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Performance of two-stage vegetable waste anaerobic digestion depending on varying recirculation rates

Zhuang Zuo [a], Shubiao Wu [b,*], Wanqin Zhang [a], Renjie Dong [b]

[a] College of Agronomy and Biotechnology, China Agricultural University, Beijing 100193, PR China
[b] Key Laboratory of Clean Utilization Technology for Renewable Energy in Ministry of Agriculture, College of Engineering, China Agricultural University, Beijing 100083, PR China

HIGHLIGHTS

- The performance of VW anaerobic digestion under varying RR was investigated.
- The appropriate RR could improve acidogenesis in acidogenic reactor.
- Recirculation influenced COD and VS removal efficiency of the whole system.
- Biogas production from the whole two stage system was improved by increasing RR.

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ABSTRACT

Vegetable waste, which characterized by high moisture content, was evaluated as a substrate for biogas production. The effects of recirculation rate (RR) on the performance of two-stage anaerobic digestion were investigated. The system was operated at an organic loading rate of 1.7 g VS/L/d with varying RRs (0, 0.6, 1, and 1.4). Results demonstrated that volumetric biogas production rates in acidogenic reactor increased from approximately 0.27 L/L/d to 0.97 L/L/d, when pH is increased from approximately 5.1 to 6.7. These indicate that recirculation of alkaline effluent from the methanogenic reactor helps create a favorable condition for biogas production in the acidogenic reactor. The decrease in chemical oxygen demand (COD) concentrations from approximately 21,000 mg/L to 6800 mg/L was also observed in the acidogenic reactor. This condition may be attributed to dilution under recirculation. The dynamics between hydrolysis and methanogenesis under recirculation indicated that mass transfer capacity between two-stage reactors improved.

1. Introduction

Vegetable waste (VW) is generated in the processes of harvesting, transportation, processing, marketing and storage (Sahu, 2004). VW is made up of highly biodegradable organic matter content and can be beneficially used for renewable energy production by anaerobic digestion (Bouallagui et al., 2005). A major limitation of the anaerobic digestion of VW in a one-stage system is the accumulation of volatile fatty acids (VFA), which results in a rapid decrease in pH, potentially inhibiting methanogens activity (Bouallagui et al., 2009; Jiang et al., 2012). In such a case, a number of studies introduced remedial measures, e.g., co-digestion with other organic wastes to improve buffering capacity (Callaghan et al., 2002). However, co-digestion depends on feedstock availability and transportation efficiency and may be limited in vegetable production areas situated far from livestock farms (Poeschl et al., 2010). The two-stage system is another technology designed to improve the overall process stability. The advantage of such system lies in the buffering of the organic loading rate (OLR) in the first stage, which in turn allows for a more constant feeding rate in the methanogenic stage (Bouallagui et al., 2004; Schievano et al., 2012).

The two-stage system has been widely suggested for enhancing digestion performance, employing a process configuration that utilizes reactors for acidification and methanogenesis, allowing for the optimization of both processes (Boe and Angelidaki, 2009; Kafle and Kim, 2011). However, a limited amount of data is available in the literature on the two-stage anaerobic digestion of VW. There are problems associated with the operation of anaerobic treatment processes due to the low specific growth rate and

* Corresponding author. Address: Key Laboratory of Clean Utilization Technology for Renewable Energy in Ministry of Agriculture, College of Engineering, China Agricultural University, No. 17 Qinghuadonglu, Haidian District, Beijing 100083, PR China. Tel.: +86 10 62737852; fax: +86 10 62737885.

E-mail address: wushubiao@gmail.com (S. Wu).

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sensitivity to changes in operating conditions of some of the methanogens involved. It is also important to control the reaction pathway towards the selective production of desired end-products. The concentration and composition of VFAs which are highly dependent on the substrate type and process conditions (Li and Yu, 2011). Therefore, the operation and control of the anaerobic digestion process should be directed to ensure process efficiency and biogas production improvement (Schievano et al., 2012). The effluent recirculating from the methanogenic reactor to the acidogenic reactor is one of the important operations and control methods, which exerts considerable influence on the overall process performance. The two-stage system with recirculation has recently been successfully operated with a variety of solid organic waste, such as biowaste, and food waste. It is reported that recirculation could accelerate the rate of soybean meal degradation in a rotational drum fermentation system (Chen et al., 2007). The recirculation makes better gas yields where the pH reached an optimal value thanks to the buffering capacity of the recycle stream (Cavinato et al., 2011). In addition, Kobayashi et al. (2012) suggest that the recirculation of active methanogenic sludge had an inhibitive effect on the hydrogen production and supplemented the NH_4^+ in the first stage reactor. Results of previous studies showed that the main effect of the recycle stream is the alleviation of the problem of low pH level caused by a high VFA level in the acidogenic reactor. Moreover, recirculation also affects the microbial ecology, hydraulic regime, and other characteristics of the operating system because of the sludge exchange between the two digesters, in which anaerobic microorganisms share nutrients and intermediates (Song et al., 2004). Recirculation leads to excess VFA in the acidogenic reactor transfers to the methanogenic reactor. The recirculation in turn transfers effluent from methanogenic reactor rich in alkaline and methanogens to the acidogenic reactor. The recirculation could balance the VFA, alkalinity, and methanogens in both the reactors and thus improve the efficiency of the system (Kafle and Kim, 2011). However, the effects of recirculation in the anaerobic digestion of rapidly degrading materials such as VW with varying recirculation rates (RR) remain unclear.

