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UASB treatment of wastewater with VFA and alcohol generated during hydrogen fermentation of food waste

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Abstract

The performance of an upflow anaerobic sludge blanket (UASB) reactor treating wastewater with volatile fatty acids (VFA) and alcohol generated during hydrogen fermentation of food waste was investigated. The chemical oxygen demand (COD) removal efficiency exceeded 96% up to the loading rates of 12.9 g COD/L d, corresponding to a food/microorganism ratio of 0.61 g COD/g VSS d. The methane production rate increased to 4.1 L/L d. Each gram of granule in the reactor had a daily maximum capacity of converting 0.55 g of COD to methane at the specific substrate utilization rate of 0.59 g COD/g VSS d. Of all the COD removed, 93% was converted to methane and the remaining presumably to biomass with a yield of 0.051 g VSS/g COD. At loading rates over 15.3 g COD/L d, the COD removal efficiency deteriorated due to sludge flotation and washout in the reactor, which resulted from short hydraulic retention time (HRT) of less than 5.8 h. The specific methanogenic activity (SMA) of granule was the highest for butyrate, and the lowest for propionate. *Methanosaeta*-like bamboo-shaped rods were present in abundance.

Keywords: UASB reactor; Methanogenic activity; VFA; Alcohol; Hydrogen fermentation; Food waste

1. Introduction

When fossil fuels are burned in coal-fired power plants or automobiles, carbon dioxide and other pollutants are generated. Excess carbon dioxide in the atmosphere causes global warming due to the greenhouse effect. Thus, as a clean and sustainable source of energy in the future, hydrogen is a promising alternative to fossil fuels because it produces water instead of greenhouse gases when combusted [1]. Also, hydrogen has a high-energy yield (122 kJ g^{-1}), which is about 2.75 times greater than that of hydrocarbon fuels and can be directly used to produce electricity through fuel cells [2,3].

Hydrogen can be generated in a number of ways, such as electrochemical processes, thermochemical processes, photochemical processes, photocatalytic processes or photoelectrochemical processes [4,5]. However, these processes require electricity derived from fossil fuel combustion so that they are energy intensive and expensive. Biohydrogen production is potentially attractive, especially if organic waste could be used as a raw material. Many studies have reported on the groundwork for creating renewable biohydrogen production systems through either photosynthesis [6–8] or fermentation [9–11]. Hydrogen production by fermentative bacteria is technically simpler than by photosynthetic bacteria. Also, the fermentation process could generate hydrogen from refuse or organic wastes [1,12].

The generation of municipal solid waste (MSW) amounts to 48,499 tonnes per day in Korea, of which 23.2% is food waste from restaurants, dinning halls, markets and households [13]. Food waste is the main source of decay, odour and leachate in collection and transportation due to its high volatile solids (85–95%) and moisture content (75–85%). Most food waste has been landfilled together with other wastes, resulting in various problems such as odour emanation, vermin attraction, toxic gas emission and

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groundwater contamination. Interest in anaerobic treatment has, therefore, increased for the efficient management of food waste because it has advantages of volume reduction and energy recovery. Hydrogen recovery from food waste has a potential to enhance the economic feasibility of waste treatment than methane recovery.

Anaerobic bacteria use organic substances as the sole source of electrons and energy, converting them into hydrogen. The reactions involved in hydrogen production (Eqs. (1) and (2)) are rapid and do not require solar radiation, making them useful for treating large quantities of wastewater.

$$\text{Glucose} + 2H_2O \rightarrow 2\text{acetate} + 2CO_2 + 4H_2 \quad \Delta G = -184.2\,\text{kJ} \qquad (1)$$

$$\text{Glucose} \rightarrow \text{butyrate} + 2CO_2 + 2H_2 \quad \Delta G = -257.1\,\text{kJ} \qquad (2)$$

Since they cannot utilize light energy, the decomposition of organic substrates is incomplete and organic acids remain. Nevertheless, these reactions are still suitable as an initial step of hydrogen production from waste, which is followed by methanogenesis. A two-stage process is a rational configuration because it provides the preferred environments for acidogenic hydrogenesis and methanogenesis in two separate spaces.

In this study, the BIOCELL process was newly devised as an ideal method for energy recovery from food waste as shown in Fig. 1. The BIOCELL process consisted of two main parts: three leaching-bed reactors for acidogenic hydrogenesis and an upflow anaerobic sludge blanket (UASB) reactor for methanogenesis. Feedstock for this experiment was food waste collected from a dining hall. The composition of grains, vegetables and meats in the waste was 65.5, 26.2 and 8.3%, respectively. Three leaching-bed reactors for hydrogen recovery were operated in a rotation mode with a 2-day interval between degradation stages. It was reported that hydrogen-producing bacteria, i.e., *Clostridium* sp., could switch from the H_2- and acid-producing phase to the alcohol-producing phase depending on the environmental conditions of H_2 fermentation, because they formed volatile fatty acids (VFA) during the exponential growth phase but alcohol during the late growth phase [2,12]. Thus, the UASB reactor converted VFA and alcohol generated from the leaching-bed reactors to methane.

