Co-digestion of Wheat Straw and Fruit/Vegetable Waste by Using an Innovative Integrated Two-phase Anaerobic Reactor

Wei XING*, Xiaojie CHEN*, Jiane ZUO*, Jia LIN*, Chong WANG* and Kaijun WANG*

* State Key Joint Laboratory of Environment Simulation and Pollution Control (SKLESPC), School of Environment, Tsinghua University, Beijing 100084, China.
(E-mail: *xingwei@tsinghua.edu.cn; jiane.zuo@tsinghua.edu.cn*)

Abstract

Anaerobic digestion of agricultural wastes has been widely applied to recover renewable energy from wastes. To improve biogas production, an innovative integrated two-phase anaerobic was designed, and applied to co-digestion of wheat straw and fruit/vegetable waste. The highest organic loading rate in this reactor was 0.87 kgVS/(m^3·d), the maximum rate of daily biogas production achieved 2.80 Nm^3/(m^3·d), and the VS removal efficiency achieved above 85%. In the performance of the reactor, the digestion of wheat straw could be confirmed, and the results of pH value and VFA concentration indicated that different operational conditions could be provided in acidogenic unit and methanogenic unit.

Keywords
Co-digestion; anaerobic reactor; two-phase; wheat straw; fruit/vegetable waste; agricultural waste

INTRODUCTION

Anaerobic digestion of agricultural wastes has been widely applied as an efficient and sustainable technology (Demirbas *et al.*, 2011). However, when treating waste with high organic content such as wheat straw and fruit/vegetable waste, anaerobic digestion is normally confronted with some drawbacks, including low hydrolysis rates and difficult separation of solid and liquid phases. Moreover, the balance of anaerobic micro-ecosystem is easy to be broken, because the growth rates and optimal conditions of hydrolytic bacteria, fermentative bacteria and methanogens are different.

Compared with one-phase anaerobic digestion, two-phase anaerobic digestion, in which hydrolytic and fermentative bacteria are separated from methanogens, can improve the stability and efficiency (Demirel and Yenigun, 2002; De Gioannis *et al.*, 2008). However, it still has some disadvantages. For example, phase separation breaks the syntrophic cooperation among microbial population, and costs more land occupation and higher maintenance charge.

In order to solve these problems, some researchers have suggested conceptions of integrated two-phase anaerobic digestion (Chanakya *et al.*, 1993). In this paper, a practical and innovative integrated two-phase anaerobic reactor was designed, and then applied to co-digestion of wheat straw and fruit/vegetable waste. The results proved that this innovative reactor could achieve high efficiency for co-digesting agricultural waste.

MATERIALS & METHODS

In this study, wheat straw was collected from a farm near Beijing, China. Fruit/vegetable waste was collected from a fruit and vegetable market, composing of the residues of pear, apple, banana, water melon, Chinese cabbage and lettuce, etc. Both wheat straw and fruit/vegetable waste were shredded and homogenized to small particles. Composition characteristics were analysed and are shown in Table 1.

Biogas production of the reactor was determined by a LML-2 style wet gas meter (Changchun Instruments Company), methane content and the concentration of VFAs were analyzed by using gas chromatography (N2000, China; Agilent-6890N GC, USA). Other parameters, such as total solids (TS) and volatile solids (VS), were measured according to standard methods (China EPA 2002). At the end of operation, microorganisms and wheat straw were observed by scanning electron microscopy (SEM, Quanta200, FEI Company, USA).

Table 1. Characteristics of Wheat Straw and Fruit/Vegetable Waste

Substrates	TS (%)	VS (%)	Element content (%TS)			
			C	H	N	O
Wheat straw	94.47	83.75	42.22	5.36	0.85	39.68
Fruit/vegetable waste	7.37	6.49	43.26	5.18	38.01	2.77

