Waste Management xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Waste Management

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

Optimized anaerobic-aerobic sequential system for the treatment of food waste and wastewater

S. Ghanimeh *, C. Abou Khalil, C. Bou Mosleh, C. Habchi

Faculty of Engineering, Notre Dame University-Louaize, Lebanon

ARTICLE INFO

Article history:
Received 20 February 2017
Revised 19 May 2017
Accepted 15 June 2017
Available online xxxx

Keywords:
Anaerobic-aerobic sequential system
Food waste
Wastewater
Mixing
Computational fluid dynamics

ABSTRACT

Considering that modern wastewater and solid waste processing facilities seek efficient energy recovery methods, this study investigates anaerobic-aerobic sequential systems for combined treatment of raw wastewater with food waste. The optimum loading rate was found to be 1.6 mg VS L^{-1} d^{-1} resulting in a stable operation of the anaerobic compartment. Yet, the increase in ammonia concentration resulted in gradual accumulation of VFA, until reaching a tipping point of 3000 mg L^{-1} beyond which an abrupt increase in VFA to above 6000 mg L^{-1} was observed, with acute stability loss and performance deterioration. The aerobic system was modeled using computational fluid dynamics methods. Optimum performance was achieved at an average strain rate magnitude of 12.7 s^{-1} yielding a DO concentration of 4 mg L^{-1} which have resulted in 74% conversion of ammonia nitrogen. Under optimum conditions, the studied AASS yielded high total removal rates of 93% VS and 94% COD, with a high specific methane yield of 845 L kg VS^{-1} and a CO_2-to-CH_4 ratio of 0.63.

1. Introduction

Treatment of wastewater (WW) is often considered expensive due to elevated energy costs and Wastewater treatment plants (WWTPs) are seeking novel approaches for energy self-sufficiency (Sattler, 2011). Traditionally, domestic WW is treated using aerobic biological methods, such as the Waste Activated Sludge (WAS) process, where aeration is provided to ensure adequate oxygen content for the growth of aerobic microorganisms (Droste, 1997; Metcalf and Eddy, 2004). After removal of the relatively clean supernatant, the high-solid sludge, remaining at the bottom of the treatment units, is collected and sent for Anaerobic Digestion (AD). The latter consists of converting the biodegradable solids into CO_2 and CH_4, a source of energy, by a consortium of anaerobic microorganisms. However, raw WW is seldom treated anaerobically, mainly due to its low-strength (low solids content) leading to low gas generation and low process efficiency.

Similarly, food waste (FW) is usually treated using aerobic biological methods, namely composting, where the organic matter in the waste is oxidized into CO_2 and H_2O (Wei et al., 2017). In the last decade, there has been an increasing interest in applying AD technology to treat high-strength wastes such as FW. The latter has a high specific methane yield of 276–483 L of CH_4 per kg (EPA, 2008), equivalent to triple the methane generated from WW sludge (Jang et al., 2015). Yet, given the high biodegradability of FW, acid generation occurs, often fast, leading to pH drop and inhibition of the methane-generating microorganisms. Therefore, FW is often diluted with water and digesters are fed at low organic rates (El-Fadel et al., 2013; Ghanimeh et al., 2013). Yet, anaerobic treatment alone has generally not been sufficient to meet stringent effluent requirements for Chemical Oxygen Demand (COD) and suspended solids (SS) for all types of organic waste, including FW, thus often necessitating a post-treatment such as aerobic degradation (Zeng et al., 2016; Tomei et al., 2011; Jang et al., 2015).

