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Anaerobic co-digestion of food waste and domestic wastewater – Effect of intermittent feeding on short and long chain fatty acids accumulation

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ABSTRACT

This work investigates the anaerobic co-digestion of a mixture of food waste and domestic wastewater (0.09, v/v) using an upflow anaerobic sludge blanket (UASB) reactor to generate renewable energy in form of biogas. The reactor was operated under the conditions of mesophilic temperature (35 °C), pH 7.2, and 10 days of hydraulic retention time (HRT). The chemical oxygen demand (COD) removal efficiency and the methane content were 80 ± 1.3% and 56%, respectively, when the reactor was operated continuously at the organic loading rate of 2 g COD/L/d in 2 days of operation, while the COD removal efficiency started decreasing and reached 61 ± 1.7% after 10 days, with the methane content of 37%. The deterioration of reactor efficiency on converting organic matter to methane was attributed to the accumulation of long chain fatty acids (LCFAs) onto the sludge. To overcome the physical and metabolic inhibition by LCFAs, the application of intermittent feeding mode (48 h feed and 48 h feedless) was chosen and applied at different organic loading rates (OLRs; 2–4.5 g COD/L/d) to evaluate the reactor performance in terms of COD removal, methane content, accumulation of LCFAs and short chain fatty acids (SCFAs). The COD removal efficiency and methane content were 82 ± 1.1%, 75 ± 0.9%, and 62 ± 1.5% and 58%, 56%, and 51% at the OLR of 2, 3, and 4.5 g COD/L/d, respectively. The 48 h feed/48 h feedless cycle seemed a promising alternative to treat real food wastewater. However, further studies are still necessary to better evaluate the application of intermittent feeding to treat different mixtures of food waste and domestic wastewater at higher organic loading rates.

1. Introduction

Macau is a Special Administrative Region (SAR) of China with a population around 640,000 concentrated in an area of only 30 km^2, considered one of the most densely populated regions in the world. In 2010, around 300 tons of solid waste was incinerated and the half was organic waste [1]. In 2015, almost all the energy consumed in Macau was imported from mainland China with only 15.1% generated own by the Macau Energy Company [2]. Therefore, especially from the regional perspective, it is important to create alternative technologies for a better food waste management and energy generation such as to use anaerobic digestion (AD) for the waste treatment with the simultaneous energy production, reusing food waste (FW) as a resource to produce renewable and eco-friendly energy as biogas. AD has been extensively used in Europe but still only about 3% of biodegradable solid waste has been treated anaerobically [3]. Although FW is a promising substrate for AD due to its high biodegradable organic matter content [4], its long-term mono-digestion is commonly associated with the reactor failure due to nutrient imbalance, short chain fatty acids (SCFAs) accumulation, and excess of macronutrients and lipids [5]. Many researches have been carried out to improve the biogas production performance by applying co-digestion of food waste with other substrates [6–10], with different reactor configurations [11], or the substrate pre-treatments [12,13]. However, almost no research has been conducted with the co-digestion of food waste and domestic wastewater. The anaerobic treatment of domestic wastewater is feasible [14] but cannot be digested alone due to its unbalanced carbon to nitrogen (C/N) ratio [15]. In comparison, when the domestic wastewater is mixed with such easily degradable substrates as food waste, it is suitable for the anaerobic co-digestion [16].

Food waste has a complex composition, made of carbohydrates,

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Nomenclature

AD	Anaerobic digestion
COD	Chemical oxygen demand (mg/L)
DWW	Domestic wastewater
FW	Food waste
FWW	Food wastewater
HRT	Hydraulic retention time
LCFAs	Long chain fatty acids (mg/L)
OLR	Organic loading rate (g COD/L/d)
SCFAs	Short chain fatty acids (mg/L)
TN	Total nitrogen (mg/L)
TP	Total phosphorus (mg/L)
TSS	Total suspended solids (mg/L)
UASB	Upflow anaerobic sludge blanket
VSS	Volatile suspended solids (mg/L)

cellulose, proteins, and lipids. Although lipids have the higher theoretical methane yield (0.99 L CH_4/g) compared to proteins (0.63 L CH_4/g) and carbohydrates (0.42 L CH_4/g) [17], the most frequent cause for the upflow anaerobic sludge blanket (UASB) reactor failure is attributable to the long chain fatty acid (LCFA) accumulation/adsorption onto the sludge. The accumulation creates a physical barrier and retards the transfer of substrates and products (biogas) to/from the microbial cells [18], promotes sludge flotation and washout, and inhibits the anaerobic microbial activities, mainly methanogenic and aceticlastic organisms, at low concentrations [19]. Linoleate, oleate, and palmitate are the main LCFAs commonly found in raw materials and wastewaters [20], and they can inhibit anaerobic microorganisms (IC_{50}) at over 30 mg/L, 50–75 mg/L, and 1000 mg/L, respectively, at the mesophilic temperature range [21,22]. However, this inhibition is considered reversible [18] and some strategies have been considered to overcome the LCFAs accumulation and to improve the reactor activity performance. Co-digestion [17], adsorbent addition [21], intermittent feeding [23], and microbial consortium adaptation by the LCFAs pulse exposure [24] are commonly applied to the AD of high-lipid wastes.

