Renewable and Sustainable Energy Reviews 90 (2018) 700–709

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

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

Towards utmost bioenergy conversion efficiency of food waste: Pretreatment, co-digestion, and reactor type

Chaonan Ma[a], Jianyong Liu[a,*], Min Ye[a], Lianpei Zou[a,*], Guangren Qian[a], Yu-You Li[b]

[a] *School of Environmental and Chemical Engineering, Shanghai University, 333 Nanchen Road, Shanghai 200444, PR China*

[b] *Department of Civil and Environmental Engineering, Graduate School of Engineering, Tohoku University, 6-6-06 Aza, Aramaki, Aoba-ku, Sendai, Miyagi 980-8579, Japan*

ARTICLE INFO

Keywords:
Food waste
Bioenergy conversion
Pretreatment
Co-digestion

ABSTRACT

Food waste (FW), which contains a large amount of easily biodegradable organic matter, has great potential for methane production using anaerobic digestion (AD). However, the bioenergy conversion efficiency in this method is not ideal because FW has a long hydraulic retention time (HRT) of > 20 days, low organic loading rate (OLR) of 1–6 g VS /L.d and low bioenergy conversion rate 40–70%. To improve the efficiency of bioenergy conversion, pretreatment technologies, co-digestion with other organic wastes and the effect of reactor types are reviewed and discussed. Enzymatic pretreatment and co-digestion of FW with landfill leachate are preferable for hydrolysis of organic solids, enhancement of methane production and stability improvement of the AD system. Based on the discussion and our preliminary experiment results, the feasibility of FW treatment using a third generation anaerobic reactor is proposed and analyzed. If the proposed concept can be applied practically in the future, more than 90% of the organic matter in FW could be recovered as bioenergy with an OLR greater than 20 kg COD/m^3 d.

1. Introduction

An increase in food waste (FW) amount related to a rise in population and living standard improvements has resulted in a severe environmental problem in both developing and developed countries [1,2]. FW from canteens or restaurants, which contains a high content of easily biodegradable organic matter, is regarded as a great bioenergy source [3,4]. Anaerobic digestion (AD) is a well-studied and pollution free technology for converting organic matter into bioenergy [5,6]. In view of both theoretical and practical applications, AD is and will remain the preferred technology for bioenergy conversion of FW [6,7].

FW contains large amounts of insoluble organic matter and high molecular compounds such as lipids, sugars, starches and proteins, present as suspended solids (SS) [8–11]. This high SS content affects the efficiency of AD, which has a low organic loading rate (OLR) of about 1–6 g VS /L.d, long hydraulic retention time (HRT) of more than 20 days and low bioenergy conversion rate of 40–70% [12,13]. Because of the high solid content in FW, only batch and continuous stirred tank reactors (CSTR) can be applied [14,15]. The second and the third generations of anaerobic reactor such as upflow anaerobic sludge bed (UASB), expanded granular sludge bed (EGSB) and internal circulation (IC) reactors) cannot be employed. Although these reactors possess many advantages, such as high OLR, and pH buffering capacity, they require low solid content owning to the HRT and high upflow velocities applied [16].

Extensive research has been conducted on pretreatment methods to accelerate hydrolysis of organic solids to soluble organic matter [15,17–19]. With enzymatic pretreatment, the volatile SS reduction rate could reach 64% [20]. In addition, co-digestion is always preferred, with two types of wastes being treated together efficiently [21–23]. Co-digestion of FW with landfill leachate is a promising method for enhancing the AD of FW, because it improves the pH buffering capacity and the amount of nutrient elements [24–26]. In addition, the dilution effect of adding landfill leachate can also help to reduce the SS content to meet the demand of a third generation reactor.

