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Anaerobic treatment of source-separated domestic bio-wastes with an improved upflow solid reactor at a short HRT

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ABSTRACT

Anaerobic treatment is the core technology for resource and energy recovery from source-separated domestic bio-wastes. The higher efficiency of an improved upflow solid reactor (IUSR) designed in this study was demonstrated in the treatment of concentrated black water and kitchen waste. The highest methane production of 48 L/person/day was achieved at the hydraulic retention time (HRT) of 7 days, while the other measures of performance at the HRT of 8.3 days were better than at the HRT of 7 or 10 days, achieving a methane production of 43 L/person/day, removal of total chemical oxygen demand (TCOD) of 89%, removal of soluble chemical oxygen demand (SCOD) of 92%, and conversion of chemical oxygen demand (COD) to methane of 71%. It is not recommended to decrease HRT lower than 7 days due to the instability of the initial period. The concentrations of volatile fatty acids (VFAs) in the IUSR were less than 10 mg/L, indicating that the anaerobic process was stable. Sludge bed development showed that sludge bed with high microbial activity was formed in the bottom and that the precipitation zone of effluents formed should preferably occupy 30% of the height of the IUSR. The effluents of the IUSR could be used for irrigation in agriculture in combination with a settling tank accompanied by disinfection to remove solids and pathogens.

Introduction

Anaerobic treatment is one of the most promising treatment technologies for building more sustainable sanitation and is considered to be the core technology for resource and energy recovery from domestic source-separated bio-wastes (Kujawa-Roeleveld et al., 2006; Bernstad and la Cour Jansen, 2012; Larsen et al., 2013), including concentrated black water (CBW), concentrated brown water (BRW) from vacuum toilets, and kitchen waste (KW). However, there are only a few publications reporting the anaerobic treatment of source-separated domestic bio-wastes in various anaerobic reactors, such as the continuous stirring tank reactor (CSTR) (Wendland et al., 2006; Rajagopal et al., 2013), accumulation reactor (AC) (Kujawa-Roeleveld et al., 2003; Elmitwalli et al., 2006), upflow anaerobic sludge blanket (UASB) (de Graaff et al., 2010a, 2010b; de Graaff et al., 2011a, 2011b, 2011c) and UASB-septic tank (UASB-ST) (Kujawa-Roeleveld et al., 2005, 2006; Luostarinen et al., 2007). The CSTR reactor is a simpler reactor with a mixer rather than a high-rate reactor, because there is no retention of high-activity biomass. The simplest and largest reactor is the AC reactor, which is continuously fed and discharged at once when it reaches the required longer retention time. The AC reactor is recommended for more concentrated wastes, like livestock manure, brown

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water and kitchen waste. The UASB is suitable for treating bio-substrates with lower solid concentrations, and thus is only applied to treat concentrated black water, requiring a shorter hydraulic retention time (HRT) and smaller reactor volume. A gas/solid/liquid separator and influent distributor are indispensable for the UASB, resulting in its complicated configuration. The UASB-ST reactor, combining the features of a UASB and ST, can be applied to treat bio-substrates with higher solid concentrations (Fan et al., 2017), like CBW, BRW and KW. Above all, it can be concluded that development of a more efficient and simple reactor should be a priority.

The upflow solid reactor (USR), derived from the UASB, is a simple configuration reactor without a gas/solid/liquid separator and an influent distributor. The USR was first introduced to treat sea kelp (Srivastava et al., 1988), and had a longer solids and microorganism retention time than the UASB, leading to better performance. The USR is known for treating waste with higher total solid (TS) content, *e.g.*, livestock manure (Zhou and Yang, 1996), maize silage (Mumme et al., 2010) and wheat straw (Pohl et al., 2012). It has been reported that the biogas engineering applications of anaerobic digestion reactors operating in the surrounding counties of Beijing were generally dominated by USR technology by 2010 (Chen et al., 2012; Zhou and Zhou, 2013). However, the weaknesses of USR technology cannot be ignored, such as its low biomass transfer efficiency and the problem of encrustation (Wang et al., 2009). USR technology has not been investigated for the practicability of treating source-separated domestic bio-wastes, so it needs further study.

