Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 79 (2015) 943 – 949

Energy Procedia

2015 International Conference on Alternative Energy in Developing Countries and Emerging Economies

Biohythane Production from Co-Digestion of Palm Oil Mill Effluent with Solid Residues by Two-Stage Solid State Anaerobic Digestion Process

Wantanasak Suksong[a], Prawit Kongjan[b], Sompong O-Thong[a,c*]

[a]*Biotechnology Program, Faculty of Science, Thaksin University, Phatthalung, Thailand*
[b]*Department of Science, Faculty of Science and Technology, Prince of Songkla University, Pattani, Thailand,*
[c]*Microbial Resource Management Research Unit, Faculty of Science, Thaksin University, Phatthalung, Thailand*

Abstract

Biohythane production from co-digestion of palm oil mill effluent (POME) with empty fruit bunches (EFB) and decanter cake (DC) by two-stage solid state anaerobic digestion process was investigated. The first stage, thermophilic hydrogen fermentation of co-digestion of POME with DC at 10, 30, 50 and 70% of DC in POME has hydrogen yield of 16, 14, 3 and 1 ml H_2/gVS, respectively. Co-digestion of POME with 10% DC gave the best hydrogen yield of 16 ml H_2/gVS with hydrogen production of 1.4 m^3/ton mixed waste. Co-digestion of POME with 10% EFB gave the best hydrogen yield of 16 ml H_2/gVS with hydrogen production of 1.4 m^3/ton mixed waste. The effluent from the hydrogen production was further converted to methane in the second stage. The methane yield from POME mixed withn10% DC was 391 mlCH_4/gVS and from POME mixed with 10% EFB was 240 mlCH_4/gVS. The hydrogen and methane content in biogas was 25.33% and 65.21% respectively. The two-stage solid stage anaerobic digestion process can be removal efficiently of cellulose 57-59%, hemicelluloses 35-40% and lignin 16-27%. Result obtained make practical use for the development of two-stage anaerobic digestion process providing hydrogen and methane co-production from palm oil waste residues.

Peer-review under responsibility of the Organizing Committee of 2015 AEDCEE

Keywords: Hydrogen, methane, palm oil mill effluent, empty fruit bunches, decanter cake

1. Introduction

Palm oil mills produce significant quantities of wastes such as palm oil mill effluent (POME), empty fruit bunches (EFB) and decanter cake (DC). These wastes could cause environmental impact and

* Corresponding author. Tel.: +66-74-693-992; fax: +66-74-693-992.
E-mail address: sompong.o@gmail.com

Peer-review under responsibility of the Organizing Committee of 2015 AEDCEE
doi:10.1016/j.egypro.2015.11.591

lifestyle qualities in nearby communities [1]. The common practice of treating POME is by using ponding or digestion tank systems without gas collection facilities which have particular disadvantages such as long hydraulic retention time of 45–60 d, bad odor and difficulty in maintaining the liquor distribution to ensure smooth performance over huge area [2]. Interest in anaerobic digestion technology has applied in recent years, as it couples the recovery of usable energy with good process efficiency. Therefore currently, most of palm oil mill plants use POME as feedstock for biogas production [3]. In most of the solid wastes from Palm oil mills industrial has high content of organic matter, mostly were applied as compost into agricultural areas. However, solid wastes from Palm oil mills industrial have potential to be used for biogas production. Because of the carbohydrates in crop residues, which exist mostly as the polysaccharides cellulose and hemicelluloses [4]. Solid stage anaerobic digestion technology (SS-AD) capacity of high solid feedstock and operator with higher than 15% total solid. SS-AD digested can be used as a fertilizer its high content of nitrogen, phosphorus and potassium. However, SS-AD also needs a longer time of biological degradation around 60 days that is caused by plant cell wall content of lignin around 5-35%. Cause the slow growth and metabolic rate of microbes under anaerobic conditions [5]. Therefore two-stage anaerobic digestion for hydrogen and methane production has now emerged as an attractive and promising process. In this process, two separate conditions are connected in series, separating acidogenesis and methanogenesis [6]. In the first stage of the anaerobic digestion process hydrolysis and acidogenesis occurs. This stage bacterial are grown under an optimal pH range of 5–6 for 1 to 3 days they can convert carbohydrates, proteins and lipids to sugar, amino acid and fatty acid after that, the production of hydrogen, acetate and butyrate along with other by-products of propionate, ethanol, and lactate. In the second stage, the remaining organic content in the acidogenesis effluent is anaerobically converted to methane under a neutral pH range of 7–8 for 10 to 15 days by methanogens [7]. Therefore, this study aimed to determine the biohydrogen and biomethane potential from solid state anaerobic co-digestion of POME with DC and EFB for two-stage hydrogen and methane.