The objective of this paper is to discuss the feasibility of enzymatic pretreatment and co-digestion of FW with landfill leachate using a third generation AD reactor to achieve high bioenergy conversion efficiency. The focus is FW from canteens, hotels, and restaurants, which has a volatile SS content of more than 90%. The discussion is based on a literature review including pretreatment methods and co-digestion of FW with other organic wastes. Preliminary experiment results are also presented, which support the proposed method. The conclusions drawn in this paper could guide scientific research and engineering

---

* Corresponding authors.
E-mail addresses: liujianyong@shu.edu.cn (J. Liu), zoulianpei@163.com (L. Zou).

https://doi.org/10.1016/j.rser.2018.03.110
Received 25 April 2017; Received in revised form 27 October 2017; Accepted 31 March 2018

Table 1
GP and MY of different solid wastes.

Substrate	TCOD (g/L)	C/N	TS (%)	VS (%)	VS/TS (%)	GP (m^3/kg VS)	MY (m^3 CH_4/kg VS)	References
FW	199	18.9	22.7	20.7	91.2	Nd	0.507	[96]
	Nd	28.4	20.0	19.2	96.0	0.490	0.281	[97]
	180	Nd	19.8	17.5	88.4	Nd	0.535	[98]
	101	Nd	7.62	7.21	94.6	Nd	0.45	[99]
	241	21.3	18.9	17.5	92.6	0.687	0.430	[100]
	132	11.3	12.3	11.6	94.3	0.411	0.296	[101]
	271	Nd	17.8	16.1	90.0	Nd	0.48	[102]
	Nd	13.4	21.2	19.7	92.9	0.894	0.465	[103]
WAS	13.5	Nd	1.44	0.88	61.1	Nd	0.250	[104]
	20.5	Nd	1.91	1.39	72.7	Nd	0.193	[105]
	Nd	Nd	1.56	0.90	57.8	0.42	0.265	[106]
	23.8	Nd	1.88	1.45	77.1	Nd	0.069	[107]
Straw	Nd	Nd	91.9	89.5	97.8	Nd	0.217	[108]
	Nd	58.6	97.3	84.0	86.3	0.325	0.178	[109]
Grass	Nd	Nd	23.1	20.9	90.7	Nd	0.167	[91]
	Nd	35.7	16.0	13.7	85.6	Nd	0.189	[110]
AM	Nd	Nd	17.0	13.6	80.0	0.565	0.240	[111]
	Nd	25	16.9	10.25	60.6	0.295	0.204	[112]

applications on bioenergy conversion of FW.

2. Great bioenergy conversion potential of FW

FW from canteens, hotels, and restaurants contain mainly rice, noodle, vegetables, oil, eggs, meat, and other waste. The chemical components of this type of FW include starch, cellulose, fat, protein, and other macromolecular organic matter, inorganic salts, and trace elements. This organic matter can biodegraded and transferred to biogas or hydrogen if treated properly, which shows great potential for bioenergy conversion. Table 1 shows the characteristics of eight types of FW, several types of waste activated sludge (WAS), agricultural straw, grass waste, and animal manure (AM). Conventional chemical parameters such as total chemical oxygen demand (TCOD), total solids (TS), volatile solids (VS), gas production (GP) and methane yield (MY) of each substrate with AD reported in literature were summarized in this study. The parameters of TCOD, TS, and VS reflect the organic solid content in the substrate and its biodegradability, whereas GP and MY reflect the biogas potential of feedstock.

Table 1 shows that the TCOD of FW at about 180 g/L is higher than that of WAS and AM. Moreover, the VS/TS ratio of FW, at about 92–95%, is also significantly higher than that of other wastes listed in Table 1. This indicates that the organic solid content of FW is indeed rich and highly suitable for AD. The MY of FW is about 0.4 m^3/kg VS, which is almost twice the amount in other waste types. Agriculture straw and grass contain significantly more organic solids with the highest TS and VS, although the MY of this type of waste is the lowest, at only 0.178 m^3/kg VS. This is because these substrates have high contents of lignin, cellulose and hemicellulose, which are more complex and difficult to be degraded [27].

Therefore, compared with other solid waste types, FW has many advantages, such as greater suitability for AD; higher TCOD, TS and VS; better biodegradability, at 91.8% of VS/TS, and higher biogas production potential [25,28,29]. However some small fluctuations were founds in the C/N and VS/TS. These characteristics are possible influencing factors of the AD process for biogas production efficiency. It is obvious that GP and MY differ greatly. The change in MY from 0.281 m^3 CH_4/kg VS to 0.535 m^3 CH_4/kg VS is attributed mainly to different processing technologies such as pretreatment, co-digestion, and reactor type, which have a strong influence on AD performance.

