Biochemical Engineering Journal 41 (2008) 198–201

Contents lists available at ScienceDirect

Biochemical Engineering Journal

journal homepage: www.elsevier.com/locate/bej

Short communication

Anaerobic digestion of food waste in a hybrid anaerobic solid–liquid system with leachate recirculation in an acidogenic reactor

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ARTICLE INFO

Article history:
Received 17 March 2008
Received in revised form 6 May 2008
Accepted 21 May 2008

Keywords:
Anaerobic digestion
Food waste
Hybrid anaerobic solid–liquid (HASL) system
Recirculation
Acidogenic reactor

ABSTRACT

Recirculation of the leachate in the acidogenic reactor was proposed to enhance anaerobic digestion of food waste in the hybrid anaerobic solid–liquid (HASL) system. Recirculation of the leachate in the acidogenic reactor provided better conditions for extraction of organic matter from the treated food waste and buffering capacity to prevent excessive acidification in the acidogenic reactor. It ensured faster supply of nutrients in the methanogenic reactor in experiment. The highest dissolved COD and VFA concentrations in the leachate from the acidogenic reactor were reached for shorter time and were 16,670 mg/l and 9450 mg/l in control and 18,614 mg/l and 11,094 mg/l in experiment, respectively. Recycling of the leachate in the acidogenic reactor intensified anaerobic digestion of food waste and diminished time needed to produce the same quantity of methane by 40% in comparison with anaerobic digestion of food waste without recirculation.

1. Introduction

Anaerobic digestion of solid food waste is considered as a perspective way for its disposal [1,2]. To increase process efficiency, two-phase anaerobic digestion can be used [3]. Liquefaction and acidification of food waste in this process are performed in an acidogenic reactor to obtain leachate containing dissolved organic matter, which is treated in a methanogenic reactor, where acetogenesis and methanogenesis are running. As hydrolysis of organic matter is a slowest step in an anaerobic process [4], its intensification usually leads to faster anaerobic digestion [5]. There are known different methods to facilitate food waste hydrolysis in an acidogenic reactor, such as mechanical reduction of particle size of digested material [6,7]; thermal pre-treatment of food waste to transform the organic solid material to liquid hydrolyzate [8–10]; and inoculation with cellulolytic bacteria from cattle rumen [11].

It is known from the practice of organic waste landfill management that a landfill leachate recirculation enhances microbial activity and shorten time required for waste conversion and stabilization [12,13]. Therefore, using hypothetic analogy, leachate recirculation in an acidogenic reactor may be the way to enhance extraction of organic matter from the treated food waste in two-phase anaerobic digestion. This assumption was tested in the hybrid anaerobic solid–liquid (HASL) system, which was developed to minimize the amount of food waste for disposal in Singapore [14,15].

The present paper is a part of the research on HASL-enhancing performance [10,16,17]. The aim of the present research was to study the effect of leachate recirculation in the acidogenic reactor on food waste anaerobic digestion in the hybrid anaerobic solid–liquid system.

2. Materials and methods

2.1. Food waste, anaerobic microbial sludge and microbial granules

Individual food waste was collected from a canteen in the university. Waste was shredded into particles with average size of 6.0 mm in a Robot-Coupe Shredder (CL50 Ultra, Hobart, France). The artificial composition of food wastes used in the experiment was as follows (% of wet weight): vegetable roots, 50; orange peels, 20; rice, 15 and noodles, 15. The content of total solids (TS) was 20.3 ± 0.8% and the content of volatile solids (VS) was 76.2 ± 1.3% of TS in the mixed waste.

Anaerobic microbial sludge, used as inoculum for the acidogenic and methanogenic reactors, was collected from an anaerobic digester of a local wastewater treatment plant. The pH of sludge was 7.1; the concentrations of the total solids and volatile solids in sludge were 3.8 ± 0.1 g/l and 2.7 ± 0.1 g/l, respectively. The microbial anaerobic granules, adapted to high concentration of volatile fatty

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doi:10.1016/j.bej.2008.05.008

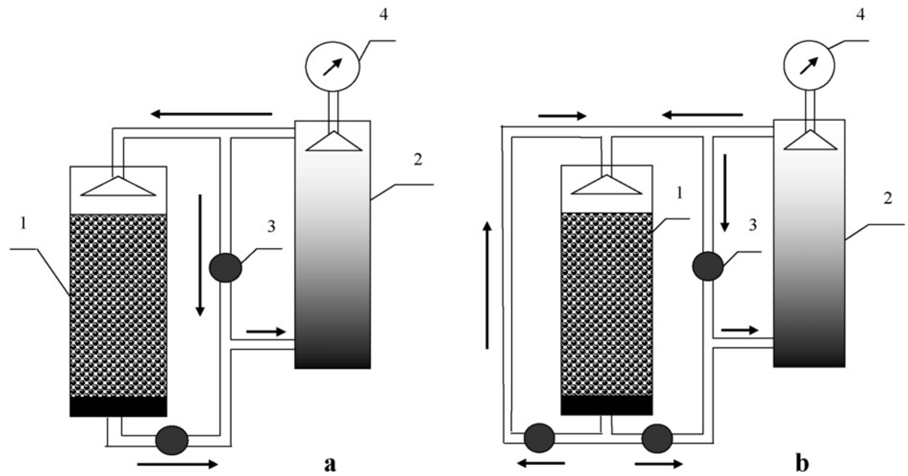

Fig. 1. Schematic diagram of the HASL system operated without (a) and with (b) leachate recirculation in the acidogenic reactor: 1, acidogenic reactor; 2, methanogenic reactor; 3, peristaltic pump; 4, wet gas meter.

acids (VFA), were used as additional inoculum for the methanogenic reactor [18].

