Bioresource Technology 227 (2017) 286–296

Contents lists available at ScienceDirect

Bioresource Technology

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

Improving anaerobic digestion of easy-acidification substrates by promoting buffering capacity using biochar derived from vermicompost

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HIGHLIGHTS

- KW & CM were anaerobically digested at high organic loading to form acidification.
- VCBC and VC were employed as buffers to improve the anaerobic digestion of KW & CM.
- VCBC exhibited better acid buffering capacity than VC.
- CM can be well anaerobically digested with VC and VCBC addition.
- KW digestion was not initialized with VC and VCBC, but it tended to be alleviated.

ARTICLE INFO

Article history:
Received 14 October 2016
Received in revised form 12 December 2016
Accepted 17 December 2016
Available online 22 December 2016

Keywords:
Anaerobic digestion
Vermicompost
Biochar
Acid-buffering capacity
Chicken manure
Kitchen waste

ABSTRACT

Acid-buffering of VCBC and VC was evaluated using 4 VFAs, and their application on anaerobic digestion of CM and KW was investigated. Results indicated acid-buffering capacity of VCBC to acetic, propionic, butyric, and valeric acid was 2.5, 1.1, 1.9 and 1.6-fold higher comparing with VC. CM digestion was not initiated at higher organic loading of 50 g TS/kg, while it worked well with 5.0% VCBC or VC. KW was not digested even though VC or VCBC was increased to 15% and 20%. However, KW digestion can be alleviated with increasing VCBC or VC proportion, in which the alleviation by VCBC was better than VC. Average VFAs concentration during CM digestion with VC was 4077.7 mg/L comparing with 2835.8 mg/L of VCBC, and biogas release was delayed for 10-days accompanying rapid pH decrease in CM digestion with VC, which reflected acid-buffering of biochar played a crucial role on improving anaerobic digestion.

1. Introduction

Anaerobic digestion is a well-constructed technology for converting various organic substrates into the gaseous fuel (biomethane) via a consortia of bacteria and archaea, which has been steadily increased in recent years (Fabbri and Torri, 2016). In addition to recovering fuel, anaerobic digestion has many environmental benefits including reducing waste volumes and potential pollution, and recycling nutrients (Murto et al., 2004). Generally, anaerobic digestion performance mainly relates to the nature of organic substrates, which can be typically classified as sewage sludge, animal manures, food wastes, energy crops and harvesting residues, and organic fraction of municipal solid waste (Romero-Güiza et al., 2016). Some of these organic substrates (for example, food wastes, manures of non-ruminant animals) are characterized by easy biodegradation and considerable CH_4 potential. Moreover, the wide distribution and abundant resources of these feedstocks make them attractive and feasible for biogas production. However, anaerobic digestion of these easily biodegradable feedstocks in practice always suffers instability and lower biogas output, even

Abbreviations: VC, vermicompost; VCBC, vermicompost biochar; CM, chicken manure; KW, kitchen waste; VFAs, volatile fatty acids; TVFAs, total volatile fatty acids; VS, volatile solid; TS, total solid; CM + VC, chicken manure digestion with vermicompost; CM + VCBC, chicken manure digestion with vermicompost biochar; KW + VC, kitchen waste digestion with vermicompost; KW + VCBC, kitchen waste digestion with vermicompost biochar; TCD, thermal conductivity detector; FID, flame ionization detector; SEM, scanning electron microscope; XRD, X-ray diffraction.

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http://dx.doi.org/10.1016/j.biortech.2016.12.060
0960-8524/

failure. This is mainly attributed to rapid accumulation of volatile fatty acids (VFAs) resulting in extra lower pH and inhibiting the methanogens, especially, their anaerobic digestion at higher organic loadings (Shen et al., 2013).

As the easily biodegradable feedstocks were anaerobically digested, alkaline chemicals are generally employed to adjust the serious acidification and maintain pH in the range of 6.5–7.0 (Vavilin et al., 2003). However, the acidification may happen again once alkaline chemicals are depleted. In addition, two-phase anaerobic digestion is always recommended to digest the easily biodegradable feedstocks, in which one digester is in charge of acidification to produce short-chain VFAs, and the other one is mainly responsible for methanogenesis (Ganesh et al., 2014). By this way, the stability of anaerobic digestion of food waste can be improved in some degree. However, the unstable digestion and decrease of biogas output still appeared as organic loading rate was increased to higher than 2.5 g(VS)/L·d of food waste (Shen et al., 2013). Besides, co-digestion is believed as an effective way to stabilize anaerobic digestion of easily biodegradable feedstocks and promote methane yield (Mata-Alvarez et al., 2014). It was reported that co-digesting food waste with other substrates can increase the buffering capacity, reduce the inhibition resulting from VFAs accumulation, and increase methane yield consequently (Sun et al., 2016; Zhai et al., 2015). However, co-digestion is not a perfect method for improving methane production because it was very hard to match a suitable combination of substrates for digestion. Especially, the employed substrates are not available in same spatial and temporal scale. For example, food waste is abundant in urban areas and corn stover is available in rural areas, although the biogas production can be well promoted by their co-digestion (Zhou et al., 2014). Based on the facts of the promoted buffering capacity by co-digestion, is there possible to construct a digestion system with enough buffering capacity to VFAs? If possible, the rapid decrease of pH resulting from VFAs accumulation and inhibition to methanogens can be potentially weakened or avoided (Gao et al., 2015).