In this study, the anaerobic system was used based on the characteristics of VW as raw material for biogas production. The conditions in the process were optimized for biomethanization of VW through the variation in recirculation rates. The objective of this study was to determine the process performance in terms of biogas production, methane content, pH, chemical oxygen demand (COD), VFA and its composition. The effects of RR on the characteristics of anaerobic digestion in a two-stage process were identified.

2. Methods

2.1. Reactors set-up and operation

The schematic diagram of laboratory-scale two-stage system is shown in Fig. 1. The hydrolysis–acidification process was carried out in a completely stirred anaerobic reactor (CSTR, diameter 16 cm, height 25 cm) and the process of methane fermentation was performed in a fixed-bed biofilm reactor (diameter 16 cm, height 30 cm). The working volume of the reactors were 3 L and 4 L, respectively. The stirring of CSTR was conducted automatically for 10 min every hour at a speed of 70 rpm throughout the entire experimental period. The fixed-bed reactor packed with activated carbon fiber (Yongtong Environmental Science and Technology Company, Jiangsu, China) as the biofilm carrier which is preferentially for Methanomicrobiales adhered. Four cylindrical activated carbon fiber textiles (inner diameter was 6 cm; height was 20 cm; thickness was 2 mm) were bundled together using a stainless steel wire and placed in the reactor. Two ports were fitted at

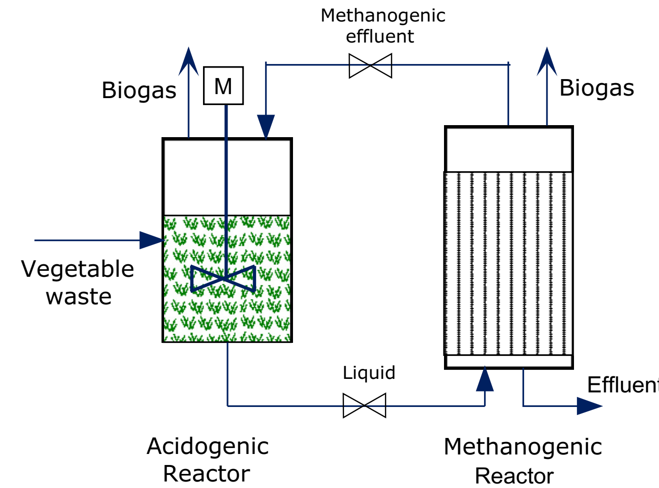

Fig. 1. Scheme of acidogenic reactor and methanogenic reactor used for the treatment of vegetable waste.

the top and bottom of the reactor walls for feeding and withdrawing.

The acidogenic reactor and methanogenic reactor were operated in semi-continuous feeding mode. Firstly, 7 L sewage sludge was added to the two reactors separately, and then diluted VW was fed to acidogenic reactor once a day by the draw-and-fill method. The output of the acidogenic reactor was fed directly to the methanogenic reactor. The overall hydraulic retention time (HRT) of the system was 14 d. The system was operated at a very low OLR of 0.5–1.7 g volatile solids (VS)/L/d for the start-up period.

After stabilization of the start-up period, the substrates were fed for digesters with OLR of 1.7 g VS/L/d (3.4 g COD/L/d) for four periods. HRTs of the acidogenic reactor and methanogenic reactor were fixed at 6 d and 8 d, respectively, without recirculation. Part of the effluent from the methanogenic reactor was recycled into the acidogenic reactor was introduced from periods II to IV, and the varying RRs of 0.6, 1 and 1.4 were investigated. The RR was defined as the ratio of the returned flow rate to that of the base inlet flow rate (Lee et al., 2010). The system was operated at a constant mesophilic temperature of 37 ± 2 °C. Gas bags were used for biogas collection from the reactors and recorded every day. Controlling parameters for the experiment were presented in Table 1.

2.2. Feedstock and inoculum

The VW used in this study was obtained from a market in Beijing (116.46°E, 39.92°N), China. It mainly included leafy waste materials (e.g. cabbage, Chinese cabbage, lettuce). The raw VW was shredded and stored in a refrigerator at −20 °C before feeding. The general chemical properties of the VW are summarized in Table 2. The seed sludge used as inoculum for the reactors was collected from a mesophilic anaerobic digester in Xiaohongmen Wastewater Treatment Plant, Beijing, China. The total solids (TS) content and volatile solids (VS) content were 5.4 ± 0.4% and 2.9 ± 0.4%, respectively.

Table 1
The system operation conditions with different RRs.

Period	Days	Feed (L/d)	COD inlet (g/L)	Recirculation (L/d)	RR
I	0–46	0.5	42.3	0	0
II	47–90	0.5	42.3	0.3	0.6
III	91–134	0.5	42.3	0.5	1
IV	135–178	0.5	42.3	0.7	1.4