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Waste utilization of palm oil decanter cake on biogas fermentation

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ABSTRACT

High biodegradable organic contents and nutrient rich compositions makes palm oil decanter cake as an attractive feedstock for biogas production. The decanter cake with varying organic loading in the range of 2.5–10% (w v^{-1}) was used for the biogas production in 0.5 L batch reactors under the condition of initial pH 7 and 37 °C. Comparative performance of the biogas production using combined sludge seed and indigenous microbes or sole indigenous microbes as inocula was evaluated. Types of inoculum seeds displayed strong effect on the biogas compositions and production kinetic. CH_4 was the predominant biogas composition, while no H_2 was observed in the combined seed fermentation. H_2 production was predominantly detected in the indigenous microbe fermentation. The presence of the sludge seed appeared to facilitate both hydrolysis and methanogenesis resulting shorter lag time and higher maximum production rate (R_m). The increase of the decanter cake concentration elevated H_2 production and the significant enhancement of CH_4 production based on the CH_4 production potential (P) and the maximum production rate (R_m). This work demonstrated the addition of sludge seed, containing methanogenic bacteria, yielded a better performance in the biogas production than the sole indigenous microbes, which presumably contained only hydrolytic and acidogenic bacteria.

Introduction

Bioenergy and biofuels from renewable feedstocks have been extensively explored to replace finite and environmentally harmful fossil fuels. Organic-rich wastes are ideal feedstocks for the production of bioenergy and biofuels. Palm oil industry plays an important role in Thailand's agro-economy. Due to the proper climate and soil conditions for large-scale palm oil plantation, Thailand is ranked as the third world largest producer of palm oil [1]. Palm oil occupies 70% of the Thai

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vegetable oil in the market, and has been estimated to contribute about 40,000 million baht per year. The average annual growth rate of 15% has been obtained during the last decade [2]. Typical palm oil mills generate significant quantities of wastes for each tonne of fresh fruit brunches (FFB) including 0.6–0.8 m^3 of palm oil mill effluent (POME), 23% of empty fruit brunch (EFB), 3.5% of oil palm decanter cake (OPDC), and 13.5% of palm mesocarp fiber (PMF) [3,4]. The vast amount of biomass generated wastes raised concerns regarding the environmental impact and sustainability of the palm oil industry. The strategy to reduce the wastes by converting to high valuable products is the sustainable means of the waste management.

The decanter cake, composed of high biodegradable organic content and nutrient-rich composition, is ideal feedstock for the production of bioenergy (e.g.CH_4 and H_2) via fermentation. Over the last decade, most decanter cake has been used as fertilizer and animal feed, a raw material for cellulose and polyose [5,6], bio-surfactant [7], biobutanol [8], bio-diesel [9] and bio-oil productions [10].

In general, the cost of producing bioenergy significantly depends on the cost of feedstocks. Agro-industrial wastes have been attractive as free cost feedstocks for biogas production by the palm oil mill industry since it can be directly used on-site for heating boilers and other applications [11]. High organic content and low cost feedstock make decanter cake a potential feedstock for biogas production. In the present study, the comparative performances of the combined sludge seed and indigenous microbes; and sole indigenous microbes in the biogas production from the decanter cake at the optimum condition with varying organic loading of palm oil decanter cake (2.5–10% w v^{-1}) was evaluated based on biogas composition, production rate, and yield; waste reduction; and energy recovery.

Materials and methods

Microbial inoculum

Anaerobic sludge seed was obtained from a full-scale upflow anaerobic sludge blanket reactor treating beverage processing wastewater (Sermsuk Industry Co. Ltd., Pathumtani, Thailand). Prior to use, the granule was sieved to the size <0.5 mm to remove coarse matters and then washed twice with tap water. The anaerobic granule sludge was re-cultivated in 0.5% (w/v) glucose solution until reach to steady state regarding the CH_4 content and volume of CH_4 production and then washed with the distilled water twice before used as a seed microbial inoculum for the biogas fermentation.

Decanter cake

Decanter cake, a feedstock for the biogas production and a source of indigenous microbes, was collected from palm oil milling plant, Suksomboon palm oil industry in Chonburi, Thailand. The sample was stored at 4 °C before use. The characteristics of anaerobic granular sludge and palm oil decanter cake are shown in Table 1.

Table 1 – Characteristics of the palm oil decanter cake and anaerobic granular sludge.

Parameter	Decanter cake (mg Kg^{-1})	Sludge seed (mg L^{-1})
Total solids (TS)	754,480	22,233
Total volatile solids (VS)	212,283	19,700
Total COD	508,810	40,153
Soluble COD	343,300	2881

Batch fermentation

Batch fermentation system was set up in 500 mL screw-cap bottles with a working volume of 500 mL. In each reactor, the anaerobic sludge was fixed at 6.73 g total volatile solids (VS) (125 mL) for the combined seed fermentation. Decanter cake was added at varying concentrations between 2.5 and 10.0% (w v^{-1}). The initial pH was adjusted to 7.0 with 6 N NaOH or concentrated H_3PO_4. The system was flushed with nitrogen gas to generate anaerobic conditions. Biogas fermentation was conducted at 37 °C with rotary shaking at 150 rpm. All experiments were set up in triplicate. During the fermentation experiment, total gas volume and composition were periodically monitored by gas counters and gas chromatography, respectively. The liquid samples were analysed for pH and volatile fatty acids (VFAs) every 6–12 h.

Analytical methods

Total solids (TS), total volatile solids (VS), and chemical oxygen demand (COD) were measured according to Standard Methods 2540 G and 5220 B, respectively [12]. The amount of generated biogas was recorded using liquid displacement gasometers. Biogas content (H_2, CH_4, and CO_2) was measured periodically every 4–6 h using a gas chromatograph (Shimadzu GC-8A, Kyoto, Japan) equipped with a thermal conductivity detector (TCD) with a Unibeads C 60/80 column (GL Sciences, Inc., Tokyo, Japan). Helium was used as a carrier gas. The temperatures of the injection port and the detector were 150 and 80 °C, respectively. VFAs were analysed by gas chromatography Shimadzu GC-7A system equipped with a flame ionization detector and a Stabilwax DA capillary column (Restek Corporation, PA, USA). The temperatures of the injection port and detector were maintained at 240 °C [13].

Kinetic analysis

The modified Gompertz equation (Eq. (1)) was used to fit cumulative hydrogen/methane production data obtained from each batch experiment [14]. This model has long been used for describing hydrogen, methane, or biogas production in batch fermentation experiments.

$$H(t) = P \cdot \exp\left\{-\exp\left[\frac{R_m \cdot e}{P}(\lambda - t) + 1\right]\right\} \quad (1)$$

Where $H(t)$ is cumulative biogas production (mL) during the incubation time, t (h), P is the biogas production potential