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Biogas Production from Biomass Residues of Palm Oil Mill by Solid State Anaerobic Digestion

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Abstract

Solid state anaerobic digestion is a safe and environmental friendly technology to dispose solid wastes, could produce methane and reduce the volume of wastes. Three biomass residues from palm oil mill plant including empty fruit bunches (EFB), palm press fiber (PPF) and decanter cake (DC) were evaluated for methane production by solid state anaerobic digestion. Oil palm biomass was mixed with inoculum at F/I ratio of 2:1, 3:1, 4:1, 5:1 and 6:1 based on the volatile solid (VS). Results show that among the five F/I ratios tested, the F/I ratio of 2:1 gave the highest methane yield and methane production for all biomass residues. The highest cumulative methane production of 2180 mLCH_4 was obtained from EFB followed by PPF (1964 mL CH_4) and DC (1827 mL CH_4) at F:I ratio of 2:1. The highest methane yield of 144 mL CH_4/gVS was obtained from EFB followed by PPB (140 mL CH_4/gVS) and DC (130 mL CH_4/gVS) at F/I ratios of 2:1. Methane production from EFB, PPF and DC by SS-AD was 55, 47 and 41 m^3 CH_4/ton, respectively. These results collectively suggested that EFB could be a promising substrate for methane production by SS-AD

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Keywords: Oil palm biomass; Solid state anarobic digestion; Biogas production; Empty fruit bunches

1. Introduction

Oil palm is vastly cultivated as a source of oil in Malaysia, Indonesia and Thailand. In Southern Thailand, oil palm is one of the most important commercial crops. Oil palm mill plant also generates large amount of solids wastes such as empty fruit bunch (EFB) (23%), mesocarp fiber (12%) and shell (5%) for

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every ton of fresh fruit bunches (FFBs) processed in the mills [1]. Raw material supplied to the mills consists of fresh fruit bunches . In 2014 the yield of fresh fruit bunches was 1.127 million tons to year and the crude palm oil production was 0.192 million tons [2]. The oil extraction rate is about 10% from the palm oil biomass with the majority 90% left as residues biomass [3]. There are various forms of solid and liquid wastes from the mills. 60% of biomass residues from oil palm mills is a solid waste, while the rest is a liquid waste. Solid oil palm biomass residues are generated throughout the year include empty fruit bunches (EFB), palm press fiber (PPF), palm kernel cake (PKC), palm kernel shell (PKS), decanter cake (DC) in palm oil mills and liquid waste as palm oil mill effluent (POME) [4]. Liquid waste could be easily convert to value as products such as hydrogen and methane gas [5]. While, solid waste are not utilize, due to its composition are difficult to degrade by microorganisms. Oil palm biomass residues composed of cellulose, hemicelluloses that could be used as substrate for methane production by anaerobic digestion [6]. However, the composition of lignocellulosic biomass such as lignin content affects methane yield were limited to liquid AD [7]. Palm oil biomass containing mainly fibrous matter, are easily entrained by gases and floats to the surface to form a matted scum layer which is difficult to break. Therefore, palm oil biomass is unsuitable for feeding liquid phase anaerobic digesters and biogas production can be severely affected due to the floating and poor mixing of fibrous materials [8]. The anaerobic digestion (AD) process can operate in both liquid and solid states in terms of total solid (TS) content. In general, the TS content of liquid AD systems ranges from 0.5 to 15%, while solid-state AD (SS-AD) systems usually operate at TS contents of higher than 15% [9].

