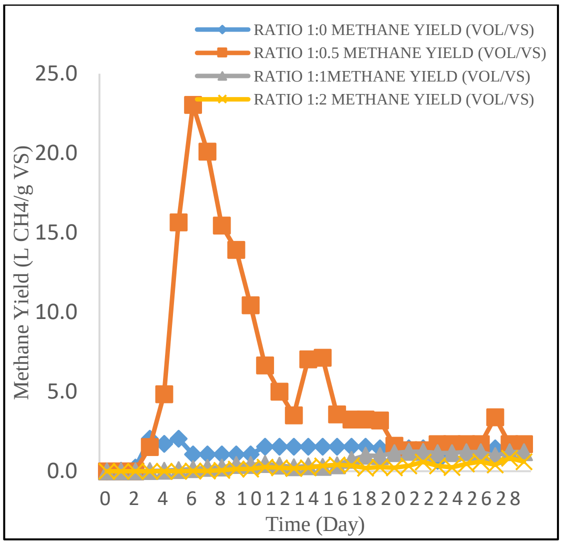

Figure 3: Daily methane yield for 30 days

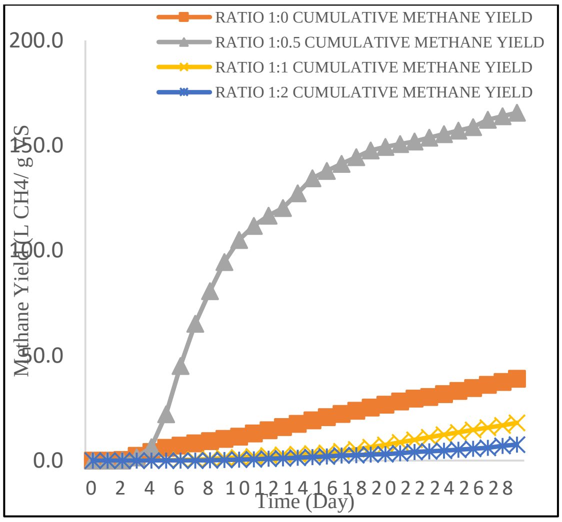

Figure 4: Cumulative methane yield for 30 days

Figure 4 shows the cumulative methane yield for four different inoculum to substrate ratios. Ratios 1:0.5 increase dramatically starting from day 5 till end of the batch fermentation. The maximum yield of methane generated is 165.6 L CH4/ g VS at the ratio 1:0.5 followed by ratio 1:0, 1:1 and 1:2 which was produced at 39.9, 18.0 and 7.4 L CH4/ g VS, respectively. The ratios of substrate shown a significant production on the methane gas. On the contrary, high concentration of lignocellulosic can inhibit the digestion process as the microorganism having difficulty to degrade the decanter cake.

Total solid and ammonia removal

Total solid removal in the organic loading was investigated for all ratios (Figure 5). Initial and final result was determined. The highest total solid removal at 25% TS content is 67.5 % at ratio 1:1 and 39.5% and 12% at ratio 1:0.5 and 1:0 respectively.

The lowest total solid removal was observed at the ratio of 1:2 as compared to the other ratios. This could probably due to the increasing amount of total solid content in the digester that may inhibit microbial activity.
The toxicity for the anaerobic digestion can happen when the ammonia-N level is higher than 1,500 mg/L (Weerapong & Thaniya, 2015). In this study, all ratios shows that ammonia-N level below 350 mg/L (Figure 6). Thus, the digestion process was not inhibited during the fermentation with no significant effect on ammonia-N removal. Sewage sludge shows the highest ammonia-N removal which is 1.8% of removal and 1.3% for ratio 1:0.5.

