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Biochemical methane potential (BMP) from anaerobic co-digestion of sewage sludge and decanter cake

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Abstract. Nowadays, anaerobic co-digestion has become a focus of interest in generating methane gas for electricity supply. In this study, a biochemical methane potential (BMP) test was conducted to determine biogas production potential from anaerobic co-digestion of sewage sludge and decanter cake. Sewage sludge has high organic content and decanter cake has a high carbon content (42.70%). Batch fermentation were performed in 125mL serum bottle with 100 mL working volume and incubated for 10 days at mesophilic temperature (38°C) in a water bath. Each bottle containing sewage sludge and decanter cake at feedstocks to inoculums (F/I) ratios of 1:0, 1:1 and 2:1. Daily biogas productions were collected using water displacement method. The highest cumulative biogas produces 0.25 L per day at the F/I ratio of 1:1. However, it was observed that the anaerobic co-digestion of sewage sludge with decanter cake at F/I ratio 2:1 provides higher methane yield production than that provided by the sewage sludge alone (1:0) and F/I ratio of 1:1. The results obtained revealed that the co-digestion of sewage sludge and decanter cake has a potential to produce methane.

1. Introduction

Anaerobic co-digestion is a conversion or degradation process where microorganism breakdown multiple organic substrates/wastes in the absence of oxygen in the digester [1-2]. A wide range of wastewater types, solid waste and biomass have been used as the organic sources for co-digestion such as agricultural waste, agro-industrial wastes, animal wastes and industrial wastes [3-4]. The end product of anaerobic co-digestion is biogas; a mixture of methane, carbon dioxide and others. The typical biogas composition in an anaerobic co-digestion consists of 55-80% of methane, 20-45% of carbon dioxide and some other gases [5-6]. The biogas produced can be used for electricity generation, cooking, pipeline injection and heating. It is a valuable renewable energy source while it can reduce the greenhouse gas emissions from fossil fuel [7]. 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 [8]. The anaerobic co-digestion also may improve the biogas production due to carbon, nitrogen and nutrient balance [9].

Recently, researches on decanter cake as a substrate in anaerobic co-digestion has been reported due to its high biodegradability [7]. Decanter cake is one type of waste produced from palm oil industry in the of oil purification [10]. Moreover, the decanter cake produced in each palm oil mill is sufficient enough to make a biogas plant in the mill cost-effective. In the palm oil mill, every ton of fresh fruit bunch (FFB) generates about 0.6 to 0.8 m^3 of palm oil mill effluent (POME), with an accumulation of 22 to 23% of empty fruit bunch (EFB), 3.5% of decanter cake (DC) and 13.5% of palm mesocarp fiber (PMF). Previous work has reported that decanter cake is suitable for animal feed [11], fertilizer and composting material [12], due to its high nutrient content. The pyrolyzed decanter cake also potential to be used as an adsorbent for the removal of metal ions from wastewater [13].

Anaerobic co-digestion between decanter cake with the POME gives practical use for the development of anaerobic process that providing hydrogen and methane co-production from palm oil residues [14]. The co-digestion between decanter cake and seafood wastewater also has a stimulatory effect on methane gas productions in BMP test [7].

Sludge is a precipitation yielded from wastewater treatment, sewage and excretion, and very difficult to process due to a high degree of organic constituents and moisture content. Sludge can be separated into organic and inorganic sludge, and organic sludge can be highly reduced by incineration [15]. Currently, the management of sewage sludge produced from wastewater treatment plants is one of the most serious challenges in biological wastewater treatment. Its amount is increasing worldwide as the quantity of wastewater being treated rises [16].

Sewage sludge is a valuable feedstock for anaerobic digestion as it contains a high percentage of nitrogen, which can provide a buffering capacity and an improved balance of nutrients [8]. Although convenient and feasible, it has been recognized that the individual digestion of sewage sludge did not achieve the most efficient production of biogas due to its inherent deficiency of carbon such as low carbon/nitrogen (C/N) ratio. In contrast, agro-wastes contain a high percentage of carbon and a low percentage of nitrogen (high C/N ratio). Different types of agro-wastes can be used in admixture with sewage sludge, such as rice straw [17], wheat straw [15] and municipal solid wastes [8]. Co-digestion of sewage sludge and decanter cake is considered the best solution for enhancing methane yield.

Biochemical methane potential (BMP) test is widely used to determine the anaerobic degradability of the wastes. It is also used to determine the quantity of methane that the waste can potentially produce in anaerobic condition [7]. BMP test is low cost and repeatable method for relative comparisons of the anaerobic digestibility and potential biogas production among various substrates. The BMP determine the amount of organic carbon in a given material that can be anaerobically converted to methane. The test is carried out by digesting nutritive materials and microorganisms into serum bottle under an optimal condition such as temperature and pH to identify the gas production amount and composition change. It was reported that it is easy to measure methane yield from organic waste and reliably compare to potential methane yield between different samples [13, 18].