SS-AD can address several problems encountered in L-AD, such as floating and stratification of fibers, that make it well suited to handle lignocellulosicm biomass [10]. Compared to liquid AD, the major advantages of SS-AD include the reduction in reactor volume, minimal agitation, fewer moving parts, and lower energy input for heating due to a smaller operating volume [11]. Furthermore, the problems encountered in liquid AD, such as floating and stratification of fibers and disposal of large amounts of liquid effluent, can be addressed in SS-AD [8]. Furthermore, the finished digestate could be a compost-like material with about 20% TS content, making the waste disposal easier [12]. Comparison of solid-state to liquid anaerobic digestion of nice lignocellulosic feedstocks including switchgrass, corn stover, wheat straw, yard waste, leaves, waste paper, maple, and pine for biogas production were evaluated no significant difference in methane yield between LAD and SS-AD, except for waste paper and pine [13]. Cui et al. [13] found that the highest methane yield was attained for corn stover (81.2 L kg^{1} VS), followed by wheat straw (66.9 L kg^{-1} VS), leaves (55.4 L kg^{1} VS) and yard waste (40.8 L kg^{-1} VS). Methane production from EFB, PPF and DC by SS-AD are still not investigated. Therefore, this work aim to determine the methane potential from EFB, PPF and DC by SS-AD.

2. Materials and Methods

2.1 Inoculum and oil palm biomass

EFB, PPF and DC used in this study were collected from a palm oil mill plant (Southern palm oil Co, Ltd. in Thailand. All biomass were oven dried at 95°C for 48 hr. in a convection oven. The oven-dried samples were then ground to pass through a 5 mm screen with a grinder and stored in air tight containers for later use. The characteristics of substrates and inoculums for methods are shown in Table 1. Prior to use, the inoculum was acclimated and degassed at 37°C for 1 weeks to minimize the background methane production [14].

2.2 Biogas production from oil palm biomass by SS-AD

The biochemical methane potential assays biomethane potential of oil palm biomass including EFB, PPF and DC were evaluated for methane production via solid-state anaerobic digestion according to Angelidaki et al. [15]. The solid-state anaerobic digestion tests were conducted at 25% total solids (TS) content using palm oil biomass at feedstocks to inoculums (F/I) ratios of 2:1, 3:1, 4:1, 5:1 and 6:1. All tests were carried out in duplicate in a thermostat incubation room at 37°C for 45 days [16]. The assay was conducted as batch cultivations in 500 mL serum bottles. Methane production was measured by water replacement method. The methane content was analyzed by a gas chromatograph (GC) equipped with a flame ionization detector [16]. Gas measurement was reported in STP conditions (standard temperature and pressure, 273 K, 1.01325 Pa). Theoretical methane potential was calculated according Bushwell's formula which is derived by stoichiometric conversion of the compound to CH_4, CO_2 and NH_3 [17].

2.3 Analytical methods

TS and VS contents were measured according to the APHA Standard Methods for the Examination of Water and Wastewater [17]. The pH, alkalinity, and total VFA measurements were prepared by suspending 5 g of sample into 50 ml of water and, subsequently, filtrating the mixture using cheese cloth [18]. pH were measured by electrometric method [17]. Total VFAs were measured by a modified two-part titration method with standard HCl solution (1.0 N) using a titrator [16]. Total lipid were measured by direct extraction methods. [17]. The lignin, cellulose, and hemicellulose contents of the feedstocks and samples were measured by Klason Method [18]. The total nitrogen were measured by Kjeldahl method [17]. The composition of biogas (CO_2, CH_4, N_2 and O_2) was analyzed using a GC (Agilent Technologies, HP 6890, Wilmington, DE, USA). The methane yield was expressed as the volume of methane produced based on the initial total VS of the feedstock.

