Bioresource Technology 227 (2017) 297–307

Contents lists available at ScienceDirect

Bioresource Technology

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

Effect of anaerobic digestion on sequential pyrolysis kinetics of organic solid wastes using thermogravimetric analysis and distributed activation energy model

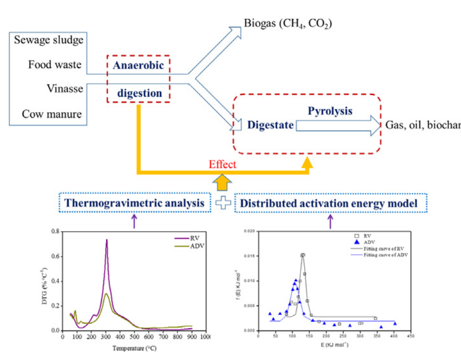
Xiaowei Li [a,b], Qingqing Mei [a], Xiaohu Dai [b,*], Guoji Ding [a]

[a] School of Environmental and Chemical Engineering, Shanghai University, Shanghai 200444, PR China
[b] State Key Laboratory of Pollution Control and Resources Reuse, National Engineering Research Center for Urban Pollution Control, College of Environmental Science and Engineering, Tongji University, Shanghai 200092, PR China

HIGHLIGHTS

- TGA-DAEM was used to explore effect of anaerobic digestion on sequential pyrolysis.
- Anaerobic digestion causes a decrease in the weight loss at the range of 180–550 °C.
- Organic matter at peak temperature of 274–327 °C enriched after anaerobic digestion.
- Anaerobic digestion had discriminative effects on pyrolysis kinetics of the OSW.
- Different organic composition between the OSW might be an important reason.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 7 November 2016
Received in revised form 14 December 2016
Accepted 15 December 2016
Available online 18 December 2016

Keywords:
Anaerobic digestion
Organic solid wastes
Thermogravimetric analysis
Pyrolysis
Distributed activation energy model

ABSTRACT

Thermogravimetric analysis, Gaussian-fit-peak model (GFPM), and distributed activation energy model (DAEM) were firstly used to explore the effect of anaerobic digestion on sequential pyrolysis kinetic of four organic solid wastes (OSW). Results showed that the OSW weight loss mainly occurred in the second pyrolysis stage relating to organic matter decomposition. Compared with raw substrate, the weight loss of corresponding digestate was lower in the range of 180–550 °C, but was higher in 550–900 °C. GFPM analysis revealed that organic components volatized at peak temperatures of 188–263, 373–401 and 420–462 °C had a faster degradation rate than those at 274–327 °C during anaerobic digestion. DAEM analysis showed that anaerobic digestion had discrepant effects on activation energy for four OSW pyrolysis, possibly because of their different organic composition. It requires further investigation for the special organic matter, i.e., protein-like and carbohydrate-like groups, to confirm the assumption.

1. Introduction

Organic solid wastes (OSW) (i.e., sewage sludge, food waste, vinasse, cow manure) offer a huge potential for the production of biofuels, mainly because of their availability and low cost (Monlau et al., 2015b). Their use could contribute to reduce the world's dependency on fossil fuels and diminish global emissions of greenhouse gases (i.e., water vapour, CO_2, CH_4, N_2O, and chlorofluorocarbons). Among biofuels, biogas generated through anaerobic digestion (AD) of OSW has several advantages over other biological processes (i.e., biodiesel, bioethanol and biohydrogen

* Corresponding author.
E-mail addresses: daixiaohu@tongji.edu.cn, lixiaowei419@shu.edu.cn (X. Dai).

http://dx.doi.org/10.1016/j.biortech.2016.12.057
0960-8524/

fermentation). Such advantages are mainly due to the simplicity and capacity of biogas to treat a wide range of substrates (i.e., industrial and municipal sludge, municipal solid wastes, manures) that possess high concentrations of readily biodegradable organic matter in the form of carbohydrates, proteins, and fats (Monlau et al., 2014). Aside from biogas, digestate is a mixture of microbial biomass and undigested material that is generated in large quantities. However, a large part (>45 wt.%) of the matter is not degraded during the process and remains in the digestate (Cao and Pawlowski, 2013; Monlau et al., 2015a; Opatokun et al., 2016).

Currently, pyrolysis of digestate is considered an innovative and alternative process because it attains considerable benefits, such as considerable reduction of weight and volume, and elimination of pathogenic content and foul odor by high temperatures (Nansubuga et al., 2015). Pyrolysis can also further convert digestate into useful products including liquid (termed bio-oil), non-condensable gaseous (termed py-gas) and soild (biochar) fractions depending on the specific interest (Cao and Pawlowski, 2012). The bio-oil product can serve as fuel or a raw material of chemicals with the advantages of easy storage and transportation (Alvarez et al., 2016a; Fonts et al., 2012), while the biochar can as adsorbent or adsorbent precursor, soil conditioner, or used for carbon sequestration (Cao and Pawlowski, 2012). Unlike the standalone anaerobic digestion plant, anaerobic digestion and sequential pyrolysis can result in an increased electricity gain (~42%) (Monlau et al., 2015a). Inyang et al. (2010) suggested that the pyrolysis of anaerobic digestion residues to produce biochar may be an economically and environmentally beneficial use of agricultural wastes. Nansubuga et al. (2015) considered that anaerobic digestion of high-rate activated sludge and its subsequent pyrolysis to form biochar at the highest heating temperature of 600 °C represent an attractive route for sludge management in tropical settings like in Uganda. In addition, biochar converted from anaerobically digested sugarcane bagasse showed superior Pb sorption characteristics to undigested biochar (Inyang et al., 2011). However, high ash content of the biochars worsen the adsorption capacity and needs to be upgraded by acid washings (Alvarez et al., 2016b; Kong et al., 2013; Smith et al., 2009).

