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Nitrogen removal from on-site treated anaerobic effluents using intermittently aerated moving bed biofilm reactors at low temperatures

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ABSTRACT

On-site post-treatment of anaerobically pre-treated dairy parlour wastewater ($DPWW_e$; 10 °C) and mixture of kitchen waste and black water ($BWKW_e$; 20 °C) was studied in moving bed biofilm reactors (MBBR). The focus was on removal of nitrogen and of residual chemical oxygen demand (COD). Moreover, the effect of intermittent aeration and continuous vs. sequencing batch operation was studied. All MBBRs removed 50–60% of nitrogen and 40–70% of total COD (COD_t). Complete nitrification was achieved, but denitrification was restricted by lack of carbon. Nitrogen removal was achieved in a single reactor by applying intermittent aeration. Continuous and sequencing batch operation provided similar nitrogen and COD removal, wherefore simpler continuous feeding may be preferred for on-site applications. Combination of pre-treating upflow anaerobic sludge blanket (UASB) - septic tank and MBBR removed over 92% of COD_t, 99% of biological oxygen demand (BOD_7), and 65–70% of nitrogen.

1. Introduction

Untreated or insufficiently treated wastewaters cause several problems, such as eutrophication, oxygen consumption, and toxicity, when discharged to the environment. New Finnish legislation concerning wastewater treatment outside centralised sewage network and treatment plants (Government Decree 542/2003) requires removal of minimum 90% of organic matter (as biological oxygen demand, BOD_7), 85% of phosphorous, and 40% of nitrogen from the produced wastewaters. This means considerable enhancement of wastewater treatment in rural Finland and need for house- or community-on-site wastewater treatment is high.

Anaerobic treatment efficiently removes organic matter from wastewaters also at low temperatures (as reviewed by Lettinga et al., 2001), and upflow anaerobic sludge blanket (UASB)-septic tank provides a cost-effective, simple, and efficient option for on-site anaerobic wastewater treatment (Bogte et al., 1993; Lettinga et al., 1993; Zeeman and Lettinga, 1999; Luostarinen and Rintala, 2005a). Anaerobic treatment has, however, limited capacity to remove nitrogen, and a combination of anaerobic and aerobic processes is needed to achieve complete nitrogen removal. It may be beneficial to utilise the fertilising value of anaerobic effluents as such (e.g. Lens et al., 2001), but as this is not always possible, post-treatment to remove nitrogen may be required. As chemical

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precipitation of phosphorous is relatively simple to integrate into treatment processes, the present interest is mostly on nitrogen removal.

Anaerobic pre-treatment may be beneficial to biological nitrogen removal (Elmitwalli et al., 2001; Kalyuzhnyi et al., 2003) due to efficient removal of organic matter and dissolution of particulate organic matter, which may enhance nitrification due to less competition between carbon-utilising heterotrophic micro-organisms and autotrophic nitrifiers (e.g. Metcalf and Eddy, 1991). This may be more pronounced at low temperatures as more dissolved organic matter is retained in the anaerobic effluent for denitrifying micro-organisms (Kalyuzhnyi et al., 2003). It is, therefore, noteworthy that the anaerobic pre-treatment should not remove all carbon, as it is still needed for denitrification during post-treatment (Elmitwalli et al., 2001; Kalyuzhnyi et al., 2003). Instead of traditional nitrification–denitrification, partial nitrification and anoxic ammonia oxidation (anammox) could also be applied (as reviewed by Jetten et al., 2002). In this study, nitrification–denitrification system was chosen due to long experience in larger scale applications and its management. It is also often used in on-site applications.

Moving bed biofilm reactor (MBBR, also known as suspended carrier biofilm process; e.g. Welander et al., 1997; Suvilampi et al., 2003; Wang et al., 2005) has been found suitable for treatment of various wastewaters, such as dairy wastewater (Rusten et al., 1994; Andreottola et al., 2002), and municipal wastewater (Ødegaard et al., 1994; Rusten et al., 1994, 1995, 1997). They have also been applied at low temperatures (3–20 °C) with little temperature dependency (Ødegaard et al., 1994; Welander et al., 1997; Welander and Mattiasson, 2003). Moreover, sequencing batch operation of MBBR has been attempted (Pastorelli et al., 1997, 1999; Helness and Ødegaard, 2001). Despite many studies, MBBR has not apparently been applied as post-treatment to anaerobic wastewater treatment, and the only anaerobic effluent thus far treated with MBBR seems to be wastewater from dewatering digested biowaste (Comett-Ambriz et al., 2003; Fux et al., 2004).