In this context, a novel system is being considered recently to improve the digestion of sewage sludge, consisting of an anaerobic compartment followed by an aerobic reactor (Tomei et al., 2011). The methane generated in the anaerobic stage can be partially used to provide the energy needed to mix and aerate the aerobic reactor, thus reducing the overall operational cost. The rationale for the additional aerobic step is that some of the organic fraction in the sludge that cannot be anaerobically digested in the first compartment may be aerobically degraded in the second. Also, the aerobic stage is helpful in stabilizing the anaerobic digestate and converting ammonia nitrogen into nitrate and, if maintained below 4 mg L^{-1}, into nitrogen gas. In fact, it has been reported that the

---

Abbreviations: AASS, anaerobic aerobic sequential system; AD, anaerobic digestion; WW, wastewater; FW, food waste; WAS, waste activated sludge; TS, total solids; VS, volatile solids; COD, chemical oxygen demand; SS, suspended solids; DO, dissolved oxygen; VFA, volatile fatty acids; OLR, organic loading rate; HRT, hydraulic retention time; CFD, computational fluid dynamics; WWTP, wastewater treatment plant.

* Corresponding author.
E-mail address: sghanimeh@ndu.edu.lb (S. Ghanimeh).

http://dx.doi.org/10.1016/j.wasman.2017.06.027

Please cite this article in press as: Ghanimeh, S., et al. Optimized anaerobic-aerobic sequential system for the treatment of food waste and wastewater. Waste Management (2017), http://dx.doi.org/10.1016/j.wasman.2017.06.027

implementation of the aerobic step, in the anaerobic aerobic sequential system (AASS), considerably reduces the nitrogen level in the effluent and improves the removal of volatile solids (VS) and COD (Kumar et al., 2006a, 2006b; Jang et al., 2015; Tomei et al., 2011). Jang et al. (2015) showed that AASS treating FW can provide high total removal rates of 90% for VS and 94% for COD. Also, Tomei et al. (2011) reported VS and COD removal rates of 32% and 29%, respectively, in the anaerobic compartment, and an additional 17% and 21%, respectively, in the aerobic reactor when treating WW sludge, with a biogas generation of 840 L per kg of VS degraded. Zupančič et al. (2008) showed that 88% of ammonia can be oxidized in the aerobic compartment of AASS.

Furthermore, compared to separate treatment of FW (through composting) and WW (through WAS, followed by AD of sludge), co-digestion in an AASS enhances the feasibility of WW and solid waste treatment. The need for a separate FW composting facility is eliminated. Also, the generation of renewable energy (in form of CH_4) in WWTPs is improved by adding high-strength FW. This approach can be useful in communities, especially in developing regions, where a large number of WWTPs remain at the planning stage, thus allowing for potential modifications in design and feed type (Sattler, 2011). On the other hand, compared to AD systems operated on FW alone, the addition of WW is expected to enhance the process stability through: (1) providing continuous re-seeding (with methanogens and other anaerobic microorganisms), and (2) introducing less easily biodegradable material (compared to FW) which can slow down the volatile fatty acids (VFA) production.

Generally, dissolved oxygen (DO) concentration in the aerobic compartment should be higher than 1 mg L^{-1} to achieve adequate degradation of solids, and higher than 4 mg L^{-1} to ensure favorable conditions for nitrification (Zupančič and Roš, 2008). Thus, nitrification requires vigorous stirring to allow re-aeration at the fluid surface, accompanied by efficient mixing to achieve adequate transfer of DO throughout the reactor. While design and control of aeration tanks often rely on empirical guidelines, computational fluid dynamics (CFD) have been recently adopted to optimize mixing and energy efficiency of aerated tanks in WAS processes (Karpinska and Bridgeman, 2016). Yet, the design of the aeration stage of AASS differs from that of WAS systems. While the latter is the primary degradation stage in a treatment facility, the former is a complementary step to further polish the anaerobic effluent and reduce soluble ammonia and, depending on the application case, total soluble nitorgen. As such, the mixing scheme has to be designed to provide system specific requirements of DO concentration and mixing efficiency.

Although combined AD of FW with WW solids (including primary and/or secondary sludge) has been extensively investigated, co-digestion with raw WW in AASS is lacking. Also, computational fluid dynamic (CFD) based optimization of the performance of aerobic reactors in AASS has not been addressed. As such, this paper considers the performance, stability and energy recover of AASS treating a mix of raw WW and FW. The mixing of the aerobic compartment is modeled using CFD and the results are correlated to ammonia conversion and performance parameters.