2. Materials and Methods

2.1 Substrates and Inoculums

The palm oil mill effluent (POME) Decanter cake (DC) and empty fruit bunches (EFB) used in this study were collected from a palm oil mill plant in Thailand. POME was stored at the temperature of 4 °C for later use. The DC and EFB was air dried (90-95 °C) to the moisture content of less than 10% (w/w). The dried DC and EFB were milled to obtain particle sizes of less than 4 mm. Then, it was stored at room temperature for later use. The average characteristics of POME, DC and EFB are indicated in Table 1. Anaerobic sludge was collected from palm oil mill wastewater treatment plant for use as the inoculums hydrogen production and cultivation of inoculums was obtained by treating anaerobic sludge at short hydraulic retention time (24 h), pH 5.5 at thermophilic condition (60 °C) to remove methanogenic bioactivity. described previously by Seengenyoung et al.[8]. The inoculums used for methane production was obtained from the pilot scale, thermophilic biogas plant, and fed with manure (Lyngby, Denmark) described previously by Kongjan et al.[7]. POME was used as a substrate for the cultivation of inoculums methane production (1:1v/v) and $NaHCO_3$ was used as a buffer for the pH adjustment (7-7.5). Total volatile suspended solid (VSS) of the inoculums for hydrogen and methane production were 0.25, 3.21% respectively.

Table1.The chemical characteristics of palm oil mill effluent, empty fruit bunches and decanter cake.

Characteristics	Characteristics		
	POME	EFB	DC
Total solid %(w/w)	5.88	97.48	99.16
Volatile solid %(w/w)	4.89	83.06	80.74
Cellulose%	4.2	49.65	32.78
COD (g/L)	44.72	-	-
TKN (mg/kg)	20.77	8.18	31.30
TVFA(g/L)	3.66	-	-
Carbohydrates(g/kg)	50.00	29.67	8.00
Fat Oil and Grease(mg/L)	1154.50	-	-

2.2 Experimental design

Hydrogen and methane co-production from solid state co-digestion of POME with EFB and co-digestion of POME with DC was examined using a two-stage process of anaerobic digestion. Co-digestion of raw POME with EFB and co-digestion of POME with DC was tested at different mixing ratios were determined in batch assays under thermophilic condition as described previously by Angelidaki et al. [9]. The hydrogen stage was operated in batch test under an initial pH 5.5 and a temperature of (60°c). Subsequently, hydrogen effluent was investigated for methane production in second under initial pH at 7 and a temperature of (60°c). The two stage batch fermentation system including hydrogen fermentation in the first stage and methane fermentation in the second stage was set up in 500 mL serum bottles with a working volume of 200 mL. The solid-state anaerobic digestion tests were conducted at 12-30% total solids (TS) content using F/M ratio of hydrogen was 4.0 and 1.5 for methane fermentation corresponding to initial organic load of 60, 90, 125 and 150 gVS/L respectively. The system was flushed with nitrogen gas to generate anaerobic conditions. During the fermentation experiment, total gas volume and composition were periodically monitored by gas counters and gas chromatography, respectively.

