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Comparison of lab-scale and pilot-scale hybrid anaerobic solid–liquid systems operated in batch and semi-continuous modes

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Abstract

The hybrid anaerobic solid–liquid (HASL) system was developed for food waste bioconversion. Lab-scale and pilot-scale HASL systems were operated in batch and semi-continuous modes. High efficiencies for conversion of food waste into biogas were shown for both the lab-scale and pilot-scale HASL systems. Semi-continuous mode of HASL system was more effective than batch process. Methane production was 0.49 $l\,l^{-1}\,day^{-1}$ and 0.71 $l\,l^{-1}\,day^{-1}$ for the lab-scale HASL system operated in batch and semi-continuous modes, respectively. It was 0.33 $l\,l^{-1}\,day^{-1}$ and 0.49 $l\,l^{-1}\,day^{-1}$ for the pilot-scale HASL system operated in batch and semi-continuous modes, respectively. Total VS removal in all experiments was from 77% to 80%. The content of methane in the biogas produced was from 70% to 74% for batch and semi-continuous operation of HASL systems. Based on the results obtained, a new pilot-scale HASL system for the treatment of 3 tonnes of food waste per day was designed and will be built in Singapore in year 2005.

Keywords: Anaerobic digestion; Chemical oxygen demand; Food waste; Hybrid anaerobic solid–liquid (HASL) system; Volatile fatty acids

1. Introduction

Food waste, collected from food-processing companies, restaurants, food courts, markets and households in Singapore, amounted to approximately 0.5 million tonnes in 2002 [1]. Almost all food waste is currently disposed of by incineration. Biological treatments of organic solid wastes, such as composting and anaerobic digestion, are popular methods for food waste utilization. However, composting of food waste is not suitable for countries with limited land resources like Singapore. Compared to incineration, anaerobic digestion appears to be a more promising food waste disposal method. Anaerobic digestion reduces the volume of food waste, generates fuel biogas, mainly methane, and produces organic residue that can be used as soil conditioner or fertiliser [2–4]. To improve process of anaerobic digestion of organic materials, the two-phase system was developed [5–7]. In a two-phase anaerobic system, organic matter is degraded to volatile fatty acids (VFA) by hydrolytic and acidogenic bacteria in an acidogenic reactor.

It was reported that application of two-phase anaerobic systems is an effective way for the treatment of solid food wastes [8–11]. VFA are converted then into methane by methanogens in a methanogenic reactor. The advantages of two-phase systems in comparison with one-stage system for anaerobic degradation of organic waste are as follows: better process stability due to lower risk of methanogenesis inhibition by pH drop, lower total digestion time, higher methane yield and content in biogas [12–15]. Two-phase anaerobic systems usually are operated in batch mode [16,17] or with periodical addition of organic matter (semi-continuous) mode [11,18,19].

The hybrid anaerobic solid–liquid (HASL) system was developed to improve food waste bioconversion in conventional two-phase anaerobic digester [15,20,21]. The HASL system includes an acidogenic reactor (Ra) to treat solid food waste and an upflow anaerobic sludge blanket (UASB) methanogenic reactor (Rm) to treat liquid leachate from acidogenic reactor (Fig. 1). The effluent from the methanogenic reactor is divided into two streams. Part of

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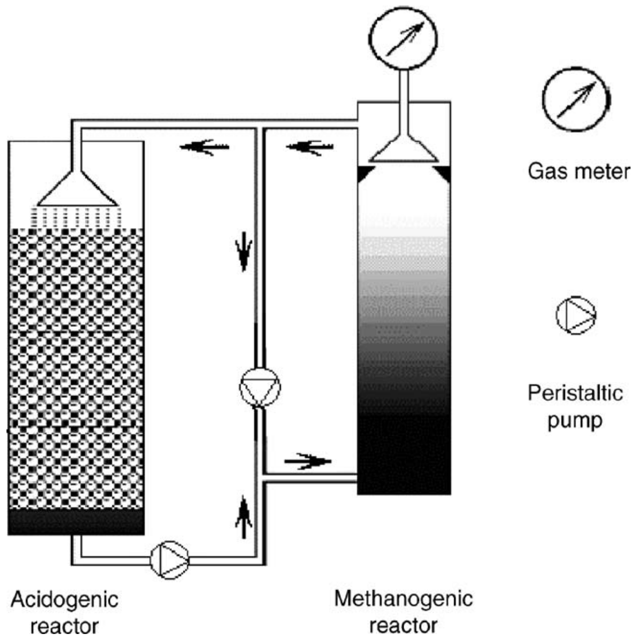

