Bioresource Technology 128 (2013) 655–663

Contents lists available at SciVerse ScienceDirect

Bioresource Technology

journal homepage: www.elsevier.com/locate/biortech

Closed-loop control of ammonium concentration in nitritation: Convenient for reactor operation but also for modeling

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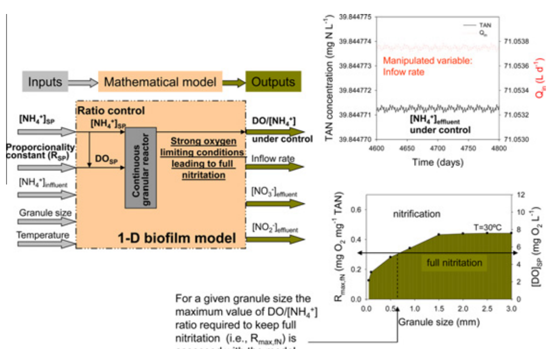
HIGHLIGHTS

- ▶ Nitritation with granular reactor under ratio control was described mathematically.
- ▶ Closed-loop control of ammonium concentration enhance stability of full nitritation.
- ▶ Granules size larger than 1 mm enhances full nitritation.
- ▶ Full nitritation with granular reactors is feasible at low temperatures.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 12 April 2012
Received in revised form 3 September 2012
Accepted 11 October 2012
Available online 23 October 2012

Keywords:
Partial nitrification
Closed-loop control
On-line ammonium measurement
Granular airlift reactor
Nitrogen loading rate

ABSTRACT

A mathematical biofilm model was developed to describe nitritation in aerobic granular reactor operating in continuous mode. The model includes the automatic closed-loop control of ammonium concentration in the effluent. This is integrated in a ratio control strategy to maintain the proportion between the dissolved oxygen (DO) and the total ammonia nitrogen (TAN) concentrations in the reactor effluent at a desired value. The model was validated with a large set of experimental results previously reported in the literature. The model was used to study the effect of DO and TAN setpoints on the achievement of full nitritation, as well as to establish the appropriate required range of the DO/TAN concentration ratio to be applied. Nitritation at 20 °C was tested experimentally and simulated with the model. Additionally, the importance of controlling the TAN concentration was highlighted with different scenarios, in which periodic disturbances were applied mimicking a poor control situation.

1. Introduction

Nitritation is a key process for the correct performance of the biological nitrogen removal via nitrite. When a separate reactor is devoted to nitritation, ammonium concentration in the reactor is of fundamental importance. Ammonium concentration in the reactor affects the conversion of the nitritation reactor because it may provide either ammonium or oxygen limiting conditions (Harremöes, 1978; Çeçen and Gönenç, 1995; Jianlong and Ning, 2004; Bernet et al., 2005; Pérez et al., 2005; Sliekers et al., 2005; Bougard et al., 2006; Guo et al., 2009; Bartrolí et al., 2010, 2011; Brockmann and Morgenroth, 2010; among many others). A second aspect to take into account is the potential inhibition of ammonia-oxidizing bacteria (AOB) and nitrite-oxidizing bacteria (NOB) by free ammonia (FA). Moreover, the following treatment step for complete nitrogen removal via denitrification or anaerobic ammonium oxidation will also benefit from a constant and suitable ammonium concentration in the effluent of the nitritation reactor. What to do to maintain a constant ammonium concentration in

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0960-8524/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.biortech.2012.10.045

the effluent of a nitritation reactor? A basic control strategy to maintain a variable close to a desired reference (known as setpoint value) is to measure it on-line and subsequently apply an action as a function of the difference between the measured value (in this case the ammonium concentration) and the setpoint. This is the basis of a feedback closed-loop control (see Fig. 1A for a block diagram showing the concept). On-line measurement of ammonium concentration is available at a reasonable cost, and in fact, it has been implemented at laboratory and pilot scale nitritation reactors (Bernet et al., 2005; Bougard et al., 2006; Bartrolí et al., 2010; Li et al., 2011). Indeed ammonium concentration is listed among the commonly used measurements performed by instrumentation on full scale wastewater treatment plants (WWTP's) (Olsson, 2012). However, in full-scale installations of SHARON–Anammox process, the loading rate applied to the nitritation reactor was carefully balanced with the available conversion capacity in the Anammox reactor during start-up (van der Star et al., 2007). From a practical point of view, this is often solved with daily off-line measurements of ammonium, nitrite and nitrate concentrations (van der Star et al., 2007). Therefore, full-scale installations will also benefit from an on-line measurement of the ammonium concentration.