Considering the characteristics of mixtures of CBW and KW, and also the applicability of the USR, the project of this paper is to demonstrate the practicability of an improved upflow solid reactor (IUSR) to treat CBW and KW from vacuum toilets and to identify the optimal operation conditions, such as HRT and chemical oxygen demand (COD) loadings. In particular, the development of the sludge bed in the reactor was evaluated, and the potential utilization of the effluent and sludge was discussed.

1. Materials and methods

1.1. Feedstock and inoculum sludge

The CBW was prepared with feces–urine by collecting the wastes from a dry toilet and adding some urea to make it identical with the BW collected from vacuum toilets in Changshu, Jiangsu Province, China the first demonstration project applying source separation technologies in rural areas. According to the eating habits of residents in China (Zhang and Fu, 2010), KW was made from a mixture of 20% cooked kitchen waste (CKW) and 80% raw kitchen waste (RKW). The CKW was collected from a restaurant, and RKW was made up of 50% pre-prandial waste and 30% fruit waste. The mixed KW was shredded to a size less than 2 mm. Based on the average of 5 L of CBW and 500 g KW per person per day in China, the feedstock used in this study was prepared with KW:CBW = 100 g:1 L, and then was stored at −20°C. Characterization of the CBW, KW and feedstock mixture is given in Tables 1 and 2. Because of the much greater amount of KW generated per person per day (500 g/person/day, China; 200 g/person/day, Germany (Wendland et al., 2006); 150 g/person/day, Singapore (Rajagopal et al., 2013)), the feedstock in our study had a higher concentration of total chemical oxygen demand (TCOD), TS and volatile solids (VS) compared with other research. The NH_3-N content in the feedstock mainly originated from urine. According to Speece (Speece, 1983), most elements were at the optimal concentrations, while it is notable that concentrations of Fe and Co were less than the optimal concentrations (10 mg/L Fe and 0.02 mg/L Co).

Table 1 – Characteristics of concentrated black water (CBW), kitchen waste (KW), raw kitchen waste (RKW), cooked kitchen waste (CKW) and the feedstock.

Parameter	RKW	CKW	KW	CBW	Feedstock (5 L CBW + 500 g KW)
TS (%)	13.85	22.40	9.55	0.92	2.1
VS (%)	12.82	20.61	8.67	0.80	1.8
TCOD (a/b)	103.2[a]	304.5[a]	175.6[a]	13,960[b]	28,554[b]
SCOD (a/b)	45.4[a]	70[a]	54.4[a]	5134[b]	13,043[b]
SCOD/TCOD (%)	43.99	22.99	30.98	36.78	45.68
Total nitrogen (a/b))	1.73[a]	4.43[a]	2.62[a]	597.2[b]	1353.1[b]
NH_3-N (a/b)	0.37[a]	0.07[a]	0.92[a]	196.7[b]	749.5[b*]
TP (mg/L)	–	–	–	–	202.3
Soluble TP (mg/L)	–	–	–	–	163.1
TVFA (g COD/L)	–	–	–	–	1.07
Acetic-acid (g COD/L)	–	–	–	–	0.64
Propionic-acid (g COD/L)	–	–	–	–	0.26
Isobutyric-acid (g COD/L)	–	–	–	–	0.005
Butyric-acid (g COD/L)	–	–	–	–	0.15
Isovaleric-acid (g COD/L)	–	–	–	–	0.009
Valeric-acid (g COD/L)	–	–	–	–	0.007

Abbreviations: TS—total solid, VS—volatile solid, TCOD—total chemical oxygen demand, SCOD—soluble chemical oxygen demand, TN—total nitrogen, TP—total phosphorus, TVFA—total volatile fatty acid.
[a] and [b] are different units, [a] mg/g, [b] mg/L, * adding urea, – not measured.