3. Results and Discussions

3.1 Characteristics of oil palm biomass

Characteristics of oil palm biomass and inoculum shown in table 1. EFB has TS, VS, nitrogen, lipids, cellulose, hemicellulose, carbohydrate and lignin of 96.3%, 75.3%, 1.07%, 4.73%, 38.8%, 35.6%, 35.5% and 25.5%, respectively. EFB has alkalinity, pH and VFA of 1.48 g/kg, 7.78 and 0.16 g/kg, respectively. PPF has TS, VS, nitrogen, lipids, cellulose, hemicellulose, carbohydrate and lignin of 93.9%, 81.8%, 1.49%, 8.19%, 32.7%, 28.5%, 26.6% and 38.7%, respectively. PPF has alkalinity, pH and VFA of 2.36 g/kg, 5.31 and 0.08 g/kg, respectively. DC has TS, VS, nitrogen, lipids, cellulose, hemicellulose, carbohydrate and lignin of 94.1%, 76.6%, 3.3%, 11.5%, 14.7%, 53.1%, 11.9% and 32.1%, respectively. DC has alkalinity, pH and VFA of 1.16 g/kg, 4.71 and 0.36 g/kg, respectively. The C/N ratio of the EFB, PPF and DC was 71, 54, 25%, respectively. All oil palm biomass was high organic content, it contained around 75-81 % of VS in dry biomass. It also high cellulose content, it could be convert to methane under anaerobic digestion .Decanter cake contained higher nitrogen and lipid than EFB and PPF, the nitrogen and lipid concentration was 0.21 g/kg and 0.14 g/kg, respectively.

3.2 Biogas production from EFB, PPF and DC by SS-AD

The total methane yields and methane production of EFB, PPF and DC at F:I ratios from 2:1-6:1 by SS-AD are shown in Fig. 1A. Methane production decreased when increased F:I ratios. The F/I ratio of 2:1 gave the highest methane yield and methane production for all the feedstocks tested (EFB, PPF and DC). SS-AD of EFB at F:I ratio of 2:1 gave the highest methane yield of 144 $mLCH_4/gVS$ followed by PPF (140 $mLCH_4/gVS$) and DC (130 $mLCH_4/gVS$). The highest methane production of 55 m^3CH_4/ton was obtained from EFB. Methane production of 55 m^3CH_4/ton was obtained from EFB followed by PPF (47 m^3CH_4/ton) and DC (41 m^3CH_4/ton) as show Fig.1B. Final volatile fatty acid (VFA) at F:I 2:1 of EFB, PPF and DC was low, while high concentration of VFA was found at high F:I ratio (3:1-6:1) as shown in Fig.2B.

Table1. Characteristics of oil palm biomass and inoculum.

Parameter	EFB	PPF	DC	inoculum
Total solid %(w/w)	93.32±0.02	93.9±0.01	94.19±0.09	7.21±0.00
Volatile solid %(w/w)	75.33±1.18	81.8±1.90	76.66±1.6	6.99±0.00
Nitrogen %	1.07±0.03	1.49±0.03	3.30±0.09	3.17±0.09
Alkalinity (g/kg)	1.48±0.60	2.36±1.98	1.16±1.07	4.48±0.57
Lipids %	4.73±0.00	8.19±0.00	11.57±0.00	42.95±0.00
pH	7.78±0.00	5.31±0.00	4.71±0.00	8.27±0.00
VFA (g/kg)	0.16±0.56	0.08±0.00	0.36±0.85	1.12±0.00
Cellulose %	38.80±0.03	32.7±0.02	14.74±0.91	-
Hemicellulose %	35.64±0.02	28.5±0.02	53.11±0.03	-
Lignin %	25.55±0.01	38.7±0.02	32.15±0.00	-
C:N	71.11±0.00	54.0±0.00	25.55±0.00	2.20±0.00
Carbohydrate %	35.54±0.02	26.6±0.04	11.91±0.00	-

The highest cumulative methane production of 2180 $mLCH_4$ was obtained from EFB followed by PPF, and DC of 1963 and 1826 $mLCH_4$, respectively at F/I of 2:1. Corresponds, the highest methane yield of 144 mL CH_4 was obtained from EFB followed by PPF and DC of 140 and 130 $mLCH_4$/gVS, respectively at F/I of 2:1. The methane yield, methane production , methane production were obtained from SS-AD of these palm oil biomass increased with decreased F/I ratio. Methane production from PPF and EFB was relatively high and produced earlier than DC. PPF and EFB via oil extraction process by used steam with a temperature of 130°C and a pressure of 3.1 bar, This process will take about 90 minutes [2]. Thus oil extraction process like pre-treatment process for EFB and PPF [19]. Steam pre-treatment of corn stover at 190°C for 5 min using SO_2 as an acid catalyst has been shown to give high sugar and methane yield. DC was by-product from purification palm oil process cause high oil. Since lipids have a low hydrolysis rate [20]. Degradation of cellulose and hemicellulose was negatively related to the lignin content in raw feedstocks.