Recently, biochar has been paid more attention in anaerobic digestion as it can enhance biogas production and improve CH_4 content. In the published work, it was believed that biochar functioned as electron carrier or conductor to favor electron transfer and accelerate ethanol or VFAs conversion to CH_4 (Chen et al., 2014; Zhao et al., 2015). It was also reported that the improvement on anaerobic digestion was attributed to mitigating the inhibition of ammonia and toxic fractions by biochar adsorption (Monlau et al., 2015; Mumme et al., 2014). Besides, the abundant pores offered a habitation to immobilize microorganisms resulting in digestion improvement (Xu et al., 2015). Moreover, the alkaline nature of biochar was regarded to increase CH_4 content by reacting CO_2 and H_2S with alkaline substances in ash and upgrade the biogas in-situ (Shen et al., 2015). Besides, VFAs generation at acidification phase and their degradation in methanogenesis phase were both enhanced as biochar was added in two-phase anaerobic digestion on food waste (Cai et al., 2016; Sunyoto et al., 2016), which suggested no serious acidification and stable pH in these 2 phases of digestion, and potentially related to the buffering of biochar.

In previous work, it was proved that biochar from vermicompost (VC) exhibited an excellent buffering to acid (HNO_3) due to its high content of alkali metals or alkaline-earth metals in ash and functional groups (Yang et al., 2015). Based on the speculation above and the fact of acid-buffering of vermicompost biochar (VCBC), it offered a possibility to construct a buffer system by adding VCBC in anaerobic digestion, especially, in digesting easy-acidification substrates. Furthermore, VCBC exhibited higher apparent density (approximately 1.90 g/cm^3 in this work) comparing with traditional biochar from lignocellulosic biomass, which may facilitate the mixing of digestion. Besides, as an important by-product of earthworm growth derived from degradation and decomposition of biomass waste like animal manures, sewage sludge, VC may potentially contain heavy metals, pathogens, parasites, antibiotics and organic contaminants. Converting VC to VCBC can be regarded as an important and safe way to utilize VC, because the containing organic contaminants can be degraded greatly, the pathogens and parasites can be deactivated totally, and the heavy metals can be stabilized mostly during the carbonization process (Yang et al., 2015). VCBC can act as a bridge to link waste biomass disposal and valorization if it can be applied in anaerobic digestion based on the nature of acid-buffering. Therefore, the buffering of VCBC to VFAs and the performances of anaerobic digestion with VCBC involvement deserve to be investigated in depth.

In order to better understand the possible role of biochar from the aspect of buffering, typic easy-acidification substrates of kitchen waste (KW) and chicken manure (CM) were selected for anaerobic digestion. Furthermore, relatively high organic loading was employed to intentionally worsen the anaerobic digestion and achieve acidification conditions, by which VCBC was supplemented to clarify the digestion performances. As the precursor of VCBC, VC has been proved with buffering capacity and applied in anaerobic digestion (Chen et al., 2010; Zhang and Yang, 2007). Thus, VC was also involved in the digestion of KW and CM as a comparison. During the digestion, the biogas, CH_4 and H_2 yield and their content, VFAs changes, pH, and total alkalinity, which can directly reflect the digestion performances, were investigated to elucidate the biochar's roles of acid-buffering in anaerobic digestion.

2. Material and methods

2.1. VC and preparation of VCBC

VC was collected from a local earthworm breeding plant in Chengdu, Sichuan, where the earthworms lived on dairy manure. The harvested VC was thoroughly mixed, air-dried, and ground to less than 0.45 mm. A forced drying on VC was performed at 105 °C for 6.0 h prior to pyrolysis. The prepared VC were pyrolyzed at 500 °C in a tube furnace (OTL 1200, Nanjing NanDa Instrument Co. Ltd.) with N_2 of 0.1 m^3/h as the protective gas. The heating rate of 10 °C/min and holding duration of 2.0 h were maintained to produce the desired biochar. The basic characteristics of VC and VCBC were listed in Table 1.

2.2. KW, CM and inoculum

KW was collected from the canteen in Sichuan Agricultural University, Chengdu Campus, and the indigestible materials, such as bones, egg shells, plastics, chopsticks and so on, were picked out by hand. Afterwards, KW was homogenated using a homogenizer at 12,000 r/min for 5.0 min. CM was taken from the chicken farm in Sichuan Agricultural University, Chengdu Campus. CM was also checked for the indigestible materials and homogenated with similar process of KW. The homogenated KW and CM were stored in −8 °C for anaerobic digestion. Inoculum of seeding sludge for anaerobic digestion was obtained from the Biogas Institute of Ministry of Agriculture, Chengdu, China. The inoculum was pre-incubated for 15 days at mesophilic temperature in order to deplete the residual biodegradable organic matters. The basic characteristics of KW, CM and seeding sludge were exhibited in Table 1.

2.3. Determining the buffering capacity of VC and VCBC to VFAs

In order to check the buffering capacity of VC and VCBC to VFAs, they were individually mixed with the deionized water at the pro-