Therefore, the aim of this study is to evaluate the biogas and methane potential of anaerobic co-digestion from sewage sludge and decanter cake using BMP test. The methane yield was measured at different ratio of inoculum to substrate. The biogas composition was also analyzed daily to determine the biogas produced in anaerobic co-digestion of sewage sludge and decanter cake.

2. Materials and Methods

2.1 Substrate and inoculum

Sewage sludge was obtained from wastewater treatment plant of Indah Water Konsortium. The sludge was sieved using a 1mm screen. The decanter cake was collected from Seri Ulu Langat Palm Oil Mill, Dengkil, Selangor. 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 content (C) and nitrogen content (N). All analytical procedures were performed in accordance with standard method (APHA, 1998).

2.2 Experimental setup
The BMP test was conducted in 125mL serum bottles enclosed with rubber stoppers at working volume of 100mL (Figure 1). The samples were flushed with nitrogen gas for 2 min before seal to remove traces of oxygen and to ensure anaerobic condition. The cumulative biogas production was measured by water displacement method [9]. Batch fermentation was conducted in anaerobic mesophillic at 38±1°C temperature in a water bath (Memmert Waterbath WNB 45) for 10 days. The digesters containing sewage sludge and decanter cake were mixed at feedstocks to inoculums (F/I) ratios of 1:0, 1:1 and 2:1. The sewage sludge alone at F/I ratio 1:0 were used as control and incubated in the same water bath. The pH of samples were adjusted to 7±1.0 using sodium hydroxide (NaOH) to provide better growth conditions for methanogenic bacteria can produce biogas and methane effectively at a pH value from 6.5 to 8.0 [19]. The methane yield was expressed as the volume of methane produced based on the initial total VS of the feedstock [8]

2.3 Biogas measurement and analysis
The biogas composition was measured by gas chromatography (GC) (Agilent 6890) with Thermal Conductivity Detector (TCD). The quantity of hydrogen (H_2), methane (CH_4) and carbon dioxide (CO_2) in 1 mL of gas samples were calculated using Equation 1, 2 and 3 [17].

H_2 area / 3844.10 = qH_2 quantity in 1mL gas sample, (1)
CH_4 area / 2291.67 = qCH_4 quantity in 1mL gas sample, (2)
CO_2 area / 3667.21 = qCO_2 quantity in 1mL gas sample, (3)

In the next step, percentage of each individual gas in biogas was calculated using Equation 4, 5 and 6 [17]. Using the calculated percentage and the amount of accumulated biogas in the syringe, total quantity of each gas was measured. Daily amount of gas production volume per each trial was converted to STP conditions (standard temperature and pressure, 273 K, 1.01325 Pa).

$100\ qH_2 / qH_2 + qCH_4 + qCO_2 = H_2\ \%$ (4)
$100\ qCH_4 / qH_2 + qCH_4 + qCO_2 = CH_4\ \%$ (5)
$100\ qCO_2 / qH_2 + qCH_4 + qCO_2 = CO_2\ \%$ (6)

3. Results and discussion

3.1 Characteristic of sewage sludge and decanter cake
The characteristics of sewage sludge and decanter cake are shown in Table 1. The characteristic of sewage sludge was reported as; TS, VS and pH were 2.60 g/L, 12.60 g/L and 6.64, respectively. Alemahdi et al. (2015) reported that the characteristic of the sewage sludge of TS, VS and pH are 5.182 g/L, 3.734 g/L and 6.20 respectively. The characteristic of sewage sludge obtained were almost similar as compared to previous study by Alemahdi et al. (2015).

The characteristic of decanter cake was based on TS and VS were 19.40 g/L and 16.70 g/L, respectively. The previous study has reported that characteristic of decanter cake as TS and VS were 197.4 g/L and 169.7 g/L, respectively [10]. It was observed that the decanter cake was rich in the carbon contents with ratios of 42.70% relative to the dry weight. However, decanter cake has low nitrogen contents with percentages of 2.09%. In contrast, sewage sludge was characterized by a relatively low carbon content of 33.40% and a relatively high nitrogen content of 5.86% from its dry weight.

