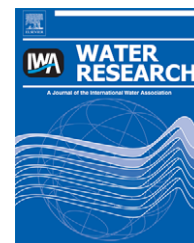


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Long term partial nitrification of anaerobically treated black water and the emission of nitrous oxide

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ARTICLE INFO

Article history:

Received 13 October 2009

Received in revised form

21 December 2009

Accepted 22 December 2009

Available online 4 January 2010

Keywords:

Black water

Partial nitrification

Nitrous oxide emission

Autotrophic nitrogen removal

ABSTRACT

Black water (toilet water) contains half the load of organic material and the major fraction of the nutrients nitrogen and phosphorus in a household and is 25 times more concentrated, when collected with a vacuum toilet, than the total wastewater stream from a Dutch household. This research focuses on the partial nitrification of anaerobically treated black water to produce an effluent suitable to feed to the anammox process. Successful partial nitrification was achieved at 34 °C and 25 °C and for a long period (almost 400 days in the second period at 25 °C) without strict process control a stable effluent at a ratio of 1.3 NO₂-N/NH₄-N was produced which is suitable to feed to the anammox process. Nitrite oxidizers were successfully outcompeted due to inhibition by free ammonia and nitrous acid and due to fluctuating conditions in SRT (1.0–17 days) and pH (from 6.3 to 7.7) in the reactor. Microbial analysis of the sludge confirmed the presence of mainly ammonium oxidizers. The emission of nitrous oxide (N₂O) is of growing concern and it corresponded to 0.6–2.6% (average 1.9%) of the total nitrogen load.

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1. Introduction

Autotrophic nitrogen removal by combined partial nitrification and anammox has gained a lot of interest to treat high strength nitrogen wastewaters containing a low amount of organic carbon (e.g. (Jetten et al., 1999); (Kartal et al., 2004)).

New sanitation concepts are based on separation at source of household wastewater streams (e.g. black water (faeces and urine), grey water, or urine and brown water (faeces)) and have a large potential to recover resources like energy, nutrients and water (Otterpohl et al., 1999; Zeeman and Lettinga, 1999).

Previous research showed that concentrated black water, collected with vacuum toilets, can be efficiently treated in

a UASB (Upflow Anaerobic Sludge Blanket) reactor at a relatively short hydraulic retention time (HRT) of 8.7 days (results to be published), in a UASB septic tank at a considerably longer HRT of 29 days (Kujawa-Roeleveld et al., 2006) or in a CSTR without separation of solids and liquid (Wendland et al., 2007). In this way the organic material in the black water is converted to methane which is a sustainable energy source. The nutrients are largely conserved in the effluent of the anaerobic treatment step and the effluent should be further treated before discharging it to surface waters. Autotrophic nitrogen removal was selected to remove nitrogen compounds from the anaerobic effluent. The main fraction of the organic material in black water was converted to methane in the

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doi:10.1016/j.watres.2009.12.039

anaerobic treatment step, and therefore the anaerobic effluent has too low COD/N ratio (only 1–2) to achieve sufficient heterotrophic denitrification. Furthermore from an energy and costs perspective autotrophic nitrogen removal is preferred over direct recovery (Mulder, 2003; Wilsenach et al., 2003).

In the nitrification-anammox process the ammonium, the main form of nitrogen in black water, is first partially oxidized to nitrite (partial nitrification). Subsequently ammonium ($\text{NH}_4\text{-N}$) and nitrite ($\text{NO}_2\text{-N}$) are converted to nitrogen gas by anaerobic ammonia oxidizers (anammox). These processes can be combined in one reactor nitrification-anammox process where anammox organisms grow in oxygen-free zones. The second option is to separate the two processes in two reactors (van der Star et al., 2007). Partial nitrification can be achieved by selecting a short sludge retention time (SRT) at elevated temperatures (30–40 °C) resulting in the wash-out of nitrite oxidizers (the SHARON process, (Hellings et al., 1998)). Other selection mechanisms have been reported as well, including inhibition by low oxygen concentrations and by high concentrations of free ammonia and nitrous acid. However, the inhibition mechanisms of free ammonia and nitrous acid and potential adaptations of nitrite oxidation are still not fully understood (Fux et al., 2003).

Anaerobically treated source-separated black water (5 L/p/d, (Meulman et al., 2008)) is about 25 times more concentrated than the total wastewater stream from a Dutch household (124 L/p/d, (Kanne, 2005)). Furthermore it has higher concentrations (1–1.5 gN/L and 1.5–2 gCOD/L) compared to sludge liquors (0.6–1 gN/L and 0.1–0.8 gCOD/L) which has been researched for the application of nitrification-anammox process to upgrade wastewater treatment plants (Hellings et al., 1998; Caffaz et al., 2006).