Previous studies focused on the advantages of anaerobic digestion-pyrolysis integration in energy recovery and biochar property. To the best of our knowledge, few studies have focused on the effect of anaerobic digestion on the sequential pyrolysis kinetics (Scott et al., 2006). In addition, whether different effects on different OSW occur as a results of their different organic matter composition is worth exploring. Understanding such influence will be of immense help in designing sequential pyrolysis or other thermochemical processes with better efficiency for special OSW.

Thermogravimetric analysis (TGA) is one of the most widely used techniques for investigating the degradation mechanism and for the determination of the kinetics parameters of pyrolysis and other thermochemical conversion processes (Bhavanam and Sastry, 2015). On the basis of TGA data, the kinetics of the pyrolysis process can be established with the use of some kinetic models such as single-step global reaction models, multiple-step models, semi-global models, and distributed activation energy model (DAEM) (Cao et al., 2014). The DAEM is used in a wide variety of complex reactions (Soria-Verdugo et al., 2013) and is considered an accurate and versatile approach of modeling the pyrolysis process (Cai et al., 2014; Cao et al., 2014; Soria-Verdugo et al., 2013). At present, the DAEM is thoroughly used to analyze the kinetics of pyrolysis of different feedstocks such as sewage sludge (Scott et al., 2006; Soria-Verdugo et al., 2013), municipal solid waste (Bhavanam and Sastry, 2015), cattle manure (Cao et al., 2014), lignocellulosic biomass (Cai et al., 2014, 2013), microalgae (Ceylan and Kazan, 2015), and coal (Li et al., 2009). Soria-Verdugo et al. (2013) reported that the sewage sludge sample showed higher activation energies (170–400 kJ/mol) compared with the biomass sample (pine pellets) (160–270 kJ/mol). Scott et al. (2006) suggested that differences in activation energies and kinetic parameters exist between digested sludge and undigested sludge, and that the majority of the differences arises from the processing of the sludge (i.e., digested versus undigested). Bhavanam and Sastry (2015) found that the range of activation energies of municipal solid waste was higher than that of the agricultural residues using the DAEM. In present study, TGA and DAEM was used to explore the effect of anaerobic digestion on pyrolysis characteristic and kinetics of OSW, i.e., sewage sludge, food waste, vinasse, and cow manure.

The objectives of this study are as follows: 1) to investigate organic matter conversion of the OSW during anaerobic digestion using TGA; and 2) to explore the influence of anaerobic digestion on sequential pyrolysis kinetics using the DAEM. Pyrolysis is not only a single process but also a first step to other processes (e.g., combustion and gasification) (Bhavanam and Sastry, 2015; Cao et al., 2014). Thus, the current study will be beneficial to the in-depth acquisition of the degradation mechanism of complex organic matter during anaerobic digestion and the development of technology using the thermochemical conversion process for digestate treatment.

2. Materials and methods

2.1. Substrates and anaerobic digestion process

Raw sludge (RS) was collected from the dewatered sewage sludge of Anting WWTP in Shanghai, China. Raw food waste (RFW) was taken from the Xiyuan canteen at Siping campus, Tongji University; the RFW was composed of meat, oil, rice, and vegetables, and used as feedstock after smashing and sufficient mixing. Raw vinasse (RV) was gained from Guizhou Moutai Distillery, Guizhou Province, China. Raw cow manure (RCM) was obtained from a cow farm in a suburb of Pudong district, Shanghai, China. Total solids of the RS, RFW, RV, and RCM were 19–23%, 18–24%, 43–47% and 18–22%, respectively.

Anaerobic digestion of these substrates was conducted in anaerobic digestion reactors with a working volume of 6 L and installed with helix-type stirrers, which were set at a rate of 60 rpm (rotations per minute) with 10 min stirring and 2 min break continuously. The reactor was operated semi-continuously (once-a-day draw-off and feeding) at 35 ± 1 °C (Duan et al., 2012). The solid retention time (SRT) and solid containing rate (w/w) of the reactors for sewage sludge, food waste, vinasse and cow manure were 20 days and 20%, 30 days and 7%, 30 days and 10%, and 30 days and 20%, respectively. In the stable period, the VS removal rates of these anaerobic digestion reactors were 42%, 87%, 77% and 60%, respectively, corresponding to previous studies (Dai et al., 2013; Zarkadas et al., 2015; Zhang et al., 2007; Ziemiński and Kowalska-Wentel, 2015), thereby implying that the performance of the reactors is normal and representative.

2.2. Sampling and analysis

After the reactors were operated for 3 SRT, the performances of the reactors tended to be stable; their effluent substrates were collected as the anaerobically digested samples, i.e., anaerobically digested sludge (ADS), anaerobically digested food waste (ADFW), anaerobically digested vinasse (ADV), and anaerobically digested cow manure (ADCM). The influent and effluent samples were freeze dried, passed through a 0.15-mm sieve, and stored in a desiccator with allochroic silica gel for further analysis.