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Table 1. Characteristic of sewage sludge and decanter cake

Parameters	Sewage sludge	Decanter cake
Total Solid (TS), g/L	2.60	19.40
Volatile solid (VS), g/L	12.60	16.70
Carbon content, %	33.40	42.70
Nitrogen content, %	5.86	2.09
C/N ratio	5.70	20.43
pH	6.64	5.52

Based on elemental analyses results, decanter cake indicated 20.43 of C/N ratio which is a suitable condition for anaerobic digestion while C/N ratio of sewage sludge was 5.7. Low C/N ratio of sewage sludge can affect the anaerobic digestion process that could be result in high total ammonia nitrogen (TAN) and high volatile fatty acids (VFAs) accumulated in the digester [9]. If C/N ratio was low, ammonia concentration can rise in the process of anaerobic digestion, and high ammonia concentration can hinder microorganism vitality serving as an obstacle to anaerobic digestion. Therefore, in the case of single digestion of sewage sludge, effective anaerobic digestion can be difficult due to low C/N ratio [13]. In consequence, co-digestion of sewage sludge and decanter cake seems to have positive effects to anaerobic digestion such as increasing in methane yield. Elsayed et al. (2016) indicated that the great variance in C/N values between sewage sludge and any agro-wastes in the mixture may increase the methane production as compared to the individual substrates.

3.2 Biochemical methane potential (BMP) test

3.2.1. Biogas production. The results of cumulative biogas production profiles for the three F/I ratios of 1:0, 1:1 and 2:1 are shown as in Figure 1. The biogas production was increase by 5 times in volume using co-digested samples as compared to sewage sludge alone. Approximately 250 mL, 140 mL and 30mL of biogas were produced in the samples that contain decanter cake and sewage sludge mixed at the F/I ratio of 1:1, 2:1 and 1:0, respectively. It was observed that biogas production was increased from day 2 until day 10. The F/I ratio of 1:1 produced more biogas than F/I ratio of 2:1. However, further biogas composition need to be investigated as to confirm the presence of methane and other component gases.

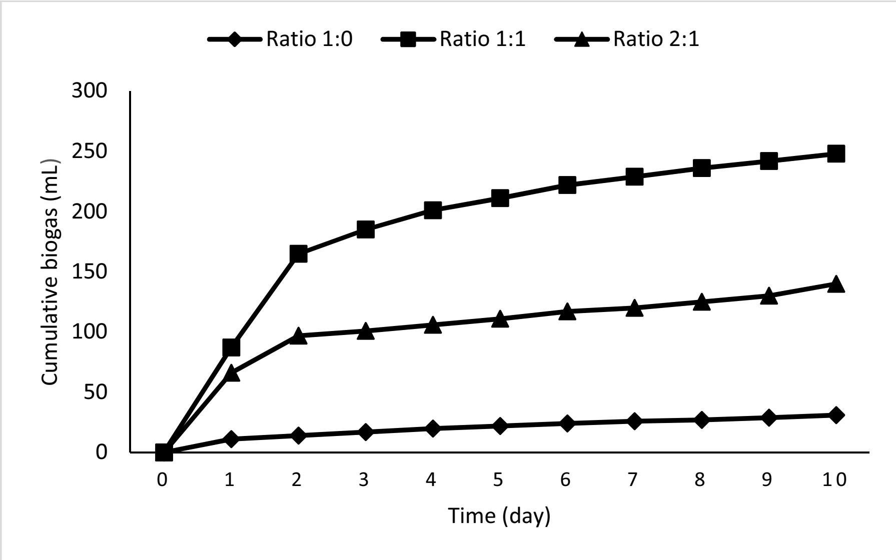

Figure 1. Cumulative biogas production

3.2.2. Biogas composition. The biogas composition in each gas samples for each day are shown in Figure 2. Based on the biogas composition, it was observed that high hydrogen yield and slightly some carbon dioxide were produced after two days of incubation. From day 3 until 10th, the CO_2 was produced and no hydrogen gas was detected. The methane gas was only observed at the 10th day. The hydrolysis and acidogenesis could happen from day 1 to 3 in converting carbohydrates, proteins and lipids to sugar, amino acid and fatty acid with the production of hydrogen, CO_2 and other volatile fatty acid (VFA). A sudden increase of methane at day 10th was observed with the highest methane yield of 3.3 mLCH4/gVS (Figure 3). This could be due to the methanogenic bacteria converting the VFA into methane. This shows that an acclimatization period of at least 10 days could be required when sewage sludge inoculum was employed for the anaerobic co-digestion with decanter cake at the F/I ratio of 2:1. Similarly, the acclimatization period for the F/I ratio of 1:1 was also observed at day 10th, but with much lower methane yield (0.6 mLCH4/gVS). Methane production decreased when increased F/I ratio [18].