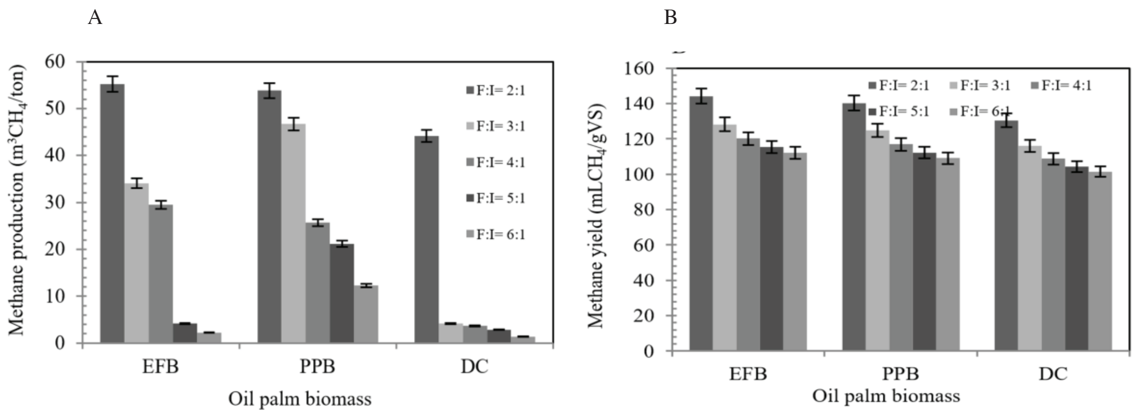

Fig. 1. Methane production from EFB, PPF and DC by SS-AD at different F:I ratios (A) Methane yield from EFB, PPF and DC by SS-AD at different F:I ratios (B) .

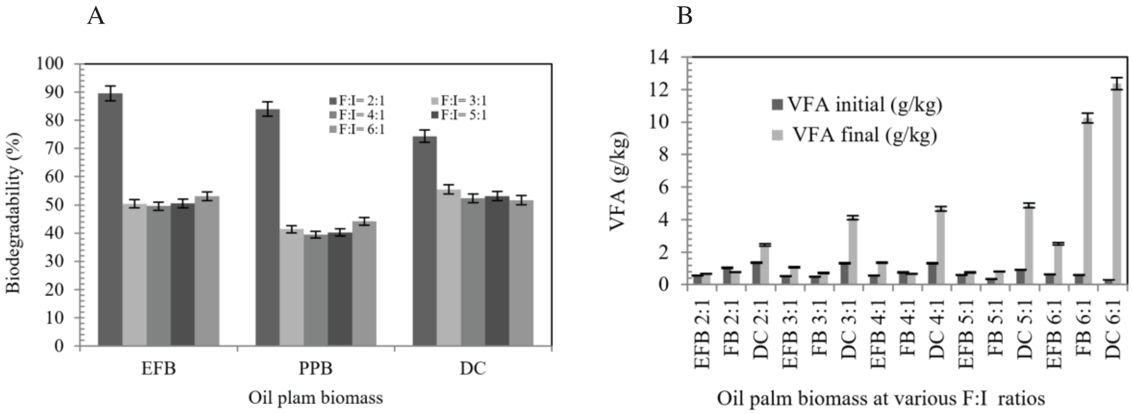

Fig. 2. Methane production of oil palm biomass at various feedstock to inoculum (A) and VFA concentration from EFB, PPF and DC by SS-AD at different F:I ratios (B).

