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Review

Anaerobic digestion of food waste: A review focusing on process stability

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HIGHLIGHTS

- AD is a well-established technology for FW management.
- Performance instability is a common operational issue for AD of FW.
- Methods for improving the stability of anaerobic digesters are reviewed.
- Process monitoring and control are suitable for evaluating digester operation.
- Microbial management facilitates early diagnosis and optimization of digesters.

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ABSTRACT

Food waste (FW) is rich in biomass energy, and increasing numbers of national programs are being established to recover energy from FW using anaerobic digestion (AD). However process instability is a common operational issue for AD of FW. Process monitoring and control as well as microbial management can be used to control instability and increase the energy conversion efficiency of anaerobic digesters. Here, we review research progress related to these methods and identify existing limitations to efficient AD; recommendations for future research are also discussed. Process monitoring and control are suitable for evaluating the current operational status of digesters, whereas microbial management can facilitate early diagnosis and process optimization. Optimizing and combining these two methods are necessary to improve AD efficiency.

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1. Introduction

Food waste (FW) consists of materials intended for human consumption that are ultimately discarded, lost, degraded, or contaminated (Girotto et al., 2015). Owing to global economic development and population growth, FW from residential, commercial (e.g., restaurants), institutional (e.g., school cafeterias), and industrial (e.g., food-processing factories) sources is being generated at an increasingly high rate (Dai et al., 2013; Girotto et al., 2015). Food safety issues frequently occur due to incomplete FW management systems, and the disposal of FW is attracting widespread attention in many countries (Li et al., 2015; Thi et al., 2015). Because of its high moisture content, low calorific value, and high lability, traditional approaches for FW disposal, such as incineration, landfills, composting, thermal treatment, and animal feed, are sub-satisfactory with respect to sustainability, environmental impact, and investment (Girotto et al., 2015; Han et al., 2016). In contrast, anaerobic digestion (AD) is an effective approach for FW management and offers many environmental benefits, such as generation of renewable energy and production of soil amendments, alcohol, volatile fatty acids (VFAs), and other valuable materials (Capson-Tojo et al., 2016; Han et al., 2017, 2015; Li et al., 2015; Zhang et al., 2013). Nevertheless, AD often suffers from process instability, which is further exacerbated when treating FW characterized by high oil, salt, and protein contents. Process monitoring and control are widely accepted methods for improving AD stability and efficiency (Boe et al., 2010; Li et al., 2014; Molina et al., 2009). Since the 1940s, a large number of studies have been carried out to identify process indicators (particularly physicochemical parameters such as gas production, pH, VFA, and alkalinity) that can effectively reflect the operational status of AD (Boe et al., 2010; Kleyböcker et al., 2012b; Kroeker and Lapp, 1979; Li et al., 2014; Lv et al., 2014; Polag et al., 2015). Accurate methods and robust equipment for monitoring those above mentioned process indicators have also developed explosively (Boe et al., 2007; Jantsch and Mattiasson, 2004; Jin et al., 2017; Lomborg et al., 2009; Pind et al., 2003). On the other hand, AD is a biochemical process with multiple phases, and its overall process stability and efficiency rely on multiple syntrophic interactions among different taxa (Goux et al., 2015; Lin et al., 2016b; Poirier et al., 2016a). Thus, understanding the dynamics of microbial communities in digesters is crucial for optimizing AD. Consequently, the management of microbial communities in anaerobic digesters has become a widely employed technique in recent years, and numerous studies have been conducted to identify anaerobic microbiomes, establish microbial indicators, and develop biotechnological methods to improve AD (Carballa et al., 2015; Goux et al., 2015; Li et al., 2016; Poirier et al., 2016a,b). In this context, we review a large number of studies to summarize the current development status of AD for FW treatment. We then discuss and compare physiochemical-based versus microbial-based techniques for managing anaerobic digesters. The main goals of this study were to summarize previous research achievements on controlling and mitigating digester instability, refine the existing limitations to AD efficiency, and provide recommendations for future research.

2. Anaerobic digestion of food waste

Food waste constitutes one of the largest components of waste around the world (Capson-Tojo et al., 2016; Zhang et al., 2014, 2013). Its theoretical methane production rate typically ranges from 0.4 to 0.5 L CH_4 g VS^{-1} (Li et al., 2015, 2014; Nagao et al., 2012), suggesting great potential for energy recovery. In view of this, interest in AD of FW has escalated over the past few decades. Capson-Tojo et al. (2016) and Uçkun Kiran et al. (2014) previously reported and reviewed laboratory-scale studies of FW treatment using AD. In many European and developed Asian countries, AD has been widely applied to treat FW on an industrial scale. Germany, Spain, England, and Korea are all equipped with full-scale AD plants with a capacity of 2500 tons per year or larger (Chiu and Lo, 2016; Thi et al., 2015). In developing countries, such as India and China, various institutes and non-governmental organizations have established different types of anaerobic digesters on household and commercial scales to develop AD technology for FW treatment (Thi et al., 2015). For example, a pilot scale study in India implemented AD to treat FW, and several institutes have developed biogas plants. In China, demonstration projects for FW disposal were initiated in 2010 and since then a total of 100 cities have been chosen as the pilot cities. Among those projects, more than 90% adopted AD technology for FW disposal.

Despite continuously increasing interest and popularity, large-scale FW anaerobic digesters are usually operated with a low organic loading rate (OLR), from 1 to 4 g VS L^{-1} d^{-1}, or long hydraulic retention time (HRT), up to 80 d (Banks et al., 2011; Tampio et al., 2014; Zhang et al., 2012). The resulting low biogas production reduces the efficiency and economic feasibility of the process. Raising the OLR (hydraulic or organic loads) can help increase gas production and improve process efficiency, but instability during continuous AD operation is a major concern (Capson-Tojo et al., 2016; Chiu and Lo, 2016). The characteristics of FW (high labile organic matter, salt, oil, and protein contents; low C/N ratio; and insufficient trace elements) makes anaerobic digesters prone to acidification, ammonia, salt, and long chain fatty acid (LCFA) inhibition, and nutrient deficiency (Banks et al., 2012; Dai et al., 2013; Gao et al., 2015; Li et al., 2015; Zhang et al., 2013). The reestablishment of stable biogas production after digester deterioration is a long-term process. Considering that biogas plants often are operated under limited profit, technical problems and upsets involving a long downtime or high repair cost can have serious economic consequences (Ganidi et al., 2009; Lienen et al., 2013; Zhang et al., 2013). Therefore, process instability is a serious limitation to AD of FW. Process monitoring and control as well as microbial management are widely used for mitigating process instability and improving AD. In view of the fact that process instability is a ubiquitous phenomenon, and the methods for controlling instability in various digesters are interlinked, a comprehensive summary of achievements in AD systems fed with various substrates may provide guidance for mitigating instability of anaerobic digesters used for FW treatment. Therefore, the following review focuses on, but is not limited to, FW-AD systems.