2.2. Characteristics and operation of the HASL system

The lab-scale HASL system includes an acidogenic reactor to treat solid food waste and an upflow anaerobic sludge blanket (UASB) methanogenic reactor to treat liquid leachate from the acidogenic reactor (Fig. 1a). Part of the effluent from the methanogenic reactor is used for the dilution of the acid effluent from the acidogenic reactor to maintain optimal pH for methanogenesis, and the rest of the effluent from the methanogenic reactor is recycled into the acidogenic reactor to avoid addition of water for food waste hydrolysis. An inner diameter of the acidogenic reactor was 140 mm and a height was 500 mm. Working 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. The HASL systems were operated in a constant temperature room at $35 \pm 1\,^{\circ}C$.

Two sources of inoculum were used for the methanogenic reactor: anaerobic microbial sludge and microbial anaerobic granules. To start up the methanogenic reactor, suspension of microbial anaerobic granules, 1 l, and anaerobic microbial sludge, 1 l, were put into the reactor, which was fed with synthetic wastewater [18]. Concentration of chemical oxygen demand (COD) in effluent (less than 500 mg COD/l) and average methane content in biogas (exceeding 70% v/v) indicated that the methanogenic reactor was in active state and ready for connection with the acidogenic reactor.

Control and experiment were carried out simultaneously in two identical HASL systems operated for 2 weeks. Food waste, 200 g, 1 l of distilled water and 36 g of $CaCO_3$ for pH buffering were placed in each acidogenic reactor. Anaerobic microbial sludge, 1 l, was added into each reactor as an inoculum. Food waste, 200 g, was added after each 24 h to the control and experimental reactors during first 4 days of anaerobic digestion. So, organic loading rate for acidogenic reactors was 5.73 g VS/day during first 4 days of operation. Totally, 800 g of food waste with the contents of total solids of 130.4 g and volatile solids of 114.7 g were added into each acidogenic reactor in control and experiment. The flow rate of leachate from acidogenic reactor in experiment with recirculation was in 21 times higher than in control. However, volume of leachate supplied into the methanogenic reactor was stable for both system 1440 ml/day (Fig. 1). Excess of leachate was recycled into acidogenic reactor in experiment to ensure better conditions for extraction of organic matter from the treated food waste and to improve anaerobic process in the acidogenic reactor.

No leachate recirculation was in control, but leachate from the acidogenic reactor was recycled onto the top of waste in the acidogenic reactor in experiment (Fig. 1b). The ratio between volume of recycled leachate and volume of leachate supplied into the methanogenic reactor was 20:1.

2.3. Chemical analysis

The leachate from the acidogenic reactor and the effluent from the methanogenic reactor were collected daily for analyses. The pH value was measured using a pH meter (CORNING 145, Halstead, Essex, England). Total solids, volatile solids, and COD of the feedstock and digested food waste were determined in the well-mixed samples in triplicates by standard methods [19]. For the determination of VFA, samples were filtrated through Whatman 0.2 μm nitrocellulose membrane filters and were then analyzed using high performance liquid chromatography (HPLC) (PerkinElmer, Series 200, Norwalk, CT, USA). The HPLC was equipped with a 220 mm × 4.6 mm polypore H column and a UV 210 nm detector. The mobile phase was 0.005N H_2SO_4 with a flow rate at 0.15 ml/min.

Gas production was monitored by a wet gas meter (Ritter TG 05, Bochum, Germany), while gas composition was analyzed by a Hewlett Packard GC HP5890A (HACH, Avondale, PA, and USA) for methane, carbon dioxide, and nitrogen. The GC was equipped with a thermal conductivity detector and a stainless-steel column packed with Hayesep Q (80/100 mesh). The operational temperatures of injector, detector and column were kept at 100 °C, 200 °C and 50 °C, respectively. Helium was used as a carrier gas at a flow rate of 40 ml/min. The pH, concentrations of dissolved COD and VFA, as well as biogas production and methane content, were determined daily.

All analytical determinations were performed at least in triplicate and mean values ± S.D.s are shown.

3. Results and discussion

Food waste was placed in the acidogenic reactors of control and experimental HASL systems without or with leachate recirculation, respectively. The results of anaerobic digestion in the HASL systems are shown in Fig. 2 and Table 1. The pH was lower in control in comparison with experiment. The lowest pH in the leachate from the acidogenic reactor was 4.6 on day 5 in control