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Applications of Anammox based processes to treat anaerobic digester supernatant at room temperature

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ABSTRACT

The supernatant of an anaerobic digester was treated at 20 °C in two systems. The first one is a two units configuration, conformed by two sequencing batch reactors (SBR), carrying out partial nitrification and Anammox processes, respectively. Partial nitrification was achieved by granular biomass with a mean diameter of 3 mm, operating at a dissolved oxygen concentration of 2.7 mg/L. The combined system allowed the removal of nitrogen loading rates around 0.08 g N/(L d).

Afterwards, Anammox biomass was spontaneously developed in the inner core of the nitrifying granules of the SBR and therefore, partial nitrification and Anammox process were carried out in a single unit. Once the stable CANON process was established, a mean nitrogen removal rate of 0.8 g N/(L d) was registered. The settling velocities of the granules ranged from 70 to 150 m/h with sludge volumetric index values lower than 50 mL/g VSS during the whole operation.

1. Introduction

The combination of a partial nitrification followed by the Anammox process, is recommended to remove ammonia from wastewater without biodegradable carbon source. The Anammox process consists of the anaerobic oxidation of ammonia (van de Graaf et al., 1996) using nitrite as electron acceptor according to the stoichiometry described by Strous et al. (1999) (Eq. (1)):

$$NH_4^+ + 1.3NO_2^- + 0.066HCO_3^- + 0.13H^+ \rightarrow 1.02N_2 + 0.26NO_3^- + 0.066CH_2O_{0.5}N_{0.15} + 2H_2O \quad (1)$$

In general it is not common to find effluents with the required composition to be treated via the Anammox process. For this reason several alternatives have been studied to obtain an influent with these characteristics. To reach this objective, half of the ammonium fed has to be converted into nitrite by the ammonium oxidizing bacteria (AOB) and therefore, the oxidation of nitrite to nitrate carried out by nitrite oxidizing bacteria (NOB) has to be avoided. The AOB and NOB are two phylogenetically unrelated groups whose different growth rates and the way this growth rates are affected by parameters like temperature, pH, dissolved oxygen (DO), etc. can be used to outcompete NOB and to uncouple both reaction rates.

Nitrite accumulations have been reported in several systems, for biomass growing in suspension (Blackburne et al., 2008), in biofilm (Garrido et al., 1997) or in aggregates/granules (Kim and Seo, 2006). Several strategies have been used to reach partial nitrification:

(1) Increasing free ammonia concentration working at high pH values and limiting the growth of NOB due to their higher sensitivity to free ammonia inhibition than AOB (Anthonisen et al., 1976).
(2) Decreasing the dissolved oxygen concentration due to the lower oxygen affinity of the NOB compared to AOB (Wiesmann, 1994).
(3) Operating at temperatures above 25 °C since the maximum specific growth rate of the AOB will be higher than that of NOB at these conditions. In fact this is the basis of the SHARON technology which consists of a continuous stirring tank reactor operated a hydraulic retention time of around 1 d and 30 °C to favor the growth of AOB and the washout of the NOB (Hellinga et al., 1998).

In order to apply the partial nitrification and the Anammox processes it is important to take into account that they can be performed in two different units (Sharon–Anammox processes) or in a single one, called by different names, CANON: Completely Autotrophic Nitrogen removal Over Nitrite process (Sliekers et al., 2002), OLAND: Oxygen-Limited Autotrophic Nitrification–Denitrification (Pynaert et al., 2004) or aerobic/anoxic deammonification (Helmer et al., 2001). Under oxygen-limited conditions a co-culture

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of aerobic and anaerobic ammonium oxidizing bacteria can be established in a single unit in a CANON system. In those systems, NOB compete for oxygen with the aerobic AOB and for the nitrite with Anammox bacteria, and thus its growth (and subsequent nitrate production) is prevented. Another reason to maintain low oxygen concentrations is that Anammox bacteria are reversibly inhibited by dissolved oxygen concentration higher than 0.5% of air saturation (Strous et al., 1997).

The main disadvantage of these processes relies on the low growth rate of AOB and Anammox bacteria. To enhance the performance of reactors involving slow growing bacteria, high sludge retention times are mandatory and therefore the attachment of bacteria on a carrier material to develop biofilms or the self-aggregation concept in granules are being applied. Aerobic granulation presents the advantage of excellent settleability of the granules, high biomass retention and high resistance to toxic compounds.

The aim of this work was to test the feasibility of the application of the Anammox process at lower temperatures using both, one and two units configurations. In the two units configuration the partial nitrification process was carried out in a nitrifying granular SBR fed with anaerobic digester supernatant. Once an adequate nitrite/ammonium ratio was obtained, the effluent of the granular SBR was fed to an Anammox SBR and the nitrogen removal process was studied. In the case of the single unit configuration, the previous granular SBR developed Anammox biomass which grew in the inner core of the nitrifying granules and provoked a change in the autotrophic nitrogen removal from a two reactors configuration to one reactor strategy. The maximal nitrogen removal rate achievable was evaluated in this case.