2.3 Analytical methods

The biogas composition was measured by gas chromatography equipped with thermal conductivity detectors (TCD). Hydrogen and methane gas was analyzed by GC-TCD fitted with an 1.5 m stainless steel column SS350A packed with a molecular sieve (80/100 mesh). Helium was used as a carrier gas at a flow rate of 14-15 ml/min. The temperatures of the injection port, oven and detector were 120, 50 and 120°C, respectively as described previously by Morimoto et al. [10]. The daily biogas production for each anaerobic digester was recorded using the water displacement method. The total solid, volatile solid, Fat Oil and Grease, Chemical oxygen demand, Total kjeldahl nitrogen, Total volatile fatty acid and pH of the materials were determined using the standard water and wastewater examination methods (APHA, 1998).[11]. The celluloses of the materials were determined as described previously by Lin and Dence 1992.[12]. The total carbohydrates of the materials were determined as described previously by Morris 1948.[13]. The methane yield was calculated as the daily volumetric methane divided by the initial total VS in POME, DC and EFB. In most of the thermal energy content of the hydrogen and methane was calculated using the lower calorific value 141.8 $MJ/kg_{hydrogen}$ and 50.1 $MJ/kg_{methane}$ as described previously by O-Thong et al. [14].

3. Results and Discussions

3.1 Hydrogen production from co-digestion of POME with EFB and co-digestion of POME with DC

In the first stage, the cumulative hydrogen production obtained from co-digestion of POME with EFB and co-digestion of POME with DC are shown in Fig. 1. The maximum hydrogen yield was 16.26-16.52 ml H_2/gVS achieved from co-digestion DC with POME at mixing ratio of 1:5 and co-digestion of EFB with POME at mixing ratio of 1:5 (Table 2). However, the maximum hydrogen production was 1.61-1.72 m^3/ton $_{waste}$ achieved from co-digestion DC with POME at mixing ratio of 1:2 and co-digestion of EFB with POME at mixing ratio of 1:2. This will be observed low hydrogen yield at high substrate concentration which indicated that they had potential to inhibit the process when overloaded and do not have an EFB and DC pretreatment [14]. Additionally, average compositions of gas produced during steady-state conditions were hydrogen 25% and carbon dioxide 75%. At the end of the 20 days digestion, The removal efficiencies of VS was 33.4, 26.7, 7.7 and 6.3% from co-digestion of POME with EFB at mixing ratio of 1:5, 1:2, 1:1 and 2:1 respectively. Corresponds, co-digestion of POME with DC removal efficiencies of VS was 12.8, 11.1, 17.4 and 8.7% at mixing ratio of 1:5, 1:2, 1:1 and 2:1 respectively.

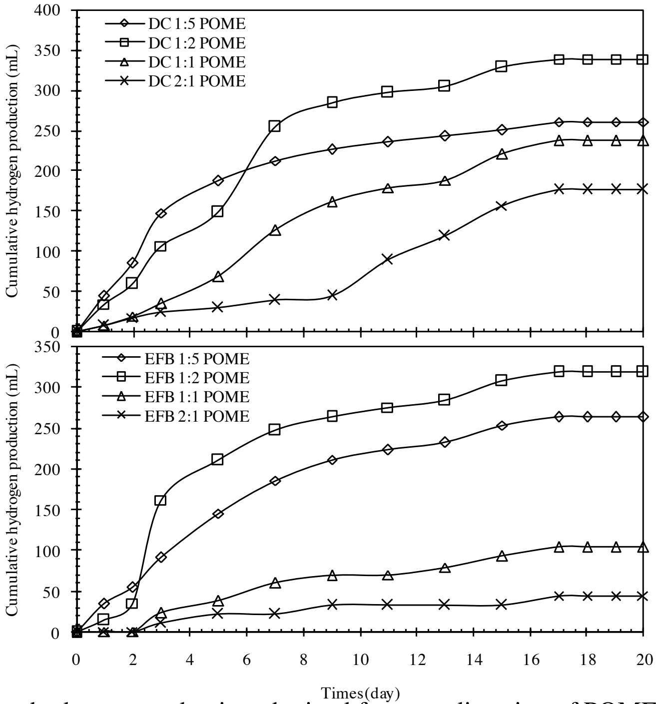

Fig. 1. The cumulative hydrogen production obtained from co-digestion of POME with EFB and co-digestion of POME with DC.

