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Production of hydrogen and methane by one and two stage fermentation of food waste

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ABSTRACT

Anaerobic digestion is an attractive process for generation of hydrogen and methane, which involves complex microbial processes on decomposition of organic wastes and subsequent conversion of metabolic intermediates to hydrogen and methane. Comparative performance of a sequential hydrogen and methane fermentation in two stage process and methane fermentation in one stage process were tested in batch reactor at varying ratios of feedstock to microbial inoculum (F/M) under mesophilic incubation. F/M ratios influence biogas yield, production rate, and potential. The highest H_2 and CH_4 yields of 55 and 94 mL g^{-1} VS were achieved at F/M of 7.5 in two stage process, while the highest CH_4 yield of 82 mL g^{-1} VS in one stage process was observed at the same F/M. Acetic and butyric acids are the main volatile fatty acids (VFAs) produced in the hydrogen fermentation stage with the concentration range 10–25 mmol L^{-1}. Little concentrations of VFAs were accumulated in methane fermentation in both stage processes. Total energy recovery in two stage process is higher than that in one stage by 18%. This work demonstrated two stage fermentation achieved a better performance than one stage process.

1. Introduction

Renewable and clean energy sources have been sought to be a substitute for fossil fuels that pose environmentally negative impacts such as the pollutant emission of carbon dioxide, carbon monoxide, hydrocarbon, nitrogen oxide and ashes. Hydrogen is extensively known as an ideal clean energy source due to its high specific energy content (122 kJ g^{-1}) [1,2] and zero carbon emission after its combustion [3]. Hydrogen can be generated from various strategies by thermochemical, electrochemical, and biological processes [4]. Biological hydrogen production is less energy intensive than non-biological processes, and so is considered more environmentally friendly. Hydrogen is generated as a product of several

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different metabolic pathways including direct water bio-photolysis by green algae, indirect water bio-photolysis by cyanobacteria, photo-fermentation by photosynthetic purple non-sulfur bacteria, and dark fermentation by heterotrophic anaerobic bacteria. Dark fermentation generates hydrogen at higher rates, uses wider spectrum of substrates, and require lower energy than that of light-dependent processes [5–7]. Several feedstocks such as municipal waste, livestock manure, crop residues, food waste, and wastewater have been utilized as substrates in the dark fermentation [8–11].

Biochemical pathway of dark hydrogen fermentation is well-established. It is generated as a product of acidogenesis and acetogenesis in anaerobic digestion (AD) process, but rapidly consumed by methanogenic bacteria in the single phase digestion. Separation of acidogenesis and acedogenesis; and methanogenesis in the two phase AD system can recover both hydrogen and methane [12,13]. The single phase AD is generally more predominant than two phase AD for the full scale application [14]. Several studies, however, demonstrated that the two phase AD achieved higher overall degradation efficiency [15,16], and is more advantageous than the single phase system for the treatment of the waste feedstocks containing a large fraction of recalcitrant organic matters such as food waste [17–19], olive pulp [20], and cheese whey [21]. Hydrogen and methane from the two phase system can be utilized either by itself or making a gas mixture called Hythane (5–10% H_2, 30–40% CO_2, 50–65% CH_4) with higher combustion efficiency and emission performance than the natural gas [22–24].

Several strategic approaches such as optimization of pre-treatment methods of feedstocks, fermentation temperature, and organic loading rates have been used to enhance hydrogen fermentation of municipal and food wastes in the first stage of two-phase AD system [18,19,25]. Hydrogen yield in mesophilic dark fermentation is generally below 50 m^3 H_2 kg^{-1} VS. The present study compared the performance of one and two stage mesophilic fermentation of food waste based on biogas yield and production rate, and overall energy recovery. The research focused on the maximization of the overall energy production in the two phase system by optimizing food to microorganism (F/M) ratio in the first stage of hydrogen production while methane production in the second stage is relied on byproducts from acidogenic and acetogenic steps in the first stage.