The LCFAs adsorption is an essential process for the lipids biodegradation during the anaerobic digestion of complex fat containing wastewaters. The initial removal mechanism is the lipid adsorption on the sludge followed by its slower biological degradation through β-oxidation mechanism to generate short chain fatty acids (SCFAs) [24–26]. According to Pereira et al. [27], the optimal specific LCFA content that provided the maximum mineralization rate and an efficient methane production was 1000 mg COD-LCFA g VSS^{-1} when the reactor was operated continuously. In addition, the transformation of oleate to palmitate was considered a non-limiting step in oleate biodegradation [17]. Kim et al. [28] also observed β-oxidation was the rate-limiting step during LCFA degradation and the lag phase was mainly dependent on the substrate (LCFA) concentration. However, when dealing with complex fat containing wastewaters, a non-feeding period would give the necessary time for the biomass to degrade the adsorbed substrate and would definitely contribute to the UASB reactor operation stability. The intermittent feeding, with different feed/feedless periods, was successfully applied to improve the anaerobic digestion of slaughterhouse [29], dairy [22,30,31], and olive mill [32] wastewaters. Since Chinese food is rich in oil, accounting for 22–31% of the food waste dry matter [34], an efficient food waste digestion is required to minimize the LCFAs accumulation and to improve the AD process in terms of biogas production and methane content. There has been no investigation about the application of intermittent feeding during the anaerobic co-digestion of food waste and domestic wastewater for biogas production, which justifies the need for further studies to better evaluate the effectiveness of this strategy for different substrates to promote a stable digestion process.

This work used a mixture of food waste and domestic wastewater to generate renewable energy (biogas) and to study the performance of UASB reactor first operated continuously at the organic loading rate of 2 g COD/L/d. The efficiency of the developed system was evaluated considering the potential inhibition by the LCFAs accumulation and their effects on COD removal and methane content. The application of intermittent mode (48 h feed/48 h feedless) was also investigated at different organic loading rates (2, 3, and 4.5 g COD/L/d) to reduce the accumulation of LCFAs onto sludge to avoid the decrease of reactor activity.

2. Materials and methods

2.1. UASB reactor setup and operation

The anaerobic co-digestion of food waste and domestic wastewater was carried out using an UASB reactor operated under continuous and intermittent modes. The reactor (working volume, 38 L; Fig. 1) had 1.6 m working height and 0.15 m internal diameter. The inside temperature was kept constant to the mesophilic condition (35 ± 1 °C), using water jacket. Nitrogen was purged for 5 min to guarantee the anaerobic environment (dissolved oxygen concentration at ~0.1 mg/L). The reactor was seeded with sludge (10 L) collected from a local wastewater treatment plant between filter pressing and dewatering processes, followed by the continuous feeding of synthetic wastewater (with COD, 500 mg/L; TN, 40 mg/L; and TP, 10 mg/L), similar to the local domestic wastewater, at the hydraulic retention time (HRT) of 10 days and 35 °C to start up the reactor for the sludge maturation/granulation. The biogas and effluent samples were collected from the top (J) and from the effluent tank (G), respectively. After the sludge maturation process was completed, the reactor was continuously fed with food wastewater at the organic loading rate (OLR) of 2 g COD/L/d at 10-day HRT. COD removal, biogas production, and methane content were monitored daily, and when the reactor performance started to decrease, the intermittent feeding (48 h feed/48 h feedless cycle) strategy was applied to see whether the reactor performance could

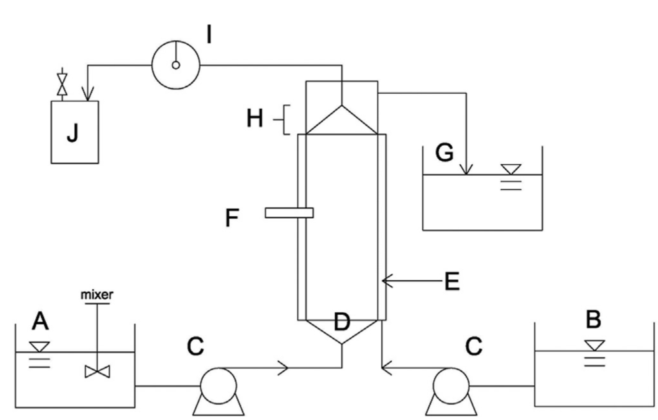

Fig. 1. Schematic of UASB reactor: A) Influent wastewater mixing tank; B) Heating water tank; C) Peristaltic pump; D) Sludge bed; E) Heating jacket; F) pH probe; G) Effluent wastewater tank; H) Three-phase separator; I) Water displacement gas meter; J) Biogas collection tank.