RESULTS & DISCUSSION

Design of the innovative integrated two-phase anaerobic reactor

To meet the requirement of decomposing agricultural waste, the innovative integrated two-phase anaerobic reactor mainly consists of two parts, i.e., acidogenic unit and the methanogenic unit. A stainless steel roller was adopted in acidogenic unit in the top part of the reactor. The roller can be rotated at a certain rate, and it is half submerged in the liquid phase. Holes with diameter of 5 mm are evenly distributed on the surface of the roller, so that the solid waste in the roller can contact with the liquid phase sufficiently. Three clapboards divide the roll as six equal parts in order to make solid waste well mixed. The methanogenic unit is in the lower part of the reactor, where granular sludge can be cultivated. Between the acidogenic unit and the methanogenic unit, recycling system, which is equipped to pump the hydrolysate into the bottom of the reactor, can efficiently prevent acid accumulation in the acidogenic unit and provide enough substance for the methanogenic unit. The reactor is kept at 35°C by using a water jacket and a heat exchanger.

The apparatus designed and applied in the current study is shown in Fig. 1. The efficient reaction volume is 115 l, with the liquid zone of 75 l and the roller volume of 25 l. Anaerobic granular sludge from a full-scale UASB reactor treating starch wastewater at 35°C, was used as seed sludge for the methanogenic unit. The design of this apparatus has bee submitted for Chinese patent application (Zuo *et al.*, 2010).

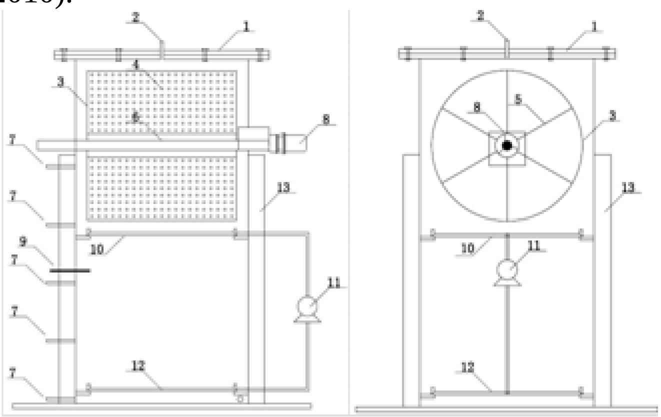

Figure 1. Schematic diagram of the innovative integrated two-phase anaerobic reactor.
(1.Top cover; 2.Biogas outlet; 3.Acidogenic reaction roller; 4.Holes on the surface of the roller; 5.Inner clapboard; 6.Rotation axis; 7.Sampling orifice; 8. Rotation motor; 9.Temperature probe; 10.Recycling pipe; 11.Recycling pump; 12. Recycling distribution; 13.Water jacket.)

Performance of the innovative integrated two-phase anaerobic reactor

The innovative integrated two-phase anaerobic reactor was operated for 21 stages to co-digest wheat straw and fruit/vegetable waste. In the set-up periods, the feeding amount was kept at about 0.4 kgVS in every stage. The retention time decreased from 24 d to 17 d, and the biogas production of the reactor increased steadily. From the fifth stage, the retention time of each stage was kept at 10 d. The total biogas production and the feeding amount of each stage in stable period are presented in

Fig. 2. The highest organic loading rate in the reactor was 0.87 kgVS/(m^3·d). The maximum rate of daily biogas production achieved 2.80 Nm^3/(m^3·d), and the methane content was above 65%. Moreover, VS removal efficiency could achieved above 85%.

