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ScienceDirect
Bioresource Technology 98 (2007) 1734–1740
BIORESOURCE TECHNOLOGY

Anaerobic on-site treatment of kitchen waste in combination with black water in UASB-septic tanks at low temperatures

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Received 5 May 2006; received in revised form 30 June 2006; accepted 5 July 2006
Available online 28 August 2006

Abstract

Anaerobic on-site treatment of a mixture of black water and kitchen waste (BWKW) was studied using two-phased upflow anaerobic sludge blanket (UASB) septic tanks at the low temperatures of 20 and 10 °C. Black water (BW) was also treated alone as reference. The two-phased UASB-septic tanks removed over 95% of total suspended solids (TSS) and 90% of total chemical oxygen demand (COD_t) from both BWKW (effluent COD_t 171–199 mg/l) and BW (effluent COD_t 92–100 mg/l). Also, little dissolved COD (COD_{dis}) was left in the final effluents (BW 48–70 mg/l; BWKW 110–113 mg/l). Part of total nitrogen (N_{tot}) was removed (BW 18% and BWKW 40%) and especially at 20 °C ammonification was efficient. A two-phased process was required to obtain the high removals with BWKW at 10 °C, while with BW a single-phased process may have sufficed even at 10 °C. BWKW also produced more methane than BW alone. Sludge in phases 1 of BW and BWKW treatment was not completely stabilised after 198 d of operation.

Keywords: Anaerobic wastewater treatment; Black water; Kitchen waste; Low temperature; UASB-septic tank

1. Introduction

Solid, organic kitchen waste (KW) from households requires treatment to reduce its uncontrolled degradation on disposal sites and subsequent greenhouse gas (GHG), odour and nutrient emissions. On densely populated areas, KW can e.g. be source-sorted and transported to centralised treatment, but on rural areas such activity is not supportable in terms of sustainability or cost-efficiency. However, with house- or community-on-site treatment, the need for transportation and subsequent emissions can be minimised.

KW is rich in nutrients and organic material, and easily biodegraded (>90% biodegradability; Veeken and Hamelers, 1999). While composting is often used, it can also be treated anaerobically. Anaerobic treatment of KW provides controlled biodegradation in closed systems, in which the produced biogas (methane) is collected and properly managed, thus recovering the energy content of the material and minimising GHG and odour emissions. Moreover, organic nitrogen is converted to ammonia, which increases the fertilising value of the final product as ammonia is directly usable to plants. Separate collection and anaerobic treatment of KW can be organised, but KW can also be mixed with produced wastewater and treated anaerobically in communities and even in individual houses. As anaerobic treatment endures high organic loading rates (OLR) and grey water (wastewater from bath, wash and kitchen) would only cause dilution (van Lier and Lettinga, 1999), anaerobic treatment of a mixture of KW and black water (BW; from toilets) may form an attractive possibility. Grey water can be treated separately in a simple system, such as sand filter, which can also post-treat the anaerobic effluent, if needed. The amount of biogas produced is usually low but may increase with increasing concentration of the wastewater treated. Biogas can be used in energy production on-site or be upgraded and fed into local gas pipes.

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doi:10.1016/j.biortech.2006.07.022

It can be oxidised (methane) or flared, depending on economical aspects and the amount of biogas produced. Further, anaerobic effluents and sludges containing most of the nutrients can be used as fertilisers on-site or on fields close-by, thus promoting reuse of nutrients, water and organic material (e.g. Lens et al., 2001).

One option for on-site (pre)treatment of a mixture of KW and BW (henceforth referred to as BWKW) is upflow anaerobic sludge blanket (UASB) septic tank. It differs from the conventional septic tank by its upflow operation, which improves the contact between anaerobic sludge and wastewater, and thus also removal of both solid and dissolved organic material (Zeeman and Lettinga, 1999; Luostarinen and Rintala, 2005; Luostarinen et al., in press). Treatment of BWKW has earlier been studied in a single-phased UASB-septic tank at 25 °C (Kujawa-Roeleveld et al., 2005) and in an accumulation system at 20 °C (Kujawa-Roeleveld et al., 2003). However, both studies were performed at relatively high temperatures and with vacuum toilets resulting in concentrated BW. In the northern hemisphere, e.g. in Finland, sewage temperatures may drop as low as 4–10 °C in wintertime and the need for efficient low-temperature treatment is high. For lower temperatures, a two-phased system has been recommended (Zeeman et al., 1997; Lettinga et al., 1999; Luostarinen and Rintala, 2005) due to the long sludge and hydraulic retention times (SRT; HRT) needed.