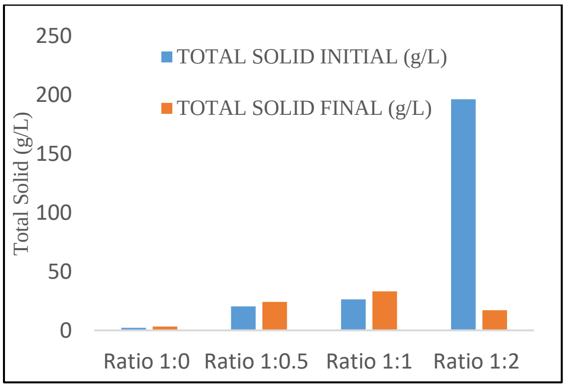

Figure 5: Total solid removal

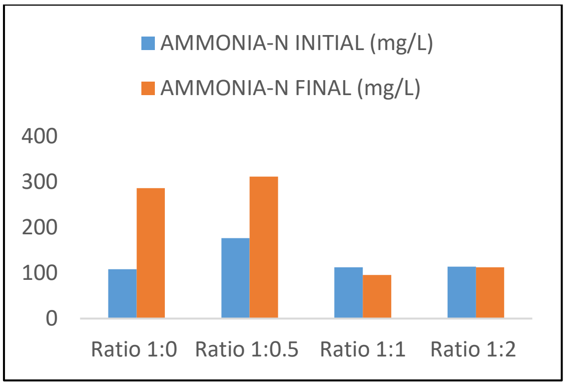

Figure 6: Ammonia-N removal

Methane and carbon dioxide end product comparison

Methane and carbon dioxide (CO_2) are both end product of anaerobic digestion. Theoretically, the biogas is mainly composed of methane (60%) and 40% of carbon dioxide (Abdeshahian et al., 2016). Both ratio 1:0 and ratio 1:0.5 shows significant results with the earlier stage of digestion while ratio 1:1 shows the significant from day 21 onwards.

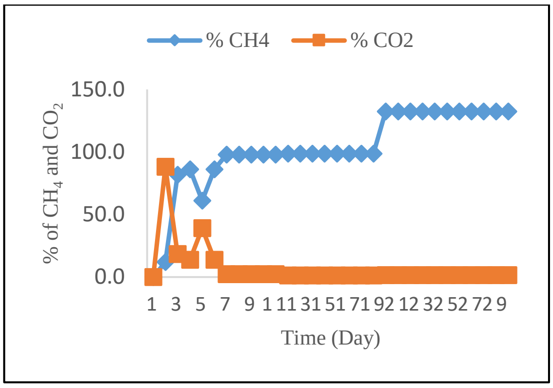

Figure 7(a): Methane and CO_2 at ratio 1:0

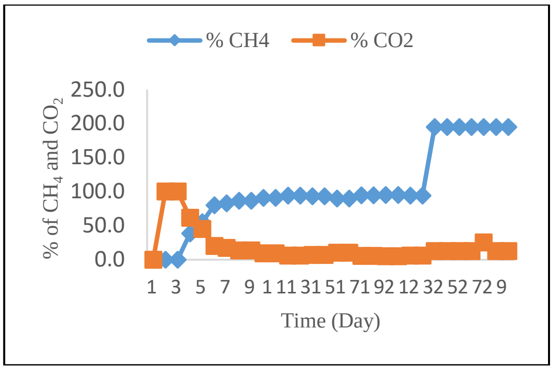

Figure 7(b): Methane and CO_2 at ratio 1:0.5

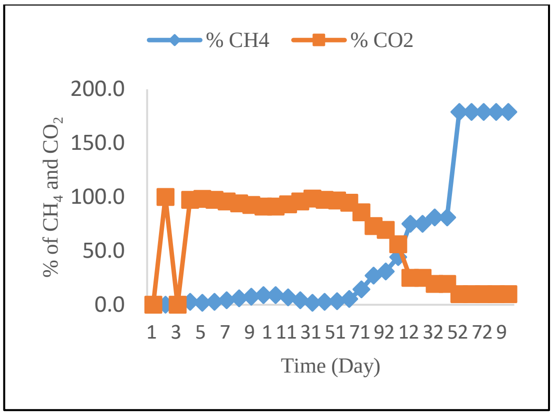

Figure 7(c): Methane and CO_2 at ratio 1:1

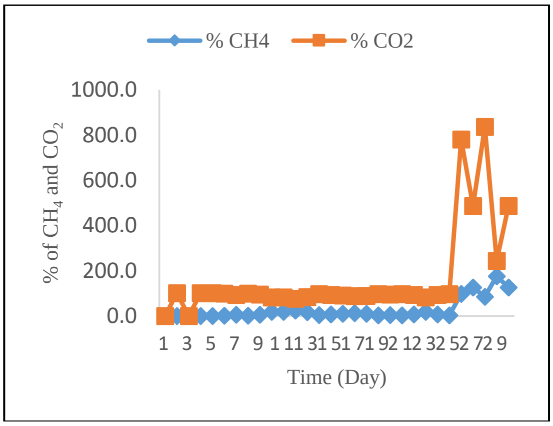

Figure 7(d): Methane and CO_2 at ratio 1:2

Conclusions

The results indicated that the methane gas can be generated by anaerobic co-digestion of sewage sludge and decanter cake. The maximum yield of methane gas produced is at I/S ratio of 1:0.5 which is 165.6 L CH_4 / g VS. This shows that the loading organic materials has significant effect on the digestion. An increased in the total solid content can inhibit the microbial activity with low production of methane gas. Mesophilic temperature of 38°C and neutral pH at initial are the optimum parameters for anaerobic digestion. In this study, the most suitable and optimum I/S ratio for anaerobic co-digestion of sewage sludge and decanter cake was ratio 1:0.5.

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