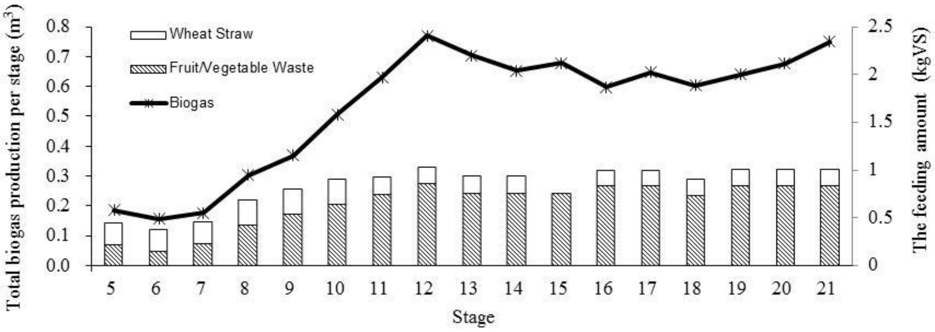

Figure 2. The total biogas production and the feeding amount of each stage

Co-digestion of wheat straw and fruit/vegetable waste with different ratios

Wheat straw is usually hard to be digested due to its high content of total solid and lignocellulose. However, co-digestion of wheat straw and fruit/vegetable waste can be achieved by using the innovative integrated two-phase anaerobic reactor. The results are shown in table 2. The efficiency of wheat straw digestion was calculated by the reduction of total VS and the hypothesis that fruit/vegetable waste was totally decomposed. The results revealed that the efficiency of wheat straw digestion could be affected by both the ratio of wheat straw and fruit/vegetable waste and the loading rate of the reactor.

Table 2. The feeding amount and efficiency of the reactor in typical stages

Stage	Wheat Straw (kgVS)	Fruit/Vegetable Waste (kgVS)	VS_{WS}: VS_{FVW}	Loading Rate (kgVS/(m^3·d))	Efficiency of Total VS(%)	Efficiency of Wheat Straw(%)
5	0.23	0.22	1.05 : 1	0.39	65.5	41.2
6	0.23	0.15	1.52 : 1	0.33	47.2	28.9
10	0.27	0.64	0.42 : 1	0.79	75.3	21.9
18	0.17	0.73	0.23 : 1	0.66	89.9	45.3

The daily and cumulative biogas production of typical stages was shown in Fig. 3. In particular for stage 10 in which both the ratio of wheat straw and fruit/vegetable waste and the loading rate of the reactor were relatively high, a second peak value of biogas production took place around the fifth day. It proves the co-digestion of the waste, and indicates that the digestion of fruit/vegetable waste is easy, but the digestion of wheat straw needs more time. Co-digestion of wheat straw and fruit/vegetable waste results in promotion of wheat straw digestion. Besides, the digestion of wheat straw can also be confirmed visually by SEM images, shown as Fig. 4.

