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Operation and model description of a sequencing batch reactor treating reject water for biological nitrogen removal via nitrite

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Abstract

The aim of this study was the operation and model description of a sequencing batch reactor (SBR) for biological nitrogen removal (BNR) from a reject water (800–900 mg NH_4^+–N L^{-1}) from a municipal wastewater treatment plant (WWTP).

The SBR was operated with three cycles per day, temperature 30 °C, SRT 11 days and HRT 1 day. During the operational cycle, three alternating oxic/anoxic periods were performed to avoid alkalinity restrictions. Oxygen supply and working pH range were controlled to achieve the BNR via nitrite, which makes the process more economical. Under steady state conditions, a total nitrogen removal of 0.87 kg N $(m^3\ day)^{-1}$ was reached.

A four-step nitrogen removal model was developed to describe the process. This model enlarges the IWA activated sludge models for a more detailed description of the nitrogen elimination processes and their inhibitions. A closed intermittent-flow respirometer was set up for the estimation of the most relevant model parameters. Once calibrated, model predictions reproduced experimental data accurately.

Keywords: Denitrification; Modelling; Nitrification; Nitrite; Reject water; Respirometry; Sequencing batch reactor; Wastewater treatment

1. Introduction

In Wastewater Treatment Plants (WWTPs), the supernatant from centrifugation of anaerobically digested sludge (reject water) contains up to 25% of the total nitrogen load in a flow, and it is usually returned to the head of the sewage treatment works (Macé and Mata-Álvarez, 2002). Biological nitrogen removal (BNR) from this wastewater (800–900 mg NH_4^+–N L^{-1}) can be achieved in the existing WWTP. An efficient alternative is the use of a sequencing batch reactor (SBR) for the treatment of this highly loaded water, since nitrogen removal efficiencies of more than 90% have been reported (Arnold et al., 2000; Rostron et al., 2001).

The BNR process is divided into two steps: the oxidation of ammonium to nitrate (nitrification) and the nitrate reduction to nitrogen gas (denitrification). Nitrification is defined as a two-step process, where ammonium is firstly oxidized to nitrite (nitritation, Eq. (1)) and subsequently nitrite is oxidized to nitrate (nitratation, Eq. (2)).

$$NH_4^+ + 3/2O_2 \rightarrow NO_2^- + 2H^+ + H_2O \quad \text{(Ammonium oxidizing biomass)} \tag{1}$$

$$NO_2^- + 1/2O_2 \rightarrow NO_3^- \quad \text{(Nitrite oxidizing biomass)} \tag{2}$$

Denitrification is then the reduction of NO_3^-–NO_2^- (Eq. (3)) and further on to N_2 (Eq. (4)) by the catabolism of heterotrophic bacteria. This process is carried out under anoxic conditions and with a biodegradable carbon source, such as acetate, as electron donor.

$$4NO_3^- + C_2H_4O_2 \rightarrow 4NO_2^- + 2CO_2 + H_2O \tag{3}$$

$$8NO_2^- + 3C_2H_4O_2 + H_2O \rightarrow 4N_2 + 8OH^- + 6CO_2 \tag{4}$$

Some authors (Abeling and Seyfried, 1992; Hellinga et al., 1999; Wett and Rauch, 2003) have discussed the beneficial

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effects of performing the BNR process via nitrite, since it suggests a saving of 25% of the aeration costs and 40% of the external carbon source needed during denitrification, as well as a reduction in the amount of sludge produced. Many ways have been described in literature to achieve the BNR process via nitrite. Anthonisen et al. (1976) determined the effect of ammonia (NH_3) and nitrous acid (HNO_2) concentration upon the ammonium oxidation and the nitrite oxidation kinetics. These authors demonstrated that nitrite oxidizing biomass (NOB) is inhibited at concentrations higher than 0.2–2.8 mg $HNO_2\,L^{-1}$ and/or 0.1–1.0 mg $NH_3\,L^{-1}$, while ammonium oxidizing biomass (AOB) is inhibited by unionised ammonia concentrations higher than 10–150 mg $NH_3\,L^{-1}$. Wett and Rauch (2003) corroborated these experimental results and experienced a partial inhibition of nitrite oxidizers in a SBR treating extremely ammonium loaded landfill leachate and reject water. Grunditz and Dalhammar (2001) also reported that NOB kinetics are more affected by basic values of pH than AOB. Furthermore, many authors (Guisasola et al., 2005; Pollice et al., 2002; Ruiz et al., 2003) have reported that, at reduced dissolved oxygen concentrations, ammonium oxidation is favoured over NOB activity due to a greater oxygen affinity for the first step of nitrification. Another technique to achieve the inhibition of NOB consists of the SHARON process (Hellinga et al., 1999). This process is based on the careful selection of a low sludge retention time (SRT) and a high operating temperature (35 °C), which enables the proliferation of AOB and the total wash-out of NOB.

