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Mesophilic anaerobic co-digestion of aloe peel waste with dairy manure in the batch digester: Focusing on mixing ratios and digestate stability

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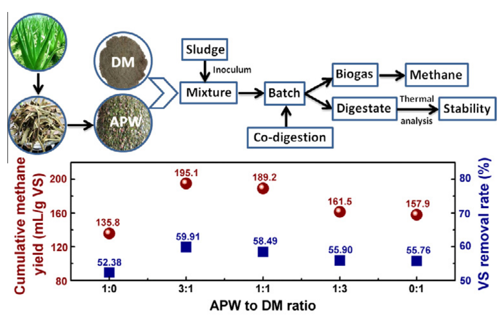
HIGHLIGHTS

- Aloe peel waste (APW) was co-digested with dairy manure (DM).
- The highest biogas and methane yields were obtained with a 3:1 ratio of APW to DM.
- The cumulative methane yield was strongly associated with the volatile solids (VS) removal rate.
- Digestate from mixture of APW and DM showed high stability based on the thermal analysis.

GRAPHICAL ABSTRACT



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ABSTRACT

Anaerobic co-digestion of aloe peel waste (APW) with dairy manure (DM) was evaluated in terms of biogas and methane yield, volatile solids (VS) removal rate, and the stability of digestate. Batch experiments were performed under mesophilic condition (36 ± 1 °C) at five different APW/DM wet weight ratios (1:0, 3:1, 1:1, 1:3, and 0:1). Experimental methane yield from the mixtures was higher than the yield from APW or DM alone, indicating the synergistic effect and benefits of co-digestion of APW with DM. The optimal mixing ratio of APW/DM was found to be 3:1. The cumulative methane yield was 195.1 mL/g VS and the VS removal rate was 59.91%. The characteristics of the digestate were investigated by the thermal analysis which indicated the high stability in the samples of the co-digestion. The co-digestion can be an efficient way to improve the degradation efficiency of the bio-wastes and increase the energy output.

1. Introduction

Aloe is known to be one of the oldest medicinal plants, and it is a unique resource of the naturally occurring nutrients (vitamins, minerals, aminoacids, fatty acids, and polysaccharides). In recent years, aloe has been broadly used in cosmetics, food products and pharmaceuticals due to its chemical diversity (Eshun and He, 2004). It has been reported that aloe plants were cultivated on over 2700 ha of land in 2010 in China. The rapid development of the aloe processing industry has created environmental pollution problems since the production process generates waste products, which mainly consist of aloe peel waste (APW). In this regard, new technologies are needed to convert APW into bioenergy and improve the sustainability of energy production.

Anaerobic digestion (AD) is a widely used technique to convert bio-organic matter into biogas by microorganisms under oxygen-free conditions. Biogas is a renewable energy source that can be used to generate heat, electricity and compressed natural gas. The digestate can be used as a soil amendment because of its rich content of nitrogen and phosphorus. AD has been proven to be an economically feasible technology for the cyclic utilization of biomass waste in full scale operation (Brummeler, 2000). Usually, AD requires a balanced carbon-nitrogen (C/N) ratio. The optimum

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C/N ratio is in the range of 20–25 (Yen and Brune, 2007). At this condition, APW as a single feedstock cannot be easily degraded by the AD process because of its high C/N ratio and nutrients for microorganism. In addition, the mono-digestion of APW lacks a buffering capacity for the chemical reaction. Compared to the digestion of a single feedstock, co-digestion offers a better nutrient balance and C/N ratio for anaerobic microorganism growth, an appropriate pH to avoid system acidification, and a high buffering capacity to prevent the pH dropping rapidly due to volatile fatty acids (VFAs) build-up. For these reason, co-digestion enhances the biodiversity in the digester and produces the synergistic effects (Zhang et al., 2016a,b; Molinuevo-Salces et al., 2013), resulting in obtaining the optimized biogas and methane yield.

As one of the main livestock manures in China, dairy manure (DM) is an excellent feedstock for anaerobic co-digestion with other biomass wastes. Until recently, various biomass wastes such as crop waste (Li et al., 2014), forestry waste (Zheng et al., 2015), fruit waste (Dias et al., 2014), vegetable waste (Belle et al., 2015), food waste (Zarkadas et al., 2015; El-Mashad and Zhang, 2010), and municipal solid wastes (Macias-Corral et al., 2008) have been used to perform a anaerobic co-digestion with DM. The co-digestion of DM with three crop straw residues (SRs) under five mass mixing ratios (SRs/DM) demonstrated that a high methane content and the highest cumulative biogas yield were achieved at the SRs/DM mass mixing ratios 1:9 and ratio 5:5, respectively (Li et al., 2014). Dias et al. (2014) evaluated the technical feasibility of anaerobic co-digestion of the pre-treated dairy cattle manure (LCM) with pear waste after a storage period (PLF) under mesophilic conditions. The introduction of the co-substrate clearly enhanced methane production rate in comparison to single substrate, and the optimal performance was achieved at the mixing ratio of 25:75 (LCM:PLF). El-Mashad and Zhang (2010) investigated the batch anaerobic co-digestion of dairy cattle manure (CM) and food waste (FW) at different mixture ratios under thermophilic conditions. The highest methane production was obtained by the ratio of 75:25 (CM:FW), which increased by 86% compared with cattle manure mono-digestion.