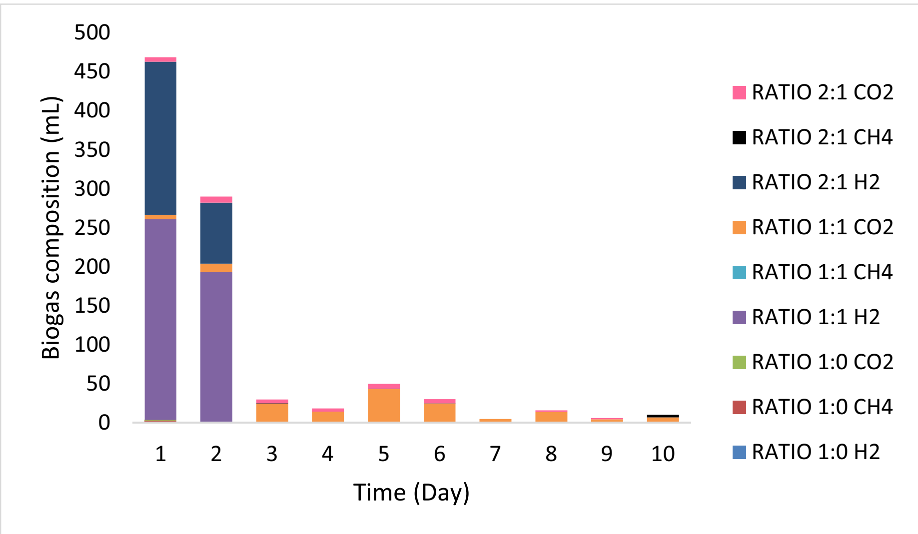

Figure 2. Biogas composition for each day

The period of acclimatization was independent upon the F/I ratio. In this study, the average of methane yield was found to be much lower with F/I ratio of 1:1 as compared to F/I ratio of 2:1. The finding was in line with a study reported by Suksong et al. (2015) showed that the methane production of decanter cake and POME mixture decreased with increasing proportion of decanter cake in mesophilic conditions. It has 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.

Moreover, increase amount of inoculum could also adding more active microoorganisms for anaerobic degradation. It has been reported by Kaosol and Sohgrathok (2014) that the mixing ratio with frozen seafood wastewater (as inoculum) increased the methane gas production volume, and also co-digestion of wastewater and decanter cake at each different HRT produced larger amount of methane gas compared to single digestion, at ambient temperature (mesophilic).

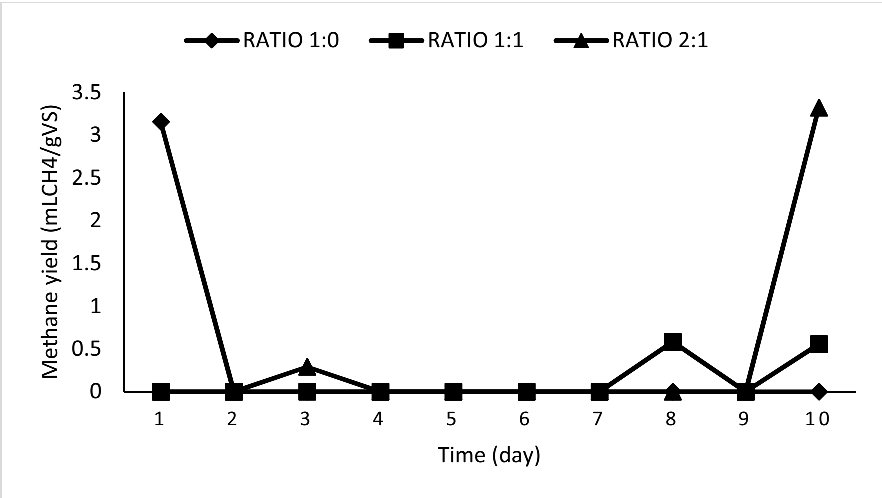

Figure 3. Methane gas production

The methane yield obtained from this co-digestion of sewage sludge and decanter cake increased with decrease F/I ratio. Therefore, F/I ratio of 2:1 produced more methane than F/I ratio of 1:1. Increasing in methane yield by co-digestion has been attributed to improve nutrient balance, mitigate toxicant levels or enhance microbial activity [20]. Solid waste in the palm oil mill such as decanter cake, empty fruit bunch and palm kernel shell are not utilize, due to its composition are difficult to degrade by methanogenic bacteria [18]. It seems necessary to introduce pre-treatment to decanter cake due to the lignocellulosic character of decanter cake. The pre-treatment techniques of the decanter cake could be with heat, ultrasonic or grinding in which to increase the degree of hydrolysis of feedstock and microbial stimulants.

4. Conclusion

The results indicated that the biochemical methane potential (BMP) tests could be used to assess the biogas and methane production from co-digestion process. It was found that the cumulative biogas production of the mixture of sewage sludge and decanter cake increased with increasing proportions of the decanter cake, however, the methane production was achieved much lower at higher load of decanter cake due to high degradability of the substrates since there is no pretreatment done to decanter cake. In consequences, still, the co-digestion of sewage sludge and decanter cake has a potential to produce methane. Therefore, preliminary study should be done to improve the digestion process. In this study, the suitable F/I ratio of anaerobic co-digestion between sewage sludge and decanter cake was F/I ratio of 2:1

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