Activated sludge models (Henze et al., 2000) represent the most widespread and successful approach to characterise the nutrient removal process for design and control (Copp et al., 2002; Seco et al., 2004). The biological nature of wastewater treatment processes implies that their model parameters must be determined (model calibration) according to the local situation (Vanrolleghem et al., 1999). Respirometry is the most popular tool used for model calibration and it consists of the measurement and analysis of the biological oxygen consumption under well defined experimental conditions (Rozich and Gaudy, 1992; Spanjers et al., 1998).

On the other hand, the IWA models (Henze et al., 2000) describe nitrification as a single step process, since nitrite does not usually appear as an intermediate product under the typical temperature range and ammonium concentrations of secondary biological reactors from municipal WWTP. However, these models must be modified to describe properly high ammonium loaded wastewater treatments and/or to study the BNR via nitrite.

In this study, a BNR via nitrite strategy in a SBR was implemented for the treatment of a specific reject water (Barcelona Metropolitan Area). Moreover, the SBR working sequence under steady state conditions was characterised by means of a modified version of the IWA ASM models (Henze et al., 2000) previously calibrated using respirometry.

2. Methods

2.1. Lab-scale SBR reactor

The BNR process was carried out in a jacketed lab-scale SBR (3 L). Operating temperature was maintained by means of a heating system (RM6 Lauda). Fill and draw stages were performed by two peristaltic pumps (Cole-Parmer Instrument 7553-85). Air flow inside the reactor was controlled by an electromagnetic valve. External carbon source was added through a peristaltic pump (EYELA Micro Tube Pump MP-3). The SBR was also equipped with a thermocouple, a pH electrode (Crison pH 28) and a DO probe (Oxi 340i, WTW). During anoxic conditions, a mechanical stirrer mixed the contents of the reactor completely. Moreover, the system was controlled and monitored by a computer with an acquisition data card (PCL-812PG), a control box and an interphase card (PCL-743/745) connecting both systems. The computer worked with the *Bioexpert version 1.1x* program.

2.2. Respirometry set-up

A closed intermittent-flow respirometer (Spanjers et al., 1998; Marsili-Libelli and Tabani, 2002) was used to characterise the activated sludge in off-line respirometric batch tests. This device, schematised in Fig. 1, consisted of an aeration vessel (3 L) and a stirred watertight closed respiration chamber (0.250 L). Air flow passed through an humidifier before being introduced into the aeration chamber in order to prevent volume variations linked to water evaporation. A heating system (Haake DC30) was used to maintain the temperature at $T \pm 0.5$ °C in the whole system. The respiration chamber was equipped with a dissolved oxygen probe (Oxi 340i, WTW) and the pH in the aeration vessel was measured with a Crison pH 28 electrode. When the oxygen level dropped below 2 mg $O_2\,L^{-1}$ or the measuring period lasted more than 300 s, the mixed liquor inside the measurement vessel was replaced by pumping aerated mixed liquor from the aeration vessel into the respiration chamber for 75 s, for sufficient time to renew three times its volume. The 4–20 mA signals of both oxygen and pH probes were collected and logged on a PC equipped with the Advantech Genie software package and combined A/D I/O Modules (Adam 4050/ Adam 4520/ Adam 4018). The pH was controlled within a narrow pH setpoint $\pm\Delta$pH region. When the measured pH value did not lie inside the desired region, acid (HCl, 0.2 N) or base (NaOH, 0.2 N) was added by opening an electromagnetic valve for a very short period of time to adjust the pH.

2.3. Substrate and inoculum

Reject water was obtained from a mesophilic anaerobic digester of a WWTP situated in the Barcelona metropolitan area (Spain). This effluent was centrifuged at 2500 rpm to remove suspended solids before its recircula-