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Effect of temperature on anaerobic treatment of black water in UASB-septic tank systems

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Abstract

The effect of northern European seasonal temperature changes and low temperature on the performance of upflow anaerobic sludge blanket (UASB)-septic tanks treating black water was studied. Three UASB-septic tanks were monitored with different operational parameters and at different temperatures. The results indicated the feasibility of the UASB-septic tank for (pre)treatment of black water at low temperatures with respect to removal of suspended solids and dissolved organic material. Inoculum sludge had little effect on COD_{ss} removal, though in the start-up phase some poorly adapted inoculum disintegrated and washed out, thus requiring consideration when designing the process. Removal of COD_{dis} was at first negative, but improved as the sludge adapted to low temperature. The UASB-septic tank alone did not comply with Finnish or Dutch treatment requirements and should therefore be considered mainly as a pre-treatment method. However, measuring the requirements as $mg COD l^{-1}$ may not always be the best method, as the volume of the effluent discharged is also an important factor in the final amount of COD entering the receiving water bodies.

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

1. Introduction

Domestic wastewater can be divided into different streams according to their origin. Generally two streams are distinguished: concentrated – black water from toilets (faeces, urine and flushing water) and diluted – grey water from bath, wash and kitchen (Henze and Ledin, 2001). Most of the organic material, nutrients and pathogens in domestic wastewater are in black water (51% of COD, 91% of nitrogen, 78% of phosphorus; Terpstra, 1999), making its treatment of the greatest importance. Moreover, treatment of more concentrated wastewater decreases the reactor size needed, therefore reducing manufacturing costs and space requirements (Lettinga et al., 2001). Recovery and reuse of the effluent may also be promoted if black water is separated from the more diluted streams (Otterpohl, 2001) and house- or community-on-site treatment systems are used. On-site treatment systems are needed in rural areas due to special circumstances such as low population density, and especially in developing countries, due to their cost-efficiency and ease of use. Average characteristics of domestic wastewater, black water and grey water are presented in Table 1.

Anaerobic wastewater treatment is considered sustainable (Lettinga, 1996; Hammes et al., 2000) and suitable for on-site treatment (Zeeman and Lettinga, 1999) due to its low energy consumption, small space requirement and relatively simple reactor design.

In the northern European climate, wastewater temperatures change with the seasons: in the summer the temperature can increase up to 20 °C, but in the winter, temperatures as low as 4 °C are possible. Temperature is an important factor in anaerobic treatment of domestic wastewater: the higher the temperature, the higher the conversion rates.

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Table 1
Average characteristics of domestic wastewater, black water and grey water from conventional flush toilets (Henze and Ledin, 2001)

Parameter ($mg\,l^{-1}$)	Domestic wastewater	Black water	Grey water
BOD	115–400	300–600	100–400
COD	210–740	900–1500	200–700
Total N	20–80	100–300	8–30
Total P	6–23	40–90	2–7

Slow hydrolysis and accumulation of suspended solids present in domestic wastewater may decrease the methanogenic activity of sludge at low temperatures, which in turn may deteriorate the process. Suspended solids can also cause formation of scum layers and sudden washout of sludge, if they are only accumulated and not stabilised within the reactor. Long hydraulic and sludge retention times (HRT, SRT) and relatively low organic loading rates (OLR) are therefore needed (Zeeman and Lettinga, 1999).

The UASB-septic tank ($UASB_{ST}$) is a promising alternative for house-on-site treatment of domestic wastewater. Unlike the conventional septic tank (Polprasert et al., 1982; Philippi et al., 1999), it is used in an upflow mode, improving the contact between wastewater and sludge, and thus resulting in better physical removal of suspended solids and biological removal of dissolved compounds (Zeeman et al., 2001). As most of the organic material in the wastewater is already removed in the $UASB_{ST}$, possible post-treatment (nutrient and/or pathogen removal) becomes simpler and the operating life of the post-treatment system (e.g. sand filter) may be prolonged. Moreover, the aim of the $UASB_{ST}$ is not only to accumulate and to stabilise the sludge within the reactor, but also to convert dissolved solids (Zeeman et al., 2001). $UASB_{ST}$ have been studied previously in tropical climate conditions (Lettinga et al., 1993), but only a few results have been published for northern European climate conditions (Bogte et al., 1993; Luostarinen and Rintala, 2005).

At low temperatures, biogas production in upflow reactors is low and does not provide enough mixing. Poor mixing can cause channelling of wastewater through the sludge bed, thus decreasing removal efficiency, and formation of gas pockets, which in turn may lead to incidental lifting of large sludge aggregates and pulse-like eruption of gas from these areas (Mahmoud et al., 2003). A sufficient upflow velocity is, therefore, needed to mix the reactor contents and to provide good contact between the wastewater and the sludge (van Lier et al., 1997). If upflow velocity cannot be increased, mechanical mixing may be needed. On the other hand, high biogas production as well as excessively high upflow velocity may lead to detachment of already captured solids (Mahmoud et al., 2003).

In this study, the effect of northern European seasonal temperature changes and low temperature on the performance of $UASB_{ST}$ treating black water was studied. For this, the 1st year operation of a $UASB_{ST}$ system operated at seasonal temperatures was compared to the present results, obtained after 13 years of operation. In addition, results from a $UASB_{ST}$ at a constant 15 °C inoculated with sludge from the above-mentioned system and from a $UASB_{ST}$ at a constant 25 °C with no inoculation were used as comparisons.

2. Methods

2.1. Reactor

Experiments were conducted at the Experimental Hall of the Sub-Department of Environmental Technology at Wageningen University, the Netherlands, using three $UASB_{ST}$ treating black water (Figs. 1 and 2). The 1.2 m^3 $UASB_{ST}$ monitored in the 1st and 13th years of operation (Fig. 1) was located in an underground concrete cellar outside the Experimental Hall and was made of steel plate with internal structures made of PVC. The flow to the system varied somewhat, since it received black water from 1 to 2 persons during the 1st year of operation and from 3–4 persons during the 13th year (one quantum per person per day including one portion of faeces and five portions of urine with six portions of flush). The system was originally inoculated (1st year) with 100 l of granular methanogenic sludge from a paper mill and was nearly full of sludge at the beginning of the 13th year of operation. Black water from three conventional flush toilets was chopped with a shredding pump before feeding to the reactor through an interceptor tank with a volume of 18 l. When the tank was full, 12 l of black water was pumped into the reactor. Effluent was collected into a tank from which it was pumped further to a local wastewater treatment plant.

The second $UASB_{ST}$ (volume 0.2 m^3; Fig. 2) was inoculated with 80 l of sludge from the 1.2 m^3 system. The 1st year operation of the 0.2 m^3 system was performed at a constant temperature of 15 °C. The third $UASB_{ST}$ was similar in construction but received no inoculation and was started-up at a constant temperature of 20 °C. The temperature was increased to 25 °C after 17 weeks from the start-up (henceforth the system will be referred to with constant 25 °C). The flow to the two 0.2 m^3 systems was exactly one quantum of black water per person per day, flush volume of the vacuum toilet being approximately 1 l. The black water was first collected into a 10 l equalisation tank, from which it was pumped with a shredding pump to a pressure release vessel on top and transported by gravity to the bottom of the system.

2.2. Analyses

The performance of the 1.2 m^3 $UASB_{ST}$ was monitored for 52 weeks during the 1st year and for 13 weeks during the 13th year of operation, while the two 0.2 m^3 $UASB_{ST}$ were monitored for 51 (15 °C) and 47 (25 °C) weeks from the start-up. Grab samples of influent and effluent were analysed for total COD, suspended solids COD and dis-