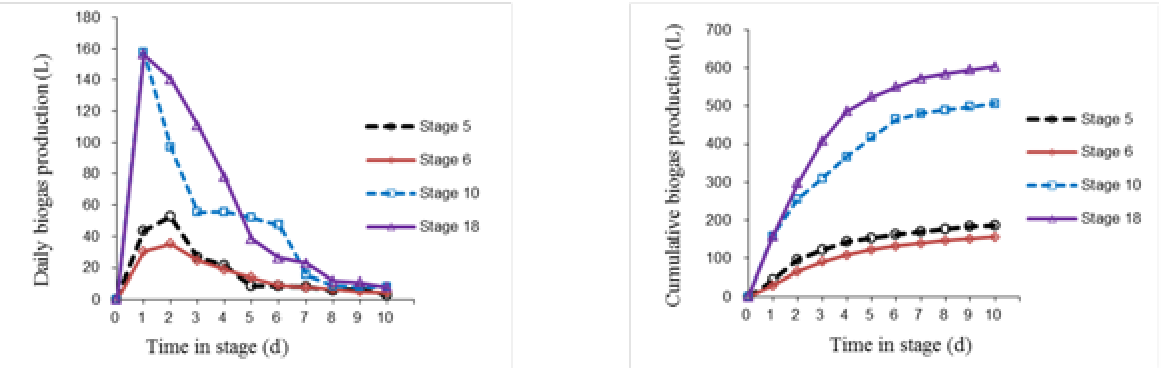

Figure 3. The daily and cumulative biogas production of the typical stages

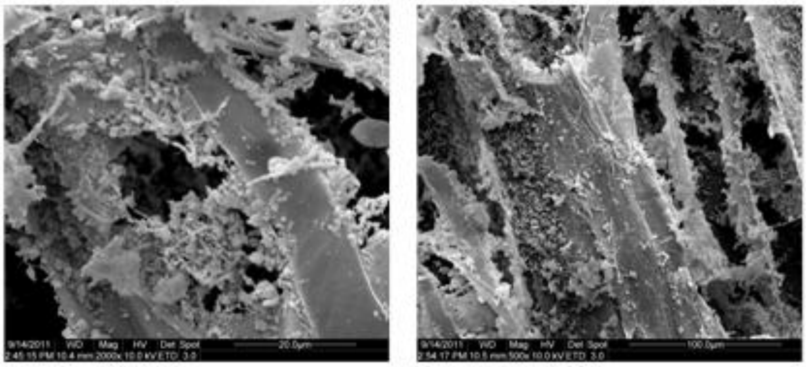

Figure 4. SEM photographs of the inner surface of wheat straw after co-digestion

pH value and VFA concentration in acidogenic and methanogenic unit

Liquid samples were collected from the acidogenic and methanogenic units of the reactor, respectively, so that the pH value and VFA concentration can be measured along with the operation. Similar trends can be found from the data of all the stages. Therefore, only those of stage 18 were displayed in Fig. 5. The fluctuations of pH value and VFA concentration in the methanogenic unit were much smaller than those in the acidogenic unit. This phenomenon indicates that different reactive conditions were provided in the different units by using the innovative integrated two-phase anaerobic reactor. Because methanogen are more sensitive than hydrolytic bacteria and fermentative bacteria, the separation of acidogenic phase and methanogenic phase in a single reactor can improve the stability and efficiency of the digestion process. Moreover, syntrophic cooperation of different microorganisms can also be maintained. In our research, clone libraries were also constructed for sludge samples from both the acidogenic unit and the methanogenic unit. The results (not shown due to space limit) presented certain difference of microorganisms in the two parts of the reactor.

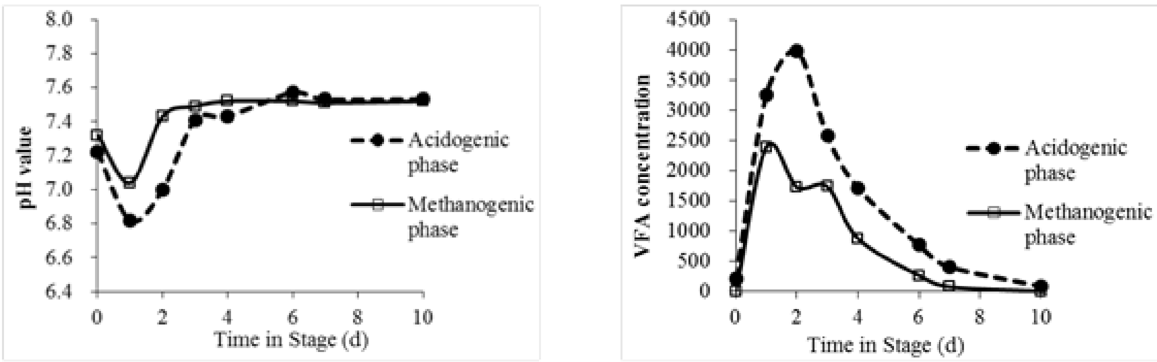

Figure 5. pH value and VFA concentration in acidogenic and methanogenic unit of stage 18

ACKNOWLEDGEMENTS

We would like to express our thanks to the support of the Major Science and Technology Programs for Water Pollution Control and Management of China (2012ZX07205-001).

REFERENCES

Chanakya, H. N., Borgaonkar S., Meena G., Jagadish, K. S. 1993 Solid-phase fermentation of untreated leaf biomass to biogas. *Biomass and Bioenergy* **5**(5), 369–377.

Demirbas, M. F., Balat, M., Balat, H. 2011 Biowastes-to-biofuels. *Energy Conversion and Management* **52**(4), 1815–1828.

Demirel, B., Yenigun, O. 2002 Two-phase anaerobic digestion processes: a review. *Journal of Chemical Technology and Biotechnology* **77**(7), 743–755.

De Gioannis, G., Diaz, L. F., Muntoni, A., Pisanu, A. 2008 Two-phase anaerobic digestion within a solid waste/wastewater integrated management system. *Waste Management* **28**(10), 1801–1808.

Zuo, J. E, Chen, X. J., Lin, J., Wang, K. J. 2010. CN201010576176. (Patent)