The emission of nitrous oxide (N_2O) during wastewater treatment is of growing concern (Kampschreur et al., 2009a). Nitrous oxide is an important greenhouse gas as it has a much stronger effect (300-fold) than carbon dioxide. Furthermore, nitrous oxide also has a large biological effect on organisms and humans (IPCC, 2001). Kampschreur et al. (2008) detected N_2O emission during full-scale reject water treatment by the two reactor nitrification-anammox process. Emission of N_2O in new sanitation concepts will negatively influence the sustainability and should therefore be avoided.

The aim of this study was to investigate the long term partial nitrification of the anaerobically treated concentrated black water at 25 °C to achieve an influent suitable for the anammox process. Furthermore the possible emission of nitrous oxide (N_2O) was investigated and the mechanisms to achieve partial nitrification of ammonium to nitrite without nitrate formation are discussed.

2. Material and methods

2.1. Anaerobically treated black water

The liquid effluent of a UASB reactor treating concentrated black water (results to be published) was used as influent for the partial nitrification reactor (Fig. 1). The UASB effluent contained 1.5 g $\text{NH}_4\text{-N/L}$ (sd 0.19) and 2.4 gCOD/L (sd 0.84).

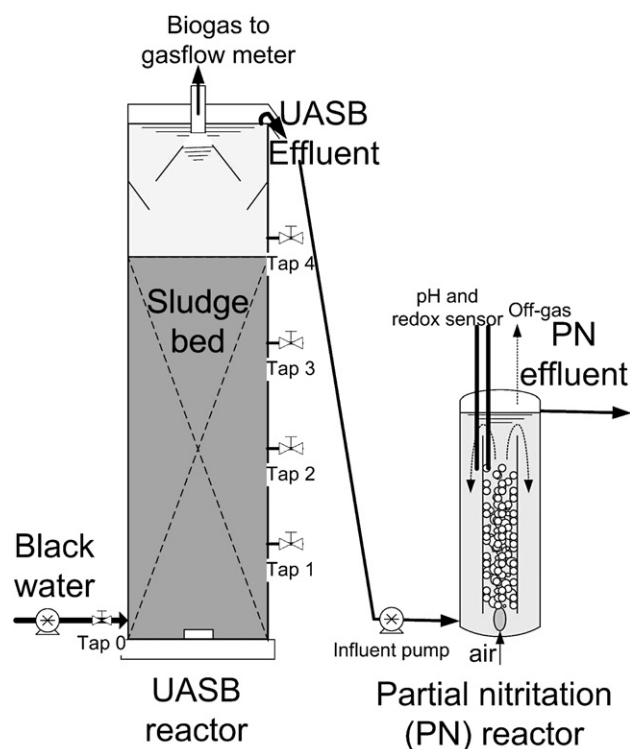


Fig. 1 – Schematic drawing of the reactors used for treatment of black water.

2.2. Partial nitrification reactor

The partial nitrification reactor was a continuous reactor without intentional biomass retention. The reactor had a volume of 3.2 L, a HRT of 1.3 days and was operated at 34 °C for 231 days. Efficient mixing of reactor contents was provided by an air-lift and at the top the reactor was overflowing. Air was supplied at the bottom at a flow rate of 1.3 L/min, maintaining an oxygen concentration above 2 mg/L and checked daily offline with a portable Hach LDO HQ10 DO meter. Temperature in the water jacketed reactor was controlled by means of a thermo stated water bath (Haake DC10/K10). When the pH exceeded 7.7, automatic 0.1 M HCl addition was applied until the pH reached a value of 7.5. Nitrifying sludge from the SHARON reactor at wastewater treatment plant Zwolle (NL) was used as inoculum (3 L, 0.5 gVSS/L). Because the inoculum was acclimated to lower ammonium concentrations (500 mg $\text{NH}_4\text{-N/L}$, personal communication wastewater treatment plant Zwolle, June 2007), the UASB effluent initially was diluted with tap water to lower the ammonium concentration. The sludge immediately started to convert ammonium to nitrite and after a stable conversion for about a week, the ammonium concentration was increased in steps by decreasing the dilution of the UASB effluent by 3, 2, 1.5 times. From day 50 onward the UASB effluent was no longer diluted. At day 231 the reactor volume was increased to 6.1 L and the temperature was reduced in steps of 1–2 °C every 7 days from 34 °C to 25 °C. This caused an increase in pH and less ammonium conversion to nitrite. When the pH increased to values higher than 7.5, the HRT was increased by reducing the flowrate in steps of 0.14 L/d (0.1 mL/min). From day 288–678

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