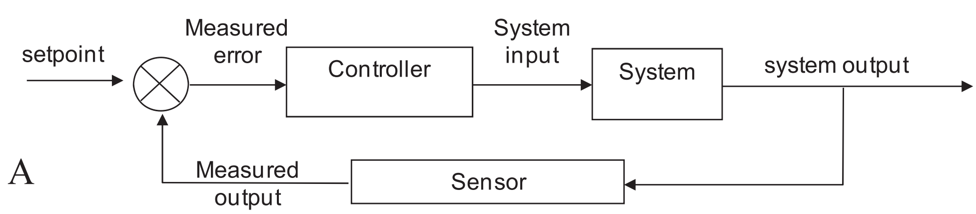
When nitritation is applied to the reject water (a rich ammonium effluent produced in the dewatering of sludge after the anaerobic treatment) the alkalinity is generally adequate to only oxidize 50% of the ammonium (van der Star et al., 2007), actuating implicitly as a regulation of the desired ammonium concentration. However, it is known that operating conditions of the sludge digester, such as the hydraulic residence time, may result in a disturbance of the bicarbonate to ammonium molar ratio, affecting the nitrite:ammonium ratio of the effluent of the nitritation reactor (van Hulle et al., 2010). Consequently, in the SHARON process, the on-line measurement of nitrite:ammonium ratio is considered as essential to gain the desired stability of the subsequent Anammox process (Volcke et al., 2006, 2007).

The indirect control of the ammonium concentration through the on-line measurement of oxygen uptake rate was shown to be crucial for the total and stable washout of NOB when using an activated sludge reactor plus settler configuration for nitritation (Jubany et al., 2009). Similarly, maintaining a high ammonium concentration in the bulk liquid when selecting high activity nitrifiers to enhance nitritation has been reported to be very useful (Chen et al., 2010).

When biofilm reactors have been used for nitritation, the control of ammonium concentration in the effluent has been recognized to be a key variable for the start-up and stability of the process (Bernet et al., 2005; Bougard et al., 2006; Bartrolí et al., 2010). When using sequencing batch reactor operation for nitritation, the ammonium concentration in the effluent has been also identified as a very important condition governing the outcomes of the reactor (Ganigué et al., 2012) and in fact, the in-line measurement of ammonium was used to maintain stable nitritation in the long term (Li et al., 2011).

From the engineering point of view, the control of the ammonium concentration in nitritation reactors (which implicitly means the control of the nitrogen loading rate), presents several interesting advantages, given that:

- Prevents the inhibition of AOB by FA during start-up (Jubany et al., 2009).
- Regulates the inhibition of NOB by FA to achieve a stable washout of NOB from activated sludge reactors with biomass retention (Jubany et al., 2009).



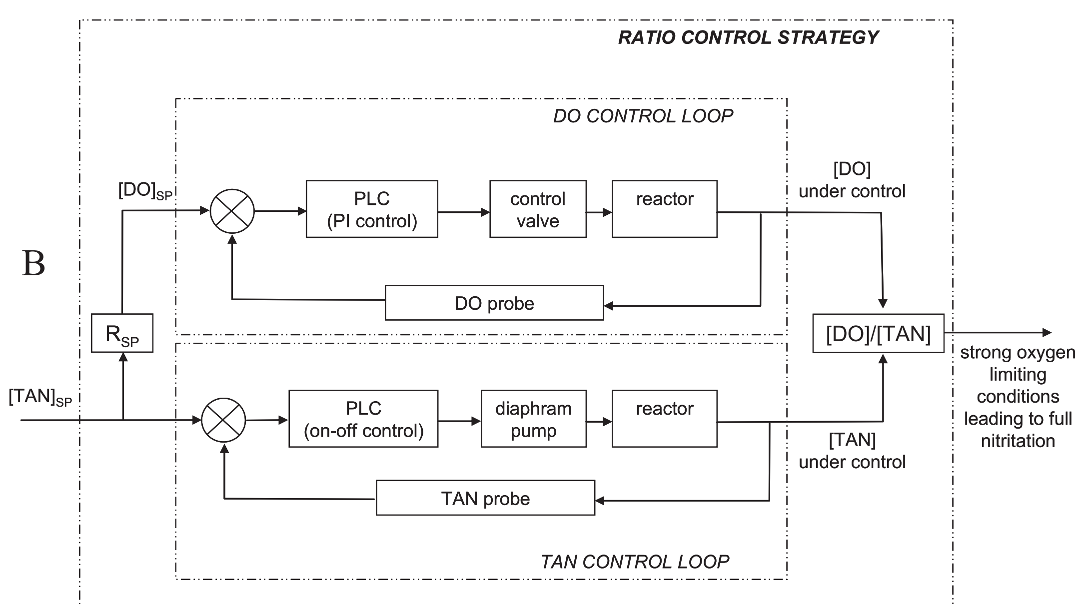


Fig. 1. (A). Basic block diagram of a feedback closed-loop control (Stephanopoulos, 1984). (B).Block diagram of the ratio control strategy to obtain full nitritation in aerobic granular sludge reactors operating in continuous mode (Bartrolí et al., 2010). DO: dissolved oxygen; TAN: total ammonia nitrogen. SP: setpoint. R_{SP}: proportionality constant of the ratio station.