Journal of Environmental Management 218 (2018) 154–164

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Review

Advanced strategies to improve nitrification process in sequencing batch reactors - A review

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ARTICLE INFO

Article history:
Received 29 December 2017
Received in revised form
2 April 2018
Accepted 4 April 2018

Keywords:
Partial nitrification
SBR
ASM
Bending-points
Data-driven models

ABSTRACT

The optimization of biological nitrogen removal (BNR) in sequencing batch reactors has become the aim of researchers worldwide in order to increase efficiency and reduce energy and operating costs. This research has focused on the nitrification phase as the limiting reaction rate of BNR. This paper analyzes different strategies and discusses different tools such as: factors for achieving partial nitrification, real-time control and monitoring for detecting characteristic patterns of nitrification/denitrification as end-points, use of modeling based on activated sludge models, and the use of data-driven modeling for estimating variables that cannot be easily measured experimentally or online. The discussion of this paper highlight the properties and scope of each of these strategies, as well as their advantages and disadvantages, which can be integrated into future works using these strategies according to legal and economic restrictions for a more stable and efficient BNR process in the long-term.

Contents

1. Introduction

Several industries discharge wastewater with high nitrogen concentrations, such as the petrochemical, fertilizer and food industries (Carrera et al., 2003). Nitrogen is mainly presented as ammonia, nitrite and nitrate, which causes dissolved oxygen (DO) depletion (Van Hulle et al., 2010), produces toxicity in aquatic fauna (Pauer and Auer, 2009) and enhances the eutrophication processes

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https://doi.org/10.1016/j.jenvman.2018.04.019
0301-4797/

List of abbreviations

ANN	Artificial neural network
AOB	Ammonia-oxidizing bacteria
ARE	Ammonia removal efficiency
ASM	Activated sludge model
BNR	Biological nitrogen removal
COD	Chemical oxygen demand
DO	Dissolved oxygen
EFuNN	Evolving fuzzy neural network
FA	Free ammonia
FNA	Free nitrous acid
FNN	Fuzzy neural network
GP	Gaussian process
IDP	Iterative dynamic programming
IWA	International water association
MPCA	Multiway principal component analysis
MSC	Moving slope change
NLR	Nitrogen loading rate
NOB	Nitrite-oxidizing bacteria
ORP	Oxidation reduction potential
OUR	Oxygen uptake rate
PID	Proportional-integral-derivative
SBR	Sequencing batch reactor
SOM	Self-organizing map
SQP	Successive quadratic programming
SRT	Sludge retention time
SVM	Support vector machine
WWTP	Wastewater treatment plant

(Wiesmann et al., 2007). Moreover, the ingestion of water with high nitrite/nitrate concentrations might cause methemoglobinemia in infants (Wiesmann et al., 2007) and increase the formation of carcinogenic nitrosamines (Rodríguez et al., 2011b).

A commonly used and economically viable alternative for the treatment of industrial and municipal wastewater is the biological nitrogen removal (BNR) process (Zanetti et al., 2012), which involves two sub-processes: nitrification (aerobic respiration) and denitrification (anoxic respiration). The BNR process can achieve high efficiency, low consumption of external organic matter and low surplus sludge (Boaventura et al., 2001). The operating costs involve energy costs for aeration, reagents like alkaline solution and exogenous chemical oxygen demand (COD) (Yan and Hu, 2009) and costs associated with sludge management (Singh and Srivastava, 2011).

Among the conventional BNR systems used, various reactor configurations are differentiated by the availability of biomass in their interior (Von Sperling, 2007): suspended biomass in the bulk liquid (activated sludge reactors, membrane bioreactors, sequencing batch reactors (SBRs)) or immobilized biomass over an inert support (e.g., polyethylene biodiscs, polyurethane foam (Singh and Srivastava, 2011)) or a granule (trickling filter, submerged aerated biofilter, rotating biological contactor) as well as by their modes of operation: continuous or batch.

The SBR stands out for its flexibility and low installation cost (Marsili-Libelli et al., 2008), in addition to having the advantage of BNR occurring in only one reactor through the sequential development of aerobic (nitrification), anoxic (denitrification) and settling phases (Poo et al., 2006). In a SBR the efficiency and energy consumption in terms of the nitrification and denitrification reactions will depend on environmental conditions (e.g., pH, temperature, DO, oxidation reduction potential (ORP)) and operational ones (e.g., feed pattern, sludge retention time (SRT), cycle length) during each reaction phase. Therefore, all these operating strategies present a series of challenges: 1) reduction of cycle length, 2) minimization of energy costs, 3) stabilization of efficiency on a long-term basis, taking into account the compliance of local legislation for nitrogen removal. In order to reach the proposed objectives, interdisciplinary operating strategies have been designed, including the development of partial nitrification, real-time control, mathematical modeling, data-driven based modeling and artificial intelligence.

In this paper, a review of several strategies applied to produce BNR in SBRs are discussed, focusing mainly on tools used for optimizing nitrification (aerobic phase) as the rate-limiting step in the overall BNR process. This is based on the intrinsic behavior of BNR, where nitrification products are further used as reactants for denitrification (Kirchman, 2012), implying that an efficient nitrification represents the first goal for developing an efficient denitrification. Most of the revised works are mainly based on suspended biomass SBRs, although in some cases the review extends over other reactor configurations.

This article is organized as follows. In Section 2, the concept of BNR through the nitrification-denitrification process and the concept of partial nitrification are introduced. In Section 3, the SBR concept, operation modes and their application to the BNR process are presented. In Section 4, activated sludge models (ASMs) are presented as a tool for dynamic simulation, a state estimator and optimization of BNR processes. In Section 5, a technique called bending-points detection is described, which can reduce operating costs by estimating the phase length for nitrification and denitrification. In Section 6, several data driven-based modeling techniques are introduced, which are able to estimate critical variables of the nitrification-denitrification process, with the aim of monitoring the process, improving efficiency and reducing costs. Finally, in Section 7 conclusions are given.

2. Biological nitrogen removal and partial nitrification

Nitrogen removal through nitrification-denitrification is a widely studied process and is one of the most frequently practiced process for removing nitrogen from wastewaters (Ruiz et al., 2006; Wiesmann et al., 2007). Compared to physical-chemical treatments, it seems to be more effective and relatively cheap (Guo et al., 2010). In nitrification under aerobic conditions, ammonium (NH_4^+) is transformed into nitrite (NO_2^-) by means of ammonia-oxidizing bacteria (AOB) in alkaline conditions. Subsequently, nitrite is transformed into nitrate (NO_3^-) by means of nitrite-oxidizing bacteria (NOB) (Antileo et al., 2006). Afterwards, the denitrification process under anoxic conditions and via easily biodegradable organic matter converts this nitrate into nitrite, then to nitric oxide (NO), then to nitrous oxide (N_2O), and finally to molecular nitrogen (N_2), which is innocuous (Mokhayeri et al., 2008; Rodríguez et al., 2011b).

Since the nitrite is formed and consumed by nitrification and formed again during denitrification, the nitrite oxidation becomes an unnecessary step (Antileo et al., 2006). Hence, the concept of partial nitrification or shortcut biological nitrogen removal emerges as an attractive alternative (Claros et al., 2012).

To carry out nitrite accumulation it is necessary to enhance the activity of the AOB and to selectively reduce/inhibit the activity of the NOB (Guo et al., 2010; Zeng et al., 2009), also called NOB