The objective of this study was to evaluate the feasibility of on-site treatment of BWKW in two-phased UASB-septic tanks at 10 and 20 °C. The main focus was on removal of COD and suspended solids, also somewhat on methane production. An additional two-phased UASB-septic tank treating BW alone was operated as reference.

2. Methods

2.1. Experimental set-up

The experiments were conducted in two laboratory two-phased UASB-septic tanks. The volume of phase 1 was 12 l (height 70 cm, diameter 15 cm) and of phase 2 3 l (height 50 cm, diameter 9 cm). Reactors were placed in a temperature regulated room. Detailed description of the reactors can be found elsewhere (Luostarinen and Rintala, 2005).

2.2. Waste materials and inoculum

Synthetic BW, made of primary sludge from a municipal wastewater treatment plant (Jyväskylä, Finland; stored at 4 °C until used for feed preparation), tap water and toilet paper (4 shredded pieces per 7 l), was prepared aiming at total chemical oxygen demand (COD_t) of 1 g/l, though the composition varied somewhat due to changes in COD_t of primary sludge, obtained every three weeks from the plant (Fig. 2). Average COD_t of BW was 1090 ± 370 mg/l, dissolved COD (COD_{dis}) 82 ± 43 mg/l, total biological oxygen demand (BOD_7) 310 ± 42 mg/l, total nitrogen

Table 1
Composition of the kitchen waste used

Component	% of wet weight	TS (g/l)	VS (g/l)	VS/TS
Potato peels	34	201	187	0.93
Fruit peels	25	187	153	0.81
Coffee + filters	15	310	286	0.92
Bread	10	662	621	0.94
Chicken	5	440	413	0.94
Sausage	5	273	256	0.94
Liver casserole	5	328	290	0.88
Egg shells	1	756	12	0.17
Kitchen waste	100	268	244	0.91

(N_{tot}) 40 ± 14 mg/l and pH 5.8–6.6. KW was average Finnish KW from individual households and prepared according to a survey on KW composition made at the Environmental Science section of University of Jyväskylä (unpublished data; Table 1). It was shredded with a kitchen blender and frozen until feeding. BWKW was prepared in the ratio of their average production in Finnish households: 0.2 kg KW/person/d and 30 l BW/person/d. Average COD_t of BWKW was 2020 ± 490 mg/l, COD_{dis} 380 ± 73 mg/l, total BOD_7 680 ± 120 mg/l, N_{tot} 57 ± 13 mg/l and pH 5.2–6.0. Both BW and BWKW were kept in a container at 4 °C for 1–3 d as an acidogenic step before feeding. Phases 1 were fed twice a day, 30 min at a time, on weekdays (5 times/week) and phases 2 continuously (Masterflex L/S pump, Cole-Parmer Instrument Company, USA). All reactors were inoculated to 50% of their volume with mesophilic digested sewage sludge from a municipal wastewater treatment plant (Jyväskylä, Finland; total solids (TS) 29.6 g/l; volatile solids (VS) 15.6 g/l).

2.3. Batch assays

Batch assays to determine specific methanogenic activity (SMA) of reactor sludges were performed in duplicate 118 ml serum bottles. Each SMA batch received 2 g VS/l of sludge and either no substrate or acetate (sodium acetate 2 g COD/l, pH 7.1). Methane production of the batches with no substrate was subtracted from the results with acetate and the SMA was calculated from the steepest slope of the methane production curve. Another set of batches was prepared with 40 ml of sludge alone (duplicates) to study methane yields and sludge stability. Initial pH was 7.2 in all batches. Detailed description of batch assays can be found in Luostarinen and Rintala (2005).

2.4. Analyses

COD, N_{tot}, ammonium nitrogen (NH_4^+), TS, VS, total and volatile suspended solids (TSS, VSS), BOD_7 and total phosphorous (P_{tot}) were analysed as previously described in Luostarinen and Rintala (2005). COD_t was measured from raw samples. Suspended solids COD (COD_{ss}) was obtained by subtracting paper filtered (S&S 595 1/2)