3.2 Methane production from hydrogen effluent.

The cumulative methane production from hydrogen effluent in first stage are shown in Fig. 2 The maximum methane yield in the second stage was 391.62 ml CH_4/gVS from co-digestion of DC with POME at mixing ratio of 1:5 and maximum methane yield from co-digestion of POME with EFB at mixing ratio of 1:5 was 240.65 ml CH_4/gVS. The initial soluble chemical oxygen demand for co-digestion of DC with POME at mixing ratio of 1:5 higher than 58% for co-digestion of POME with EFB at mixing ratio of 1:5. Corresponds, the maximum methane production was 51.59 m^3/ton $_{waste}$ achieved from co-digestion of DC with POME at mixing ratio of 1:5 (Table 2). The average compositions of gas produced during steady-state conditions were methane 65% and carbon dioxide 35%. The removal efficiency of VS was 39.8, 53.3, 61.6 and 67.9 33.4, 26.7, 7.7 and 6.3% from co-digestion of POME with EFB at mixing ratio of 1:5, 1:2, 1:1 and 2:1 respectively. Corresponds, co-digestion of POME with DC removal efficiencies of VS was 60.4, 67.8, 66.1 and 67.1% at mixing ratio of 1:5, 1:2, 1:1 and 2:1 respectively. Furthermore, the removal efficiency of cellulose, hemicelluloses and lignin for two-stage process anaerobic digestion are shown in Table 3.

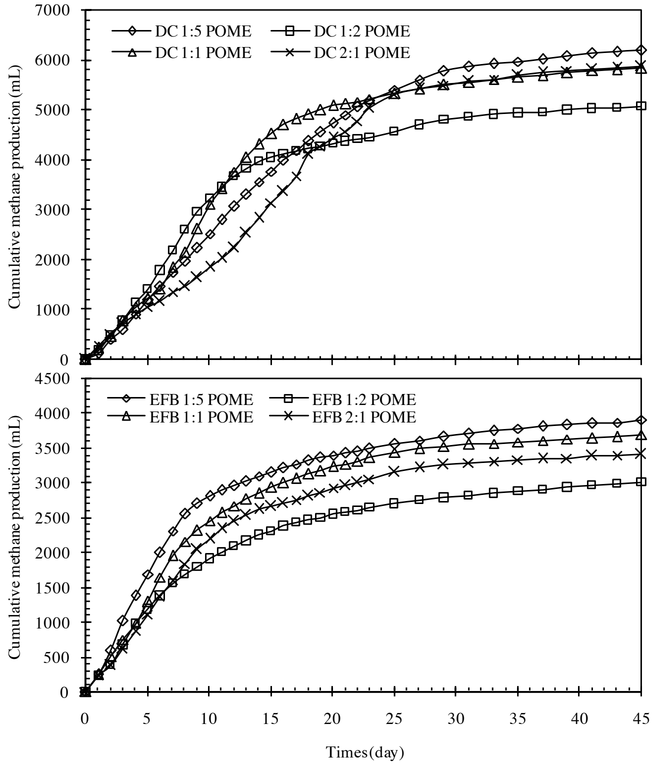

Fig. 2 The cumulative methane production obtained from hydrogen effluent.

Table2.The summary of hydrogen and methane production.

Ratio	Initial organic load (gVS/L)	Initial VS (%)	Initial TS (%)	Yield (mL/gVS)		Production (m^3/ton $_{waste}$)	
				H_2	CH_4	H_2	CH_4
EFB 1:5 POME	60	6	8	16.26	240.65	1.48	32.54
EFB 1:2 POME	90	9	12	14.08	132.62	1.61	25.01
EFB 1:1 POME	125	12.5	16	3.62	126.97	0.48	30.72
EFB 2:1 POME	150	15	20	1.26	95.95	0.19	28.34
DC 1:5 POME	60	6	8	16.52	391.62	1.46	51.59
DC 1:2 POME	90	9	12	15.56	233.05	1.72	42.34
DC 1:1 POME	125	12.5	16	8.57	210.14	1.10	48.66
DC 2:1 POME	150	15	20	5.22	173.82	0.75	48.93

Table 3.The removal efficiency of celluloses, hemicelluloses and lignin.