2. Materials and methods

2.1. Experimental setup

The AASS consists of two Plexiglas reactors (Fig. 1): the first operating under anaerobic mesophilic conditions (37 ± 1 °C, heated in a 100 L water-bath) and the second under aerobic conditions at ambient temperature (around 20 ± 3 °C). The anaerobic digester has a working volume of 7 L with 0.7 L headspace. It is made of 0.5 cm thick Plexiglas with an inner diameter of 14 cm and a total height of 50 cm. The digester's cover has three openings: (1) for biogas collection and analysis, (2) for NaOH addition, and (3) an extra port for future use. The digester's content was mixed and fed with a peristaltic pump (Masterflex, Cole Parmer, USA). Mixing was achieved by recirculating the digester liquor from the bottom to the top at a rate of 5 min per hour, for 8 h per day, through valve B – while valve C is close (Fig. 1). Intermittent mixing pattern was adopted to simulate full-scale operation (Wang et al., 2013). The digester content was mixed for 15 min prior to sampling and 90 min after feeding. Given the relatively high specific methane generation rate observed, the eight hour daily mixing pattern per-

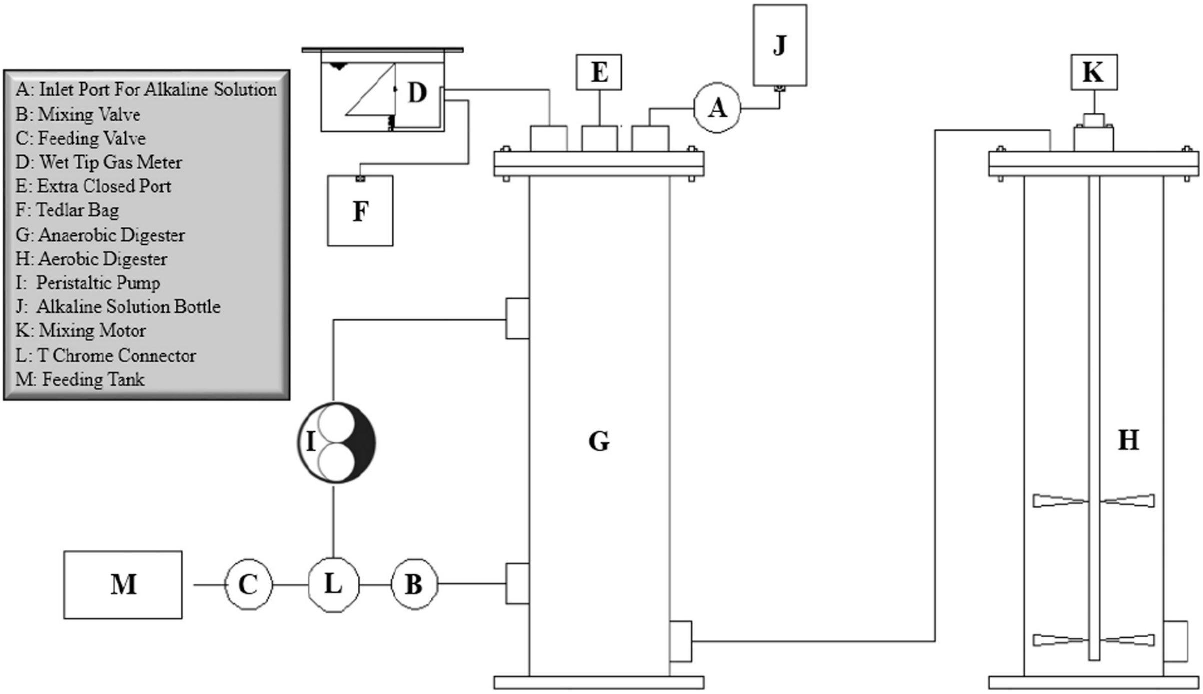

Fig. 1. Experimental setup.

Please cite this article in press as: Ghanimeh, S., et al. Optimized anaerobic-aerobic sequential system for the treatment of food waste and wastewater. Waste Management (2017), http://dx.doi.org/10.1016/j.wasman.2017.06.027