For nitrogen removal, MBBRs have usually been applied in series with aerobic (nitrifying) and anoxic/anaerobic (denitrifying) units in separate reactors. However, with other processes, such as immobilised-cell reactor (Chen et al., 2002) and activated sludge (Sasaki et al., 1996; Villaverde et al., 2001), complete nitrogen removal has been accomplished in a single reactor with alternating aerobic and anoxic phases, i.e. intermittent aeration. Such a process reduces both construction and operational costs and simplifies the treatment system (Villaverde et al., 2001) making it more appealing to on-site wastewater treatment.

The objective of this study was to investigate the feasibility of MBBR for on-site post-treatment of anaerobic effluents from two-phased UASB-septic tanks. The focus was on removal of nitrogen and residual chemical oxygen demand (COD). Different operational schemes were chosen to discover the most efficient, reliable, and cost-efficient process parameters enabling nitrogen removal in one reactor. The anaerobically pre-treated wastewaters were dairy parlour wastewater (referred to as $DPWW_e$; 10 °C) and a mixture of black water and kitchen waste (referred to as $BWKW_e$; 20 °C).

2. Materials and methods

2.1. Experimental set-up

The experiments were conducted using four laboratory MBBRs with a volume of approx. 2 l each (made of PVC; height 70 cm; diameter 11 cm). Cylindrical polyethylene carriers (cross inside and longitudinal fins outside) with 10 mm diameter, density of 150 kg/m^3, and specific biofilm surface area of 500 m^2/m^3 (Anoxkaldnes, Sweden) were added and occupied 50% of reactor volume. All reactors were covered with aluminium foil to prevent evaporation. The flow to each reactor was approx. 1 l/d. Effluents were discharged into separate containers, except with sequencing batch operated reactor, in which effluent was drawn by pump. Aeration was provided with aquarium aerators (Rena 100, USA).

2.2. Reactor operation, wastewaters, and inocula

Two MBBRs (R1, R2) were continuously fed (Masterflex L/S pump, Cole-Parmer Instrument Company, USA) with $DPWW_e$ and started up with continuous aeration (dissolved oxygen (DO) of 9 mg/l to ensure nitrification; Table 1). On day 45, intermittent aeration was initiated with R2 in a cycle of 0.5 h on /2.5 h off (DO 9 mg/l during aeration, decreasing to 2 mg/l during no aeration). No mechanical mixing was provided. R1 and R2 were inoculated with activated sludge from a municipal wastewater treatment plant (Savonlinna, Finland) with biological nitrogen removal. Sodium bicarbonate ($NaHCO_3$) was added as 4 g/l buffer solution in necessary amounts to increase reactor pH from 6.4 or less to 7.0. Operational temperature was 10 °C.

Two other MBBRs (R3, R4) were fed with $BWKW_e$ with intermittent aeration of varying cycles (Table 1). R3 was continuously fed (Masterflex L/S pump, Cole-Parmer Instrument Company, USA) with four aeration cycles per day. During periods with no aeration, mixing was provided with magnetic stirrers (Hanna HI-180, Italy; days 0–39: 150 rpm; days 40–76: 75 rpm). R4 was operated in a sequencing batch mode using two membrane pumps (Solenoid Dosing ProMinent Beta 4, USA) with 8-h-cycles consisting of fill, aeration, no aeration (mixing), settling, and draw. Fill and draw took 30 min each, while the duration of aeration, no aeration, and settling varied (Table 1). Anoxic phase was assumed to start once DO was 1.0 mg/l (30–45 min after aeration was switched off). Both R3 and R4 were inoculated with nitrifying activated sludge from a municipal wastewater treatment plant (Jyväskylä, Finland). Sodium acetate (CH_3COONa) was used as external carbon source while testing the effect of carbon addition on denitrification. Operational temperature was 20 °C.

Anaerobic pre-treatment of the original DPWW and BWKW using two-phased UASB-septic tanks has been published in detail elsewhere (DPWW, Luostarinen and Rintala, 2005a; BWKW, Luostarinen and Rintala, 2005b). Table 4 provides a short summary of the anaerobic pre-treatment during MBBR operation.

2.3. Batch assays

A set of batch assays was established to study the effect of anoxic/anaerobic period and mixing on nitrogen removal in