Ratio	% Removal efficiency		
	celluloses	hemicelluloses	lignin
EFB 1:5 POME	59.47	35.64	16.25
EFB 1:2 POME	51.66	32.53	18.66
EFB 1:1 POME	12.13	31.97	29.7
EFB 2:1 POME	0.61	23.18	14.79
DC 1:5 POME	57.60	40.98	27.21
DC 1:2 POME	41.17	39.72	22.86
DC 1:1 POME	39.12	23.88	10.7
DC 2:1 POME	22.42	12.57	3.98

4. Conclusions

Two-stage process anaerobic co-digestion of POME with DC and EFB were thermal energy content of the hydrogen and methane was 0.1, 8.82-13.9 MJ/kgVS respectively. Result obtained make practical use for the development of two-stage anaerobic digestion process providing hydrogen and methane co-production from palm oil waste residues. This technology can be implemented at large scale biogas plants improving economical and ecological characteristics of the overall process.

Acknowledgements

We would like to thank the Microbial Resource Management Research Unit, Faculty of Science, Thaksin University.

References

[1] Yahya A, Sye PC, Ishola TA, Suryanto H. Effect of adding palm oil mill decanter cake slurry with regular turning operation on the composting process and quality of compost from oil palm empty fruit bunches. *Bioresource Technology* 2010; 101:8736-8741.

[2] Zinatizadeh AAL, Mohamed AR, Abdullah AZ, Mashitah MD, Hasnain Isa M, Najafpour GD. Process modeling and analysis of palm oil mill effluent treatment in an up-flow anaerobic sludge fixed film bioreactor using response surface methodology (RSM). *Water Research* 2006; 40:3193-3208.

[3] Chin KK, Lee SW, Mohammad HH. A study of palm oil mill effluent treatment using a pond system. *Water Science and Technology* 1996; 34:119-123.

[4] Yebo Li, Stephen Park Y, Jiying Zhu. Solid-state anaerobic digestion for methane production from organic waste. *Renewable and Sustainable Energy Reviews* 2011; 15:821-826.

[5] Liangcheng Yang, Fuqing Xu, Xumeng Ge, Yebo Li. Challenges and strategies for solid-state anaerobic digestion of lignocellulosic biomass. *Renewable and Sustainable Energy Reviews* 2015; 44:824-834.

[6] Yunqin Lin, Shubin Wu, Dehan Wang. Hydrogen-methane production from pulp & paper sludge and food waste by mesophilic–thermophilic anaerobic co-digestion. *International Journal of Hydrogen Energy* 2013; 38:15055-15062.

[7] Kongjan P, O-Thong S, Angelidaki I. Hydrogen and methane production from desugared molasses using a two-stage thermophilic anaerobic process. *Engineering in Life Sciences* 2013; 13:118–125.

[8] Seengenyoung J, Prasertsan P, O-thong S. Biohydrogen Production from Palm Oil Mill Effluent Pretreated by Chemical Methods Using *Thermoanaerobacterium*-Rich Sludge**.** *Iranica Journal of Energy & Environment* 2013; **4**:312-319.

[9] Angelidaki I, Alves M, Bolzonella D, Borzacconi L, Campos JL, Guwy AJ, Kalyuzhnyi S, Jenicek P, van Lier JB. Defining the biomethane potential (BMP) of solid organic wastes and energy crops: a proposed protocol for batch assays. *Water Sci Technol* 2009; 59:927–34.

[10] Morimoto M, Atsuko M, Atif AAY, Ngan MA, Fakhru'l-Razi A, Iyuke SE, Bakir AM. Biological production of hydrogen from glucose by natural anaerobic microflora. *International Journal of Hydrogen Energy* 2014; 29:709-713.
[11] APHA. *Standard methods for the examination of water and wastewater*, 20th ed. Washington (DC, USA): American Public Health Association; 1998.
[12] Lin SY, Dence CW. *Methods in Lignin Chemistry*. Berlin: Springer-Verlag; 1992.
[13] Morris D L. Quantitative determination of carbohydrates with Dreywood's anthrone reagent. *Science* 1948;107:254-255.
[14] O-Thong S, Boe K, Angelidaki I. Thermophilic anaerobic co-digestion of oil palm empty fruit bunches with palm oil mill effluent for efficient biogas production. *Applied Energy* 2012; 93:648-654.