In addition to improving biogas and methane yield, the digestate from anaerobic co-digestion is know to show high stability (Dai et al., 2013). The thermal analysis technique is proven to be a novel and practical tool for assessing the stability of biological residues, which is based on the weight of a sample lost with increasing temperature in a controlled atmosphere (Gómez et al., 2007). Especially, thermogravimetry (TG) and differential scanning calorimetry (DSC) analysis are available on the study of digestate properties in AD (Cuetos et al., 2009; Molinuevo-Salces et al., 2013). These techniques are applied to determine the amount of combustible fraction in digestate, thereby the energy potential of the substrate.

The purpose of the present work is to investigate the anaerobic co-digestion of APW with DM in the batch digester under mesophilic conditions. This study also aim to evaluate the performance of anaerobic co-digestion based on the pH, total Kjeldahl nitrogen (TKN), total chemical oxygen demand (CODt), and volatile solids (VS) removal rate, and further assess the stability of digestate by the TG and DSC analysis. To the best of our knowledge, the combined treatment using APW and DM has not been reported in the previous literatures, with combining TG and DSC provides the substantial evidence to systematically evaluate the digestate stability.

2. Methods

2.1. Substrates and inoculum

Mixtures of APW and DM were used as substrates in this study. APW was collected from an aloe beverage factory in the Yangling agricultural high technology industry demonstration zone in Xi'an, China. APW samples were crushed into small particles of about 5 mm in diameter in a fruit mill. These particles were steeped in a 2 M NaOH solution for 24 h, and then were washed with distilled water to remove alkali residues and achieved the pH of 7 before being mixed with DM. DM was collected from a large-scale local dairy farm in Lintong district of Xi'an, China. The inoculum (anaerobic sludge) was from a municipal wastewater treatment plant (WWTP) in Xi'an city. Prior to the experiments, all the feedstocks were homogenized and stored at 4 °C. The characteristics of substrates and inoculum are presented in Table 1.

2.2. Experimental set-up

Batch experiments were performed to evaluate the biogas production in the laboratory. The co-digestion was performed in glass reactors that have a capacity of 500 mL and a working volume of 375 mL. The feeding inlet was sealed with a rubber bung, where was set up a gas outlet. Biogas volume was measured by the water displacement method, which was in calibrated plastic cylinders fitted to the glass reactor. The digestion temperature was maintained at 36 ± 1 °C with a homothermal water bath. Anaerobic co-digestion of APW with DM was carried out for five APW/DM wet weight ratios: 1:0, 3:1, 1:1, 1:3, and 0:1. The initial inoculum amount of each bottle was 30% based on the total wet weight. This proportion of inoculum was selected according to previous experiments. Inoculum with no feedstock addition was used as the control samples. Each reactor was shaken manually for 2 min once a day before the biogas volume was measured. Biogas was collected in a 50 mL gas bag using a syringe which inserted into the rubber bung of glass reactor, and the collected gas was used to measure the methane content, which is similar with the reported method in the previous literature (Zhang et al., 2014). After biogas production stopped, the digestate was tested for pH, CODt, TKN, VS removal rate, TG, and DSC. All of the batch experiments were performed in duplicate.

2.3. Analytical methods

The measurement of TS, VS, CODt and TKN were conducted according to the standard methods for the examination of water and wastewater as recommended by the American Public Health Association (APHA, 2005). pH was measured using an acidimeter (PHS-3C, China). Stove-dried APW and DM samples were used for elemental analysis (C, H, N) by an elemental analyzer (Vario EL III, Germany). The lignocellulose content of the APW and DM was analyzed using a fiber analyzer (Model ANKOM220, USA). Biogas yield expressed in mL/g VS was calculated as the volume of biogas generated per gram of feedstock VS added to the reactor. Biogas composition was analyzed using a gas chromatograph (SP-3420A,

Table 1
Characteristics of substrates and inoculum.

Parameters	DM	APW	Inoculum
TS (% FM)	15.85	12.49	5.01
VS (% FM)	12.32	8.33	3.99
VS/TS (%)	77.73	66.67	79.61
CODt (mg/kg FM)	91,400	38,241	41,384
pH	7.71	5.72	7.36
Cellulose (% TS)	27.20	37.80	N.D.
Hemi-cellulose (% TS)	31.70	28.30	N.D.
Lignin (% TS)	13.30	14.10	N.D.
C (% TS)	46.84	59.03	N.D.
H (% TS)	5.92	11.43	N.D.
N (% TS)	3.93	1.71	N.D.
C/N	11.92	34.52	N.D.

N.D.: Not determined. FM: Fresh matter.