2. Methods

2.1. Reactors description

2.1.1. Granular SBR

A SBR with a working volume of 1.5 L was used. Dimensions of the unit were: height of 465 mm and inner diameter of 85 mm, the height to the diameter ratio being 5.5. The exchange volume was fixed at 50%. A set of two peristaltic pumps was used to introduce the feeding solution (on top of the reactor) and to discharge the effluent (at medium height in the column reactor), respectively. The hydraulic retention time was fixed at 0.25 d. A programmable logic controller Siemens model S7-224CPU controlled the actuations of the pumps and valves, and regulated the different periods of the operational cycle. The duration of the operational cycles was of 3 h distributed according to the scheme described in Fig. 1.

A thermostated bath was installed to control the temperature at 20 ± 1 °C. Air was supplied to the bottom of the reactor by using an air pump to promote the transfer of oxygen into the bulk liquid and to reach a suitable mixing. The concentration of DO in the liquid phase was regulated by changing the ratio of fresh air to recycled air injected in the reactor.

The nitrifying granular biomass operated in this reactor was obtained from heterotrophic aerobic granules by the stepwise decrease of the COD/N ratio in the influent (Mosquera-Corral et al., 2005). The concentration of biomass inside the system at the beginning of this study was of 5 g VSS/L with an average diameter of the granules around 2.8 mm. The reactor was carrying out partial nitrification with a DO concentration around 2 mg/L treating a synthetic wastewater with a specific ammonia oxidation rate of 0.12 g N/(g VSS d).

2.1.2. Anammox reactor

A SBR with an effective volume of 1 L was used to carry out the Anammox process. The SBR was provided with a thermostatic jacket to keep the temperature at 20 ± 1 °C. The pH value was not controlled and remained around 7.5. Complete mixture inside the reactor was achieved with a mechanical stirrer at 100 rpm. Norprene tubing and connections were used to prevent the diffusion of oxygen into the system. The SBR was operated in cycles of 6 h (Fig. 1) according to Dapena-Mora et al. (2004) and controlled with a programmable logic controller system (CPU224, Siemens). The exchange volume was of 25% and the hydraulic retention time was fixed at 1 d. The effluent from the nitrifying granular SBR was collected and stored in a cold room (4 °C) prior to feed the Anammox reactor.

The used Anammox biomass was developed at 30 °C with synthetic wastewater (Dapena-Mora et al., 2004). The reactor contained a biomass concentration of 1.5 g VSS/L with an Anammox specific activity of 0.28 g N/(g VSS d) at 30 °C.

2.2. Operational strategy

2.2.1. Granular SBR

The nitrifying granular reactor was fed with the supernatant of an anaerobic sludge digester of the WWTP of Lugo (Spain) which was collected every month in 20 L containers and stored in a cold room (4 °C). The composition of the supernatant was: pH 7.5–8.3; NH_4^+ 400–700 mg N/L; total inorganic carbon 300–505 mg C/L and total organic carbon 20–50 mg C/L. Prior to the feeding of the supernatant, the reactor was carrying out the partial nitrification treating a synthetic influent (data not shown). The reactor operation was divided into different periods (Table 1). From period I to IV, the raw wastewater was diluted in a proportion 1:1 with tap

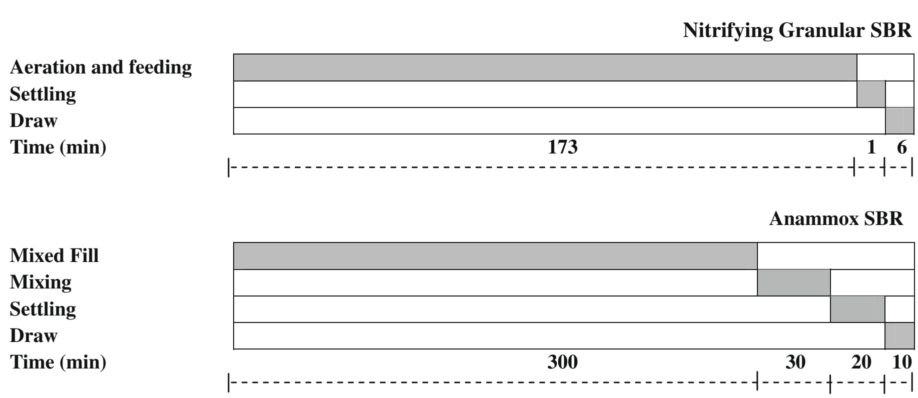

Fig. 1. Distribution of the operational cycles of the nitrifying granular and the Anammox SBRs.