In china, FW has great potential to electricity production by AD. With the rapid development of the modern catering industry, FW production is also increasing at high levels. The total FW amount was about 91.1 million tons in 2015 in China, with a daily output per capita of 0.18 kg/d person. Fig. 1 shows that the FW amount in China has grown continuously during 2010–2015. China's total annual production of FW is 3 times, 4.5 times, and 20 times that of the United States, Japan, and South Korea, respectively [25]. In China, the FW problem is particularly prominent and needs to be addressed. Generally, more than 660 MJ of bioenergy could be obtained from 1 t of FW, which amounts to about 64 kW h of electricity with 35% of generation efficiency [30,31]. In China, the amount of FW could reach 1.4×10^8 t per year in 2020 [1], which means that about 9×10^9 kW h of electricity could be recovered from FW annually.

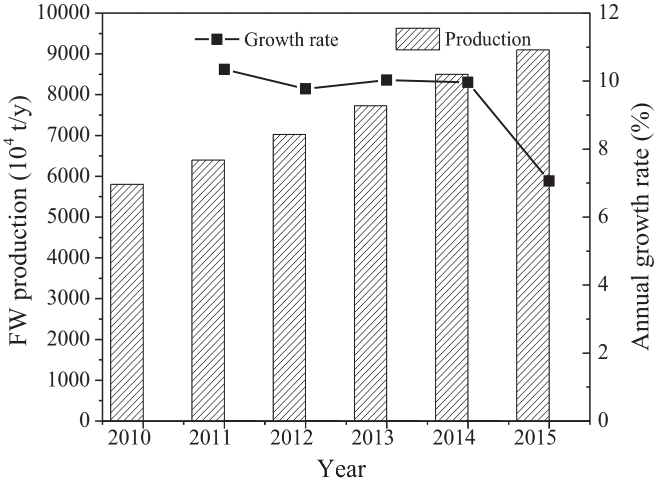

Fig. 1. Production and annual growth rate of FW in China during 2010–2015.

3. Problems faced in bioenergy conversion of FW

As previously mentioned, the main problem in bioenergy conversion of FW is very low conversion efficiency. Table 2 summarizes the main studies on bioenergy conversion of FW using continuous flow AD reactors. A comparison MYs presented in Table 2 reveals a difference of 0.218 L CH_4/g $VS_{removal}$ between the minimum and maximum MY, at 0.316 L CH_4/g $VS_{removal}$ and 0.534 L CH_4/g $VS_{removal}$, respectively. However, the gap was small in most research, and the reported MYs were all at about 0.45 L CH_4/g $VS_{removal}$. Previous research of the biogas residue process has noted severe problems such as low VS removal efficiency, at < 75%; low OLR, at < 7 g VS/L d; high HRT, at about 30 days [32]. Pretreatment and co-digestion have been shown to obviously improve AD efficiency [5,25,33,34]. Two similar studies were performed with two separate reactors with slightly higher OLR of 7.1 and 8.21 g VS/L.d, respectively, one of which was a UASB reactor with fermented supernatant as feed [35,36]. Although the amount of solids was reduced in both, the operation HRT was still high for actual processing. Moreover, the AD system was overly complicated for practical applications. Thus the problems of FW are treatment low VS removal efficiency, low OLR, high HRT, and suitable reactor type, which result in low efficiency of bioenergy conversion.

FW compositions differ significantly owing to cooking methods, food materials, eating habits, and local cultures, which create difficulty in determining statistics for each composition in FW. However the compositions can be divided into several components such as moisture, oils, proteins, and carbohydrates. Most carbohydrate polymers and proteins exist in the solid phase, including rice, vegetables and meat. Solid phase particles are irregular and have different properties. Smaller particles or liquid have large surface areas which enable easy contact with microorganisms; thus, the anaerobic biodegradability increases [37–40]. Study on AD bioenergy conversion of FW mixed with