Fig. 1. Schematic diagram of the hybrid anaerobic solid–liquid (HASL) system.

the effluent from the methanogenic reactor is used for the dilution of acid effluent from the acidogenic reactor to maintain optimal pH for methanogenesis. The flow rate ratio of the stream, which is recycled into the acidogenic reactor, to the stream, which is used for dilution of acidogenic leachate, is 1:4. The rest of the effluent from methanogenic reactor is recycled into acidogenic reactor to reduce the volume of the effluent to be discharged from the HASL system and to avoid addition of water for food waste hydrolysis. The HASL system is expected to be used on industrial scale to minimize the amount of food waste for disposal in Singapore.

The main objective of this research was to study and compare the operation of the lab-scale and pilot-scale hybrid anaerobic solid–liquid systems in batch and semi-continuous modes.

2. Materials and methods

2.1. Feedstock, anaerobic microbial sludge and microbial granules

Food waste was collected from a canteen of the university. Waste was shredded into particles with average size of 6.0 mm in a Robot-Coupe Shredder (CL50 Ultra, France). The composition of food waste used in the experiments for lab-scale and pilot-scale HASL systems are shown in Table 1.

Anaerobic microbial sludge, used as inoculum for the acidogenic reactor Ra, was collected from an anaerobic digester of a local water reclamation plant. The concentrations of suspended solid (SS) and volatile suspended solid (VSS) in the digested sludge were 4.6 g l^{-1} and 3.1 g l^{-1}, respectively.

Table 1
Composition of food waste mixture for the lab-scale and pilot-scale HASL systems (mean values ± standard deviations are shown)

Food waste	Content (%)		Composition of mixture (% of wet weight)	
	Total solids	Volatile solids	Lab-scale	Pilot-scale
Vegetable roots	6.7 ± 0.4	71.1 ± 1.1	50	0
Vegetable roots	7.1 ± 0.5	83.8 ± 0.9	0	40
Orange peels	23.9 ± 0.7	97.2 ± 0.9	20	0
Fruit peels	10.6 ± 0.4	90.5 ± 0.7	0	40
Rice	9.5 ± 0.3	56.0 ± 1.3	15	10
Noodles	45.3 ± 0.8	96.1 ± 1.4	15	0
Meat	88.1 ± 1.3	99.6 ± 0.3	0	10

The microbial anaerobic granules, adapted to high concentration of VFA, were used as inoculum for the methanogenic reactor Rm. These granules were produced in an UASB reactor with a volume of 5 l, which had been operated for more than 6 months with a synthetic wastewater with pH 5.5 [22]. The chemical composition of the synthetic wastewater was as follows (mg l^{-1}): acetic acid, 2500; propionic acid, 800; butyric acid, 800; yeast extract, 80; NH_4HCO_3, 300; $(NH_4)_2SO_4$, 150; K_2HPO_4, 300; $CaCl_2$, 150; $NaHCO_3$, 3000; $MgCl_2 \cdot 6H_2O$, 15; $FeCl_3 \cdot 6H_2O$, 20; $MnCl_2 \cdot 4H_2O$, 8; $AlCl_3$, 8; $CoCl_2 \cdot 6H_2O$, 2; $ZnCl_2$, 2; $NiCl_2$, 2; $CuCl_2 \cdot 2H_2O$, 2; H_3BO_3, 2; distilled water to 1 l.

2.2. Lab-scale batch HASL system

The lab-scale HASL system included the acidogenic and methanogenic cylindrical reactors. An inner diameter of the acidogenic reactor was 140 mm and a height was 500 mm. Total effective volume of the reactor was 5.4 l. The working volume of the methanogenic reactor was 3.0 l with inner diameter of 90 mm and a height of 600 mm.

2.3. Lab-scale semi-continuous HASL system

The lab-scale semi-continuous HASL system was the same as the batch HASL system except the design of the acidogenic reactor. It was a rotatable cylinder with top and bottom openings, which can be turned on when food waste was added. It also can be sealed after the waste was fed into acidogenic reactor, while there was one valve on each opening, which allowed the effluent from methanogenic reactor to flow into the acidogenic reactor. Another two openings were set on one side of the acidogenic reactor and were connected with tube to pump out the leachate.

2.4. Pilot-scale batch HASL system

The configuration of the pilot-scale batch HASL system was the same as the lab-scale batch HASL system except the size of the reactors. The volume of the acidogenic reactor