2. Materials and methods

2.1. Microbial seed

Microbial seed used throughout the study was obtained from a full-scale up flow anaerobic sludge blanket (UASB) reactor treating cassava wastewater (Eiamburapa Co., Ltd., Thailand). Coarse matter >0.5 mm diameter was removed by sieving and the granules were washed twice with tap water. The fine granules, used in the hydrogen fermentation were boiled at 90 °C for 30 min to deactivate methanogens [26], while those without heat treatment were used in methane production stage. The characteristics of seed cultures are shown in Table 1.

Table 1 – Characteristics of the seed culture and feedstock.

Parameter	Unit	Non heat-treated seed	Heat-treated seed	Food waste
Total solids (TS)	mg L^{-1}	67,910	66,227	45,520
Total volatiles solids (VS)	mg L^{-1}	38,570	38,000	27,578
Total COD	mg L^{-1}	–	–	57,000
Soluble COD	mg L^{-1}	–	–	29,622
Acetic acid	mmol L^{-1}	0.54	0.54	1.70
Butyric acid	mmol $^{-1}$	0.11	0.11	0.12
Propionic acid	mmol L^{-1}	0.06	0.06	0.05
Ethanol	mmol L^{-1}	0.60	0.60	0.85

2.2. Food waste

Synthetic food waste was prepared from typical locally-produced food waste with the composition of 65% carbohydrate (rice), 17% vegetable and 18% meat (*w*/*w*). The feedstock

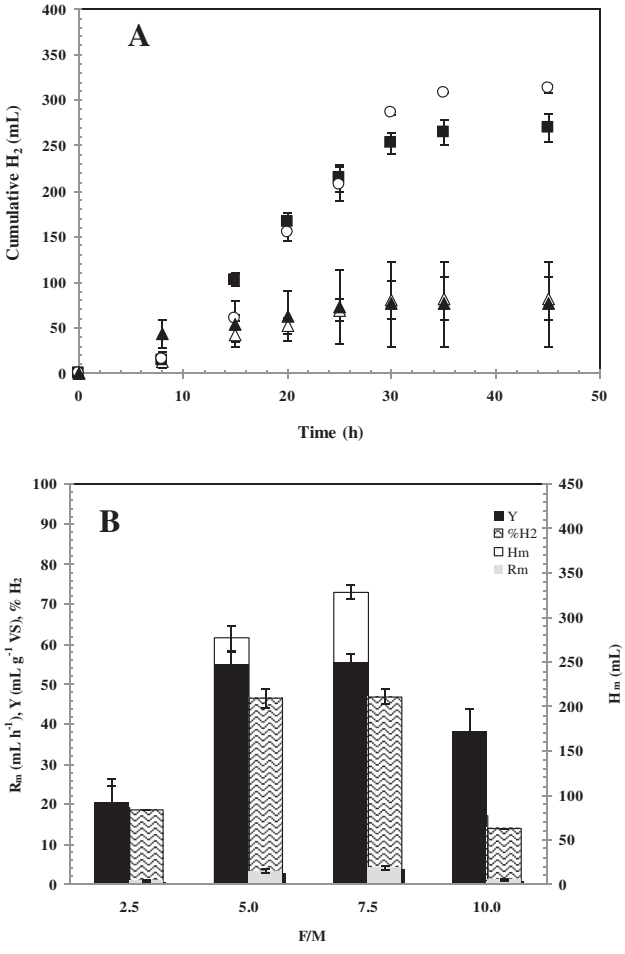

Fig. 1 – Cumulative H_2 (A) from food waste at F/M of 2.5 △, 5 ■, 7.5 ○, 10 ▲; and H_2 production potential (H_m), rate (R_m), % H_2, and yield (Y) after 35 h fermentation in the first stage (B). Symbols and histograms represent mean values of duplicate experiments, error bars represent one standard deviation.