Lignin is one of the key contributors to biomass recalcitrance and one of the primary substrate features impacting enzymatic conversion of cellulosic [21]. Due to its protective sheathing and hydrophobic nature, lignin retards cellulose accessibility to enzymes and microbial attacks thus leading to low cellulose and hemicellulose degradation [22]. Thus DC and PPF was lower methane yield than EFB.

Table 2 . pH, VFA concentration and alkalinity of methane production by SS-AD of EFB, PPF and DC at initial and final of experiments.

Sample	pH		VFA (g/kg)		Alkalinity (g/$CaCO_3$/kg)	
	Initial	Final	Initial	Final	Initail	Final
EFB=2:1	7±0.00	6.96±0.08	0.56±0.00	0.66±0.03	1.82±2.29	6.04±0.85
FB=2:1	7±0.00	7.16±0.02	1.04±0.23	0.78±0.03	5.02±0.08	3.64±2.09
DC=2:1	7±0.00	6.78±0.14	1.36±1.02	2.44±1.98	1.96±1.98	5.56±0.45
EFB=3:1	7±0.00	6.67±0.16	0.52±0.17	1.08±0.17	0.6±0.17	3.4±0.40
FB=3:1	7±0.00	7.08±0.03	0.48±0.11	0.72±0.11	0.24±0.11	4.08±0.11
DC=3:1	7±0.00	5.29±0.03	1.32±0.28	4.12±0.17	3.64±0.17	5.88±0.00
EFB=4:1	7±0.00	6.54±0.06	0.56±0.45	1.36±0.23	0.88±0.23	3.88±0.04
FB=4:1	7±0.00	6.98±0.05	0.76±0.40	0.68±0.17	0.2±0.17	3.36±0.51
DC=4:1	7±0.00	5.10±0.01	1.32±1.75	4.68±0.06	4.2±0.06	4.52±0.57
EFB=5:1	7±0.00	7.05±0.16	0.6±0.17	0.76±0.06	0.28±0.06	2.2±0.00
FB=5:1	7±0.00	6.80±0.28	0.36±0.06	0.8±0.00	0.32±0.00	4.84±1.47
DC=5:1	7±0.00	5.00±0.01	0.92±0.40	4.88±1.36	4.4±1.36	0.6±0.94
EFB=6:1	7±0.00	5.68±0.62	0.64±0.00	2.52±1.98	2.04±1.98	2.2±1.75
FB=6:1	7±0.00	5.29±0.05	0.6±0.17	10.2±0.71	9.76±3.17	2.76±0.11

DC=6:1	7±0.00	4.94±0.01	0.3±0.25	12.3±0.40	11.8±0.40	3.88±1.30

Among the five F/I ratios tested, the highest total methane yield was obtained at an F/I ratio of 2:1 for all the feedstocks. When ratio F/I increased degradation will take a long time. Which the F/I ratio was increased the total methane yields cumulative methane production and methane production were decreased. Higher F/I ratios could contribute to organic overloading, which may be indicated by the presence of higher concentration of organic acids [23]. At F/I of 6 high accumulation of VFA and lowered the pH, it around 0.2-0.6 and 4-7.0 respectively as show Table 2, causing failure of the digestion process. Overloading of organic material can cause accumulation of VFAs which might lead to inhibition of methanogens and failure of the digester [24]. The quality of biogas was also for EFB,FFB and DC with 53-65% of methane in biogas at F/I ratio 2. However, excessive organic loading rate at F/I ratios of 6 resulted in lower methane contents.

4. Conclusion

EFB converted to methane with maximum methane potential of 144 mL CH4/gVS at F/I ratio of 2:1 corresponding to cumulative methane production of 2180 mL and 89% biodegradability. F/I ratio of 2:1 was suitable for methane production from EFB, PPF and DC by SS-AD. The biochemical methane potential of EFB, PPF and DC by solid-state anaerobic digestion was 55, 47 and 41 $m^3 CH_4$/ton, respectively.The quality of biogas was also for EFB,FFB and DC with 53-65% of methane in biogas at F/I ratio 2:1.

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