Each leaching-bed reactor was operated in a sequential batch mode. Seed sludge was inoculated into the reactor after boiling for 15 min to harvest anaerobic spore-forming bacteria, i.e., *Clostridium* sp., for hydrogen recovery [2,14]. After 6 h of acclimation, dilution water was provided to the leaching-bed reactor in order to transfer generated VFA and

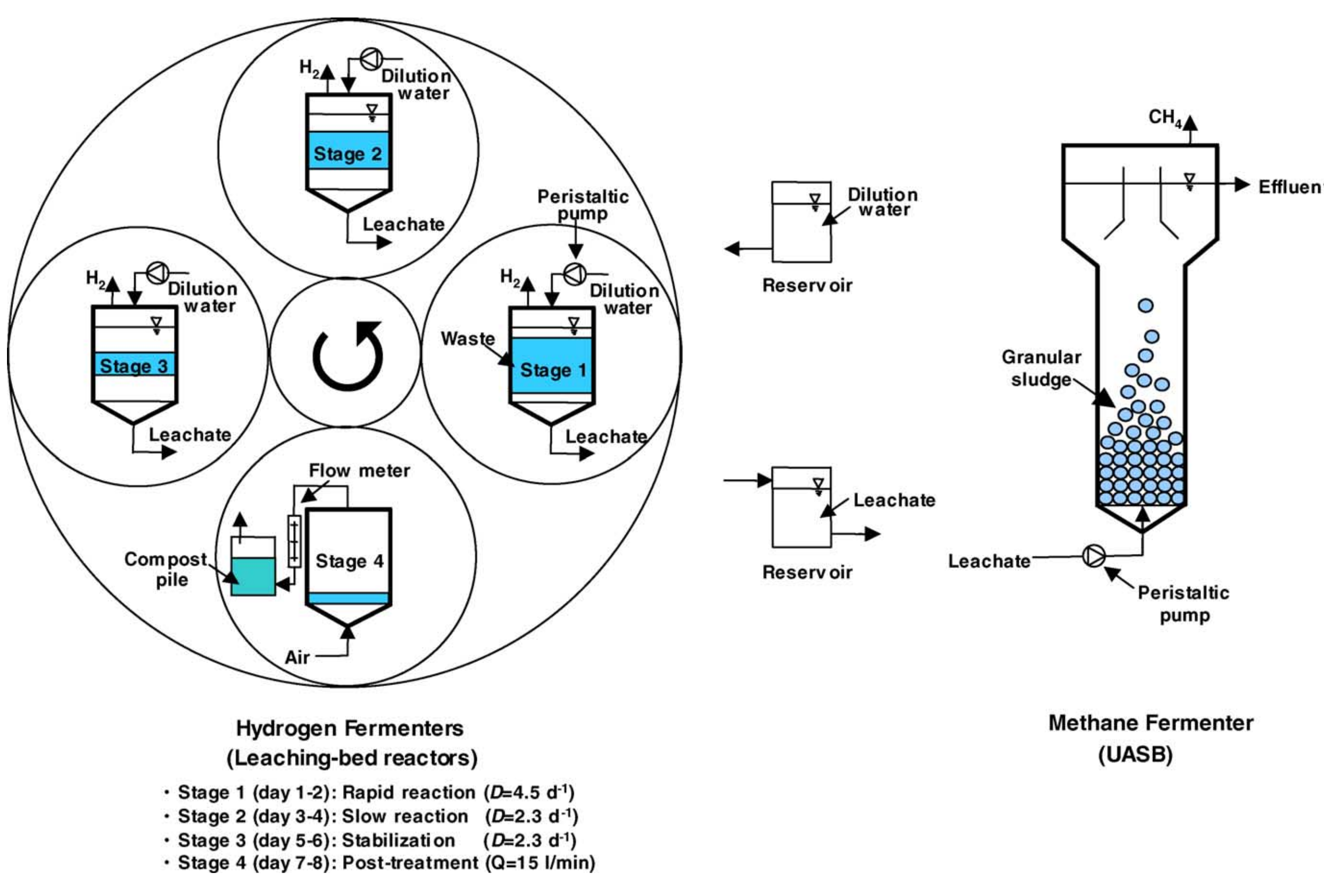

Fig. 1. Schematic diagram of the BIOCELL process converting food waste to hydrogen and methane.