Water Research 92 (2016) 44–51

Contents lists available at ScienceDirect

Water Research

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

Impact of solids retention time on dissolved organic nitrogen and its biodegradability in treated wastewater

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ARTICLE INFO

Article history:
Received 11 June 2015
Received in revised form
15 January 2016
Accepted 19 January 2016
Available online 22 January 2016

Keywords:
Biodegradable dissolved organic nitrogen
Non-biodegradable dissolved organic nitrogen
Dissolved organic nitrogen
Solids retention time
Wastewater

ABSTRACT

Dissolved organic nitrogen (DON) and its biodegradability in treated wastewater have recently gained attention due to increased regulatory requirements on effluent quality to protect receiving waters. Laboratory scale chemostat experiments were conducted at 9 different solids retention times (SRTs) (0.3, 0.7, 2, 3, 4, 5, 7, 8, and 13 days) to examine whether SRT could be used to control DON, biodegradable DON (BDON), and DON biodegradability (BDON/DON) levels in treated wastewater. Results indicated no trend between effluent DON and SRTs. Effluent BDON was comparable for SRTs of 0.3–4 days and had a decreasing trend with SRT after that. Effluent DON biodegradability (effluent BDON/effluent DON) ranging from 23% to 59% tended to decrease with SRT. Chemostat during longer SRTs, however, was contributing to non-biodegradable DON (NBDON) and this fraction of DON increased with SRT above 4 days. Model calibration results indicated that ammonification rate, and growth rates for ordinary heterotrophs, ammonia oxidizing bacteria and nitrite oxidizing bacteria were not constants but have a decreasing trend with increasing SRT. This study indicates the benefit of high SRTs in term of producing effluent with less DON biodegradability leading to relatively less oxygen consumption and nutrient support in receiving waters.

1. Introduction

Dissolved organic nitrogen (DON) constitutes about 25–80% of total dissolved nitrogen (TDN) in the final effluent of wastewater treatment plants (WWTPs) (Pehlivanoglu-Mantas and Sedlak, 2006; Sattayatewa et al., 2009; Simsek et al., 2012). Effluent DON can be biodegraded to lower weight molecular compounds such as urea, free amino acids, nucleic acids and several uncharacterized labile compounds under certain environmental conditions and eventually to ammonia. Biodegradable DON (BDON) is defined as a fraction of DON that can be ammonified by bacteria (Parkin and McCarty, 1981; Khan et al., 2009; Simsek et al., 2012). DON in surface waters stimulates algal growth and depletes dissolved oxygen (DO) if it undergoes ammonification and nitrification.

WWTPs are one of the main nitrogen suppliers to surface waters. However, there have been limited studies on biodegradability of effluent DON. In the past, removing only ammonia-nitrogen was essential for WWTPs to reduce its toxicity to aquatic organisms. DON in the effluent was not considered as a nutrient source since it was refractory to treatment processes (Bronk et al., 2010). Current technologies in advanced wastewater treatment processes can achieve more than 95% of inorganic nitrogen removal and the remaining nitrogen in the effluent mainly consists of DON. With more and more stringent regulation on total nitrogen discharge limit, it is imperative to minimize effluent DON in order to be in compliance.

Chemical composition of effluent DON varies with the influent wastewater characteristics and bacterial activity in the treatment system (Parkin and McCarty, 1981; Pehlivanoglu-Mantas & Sedlak, 2008; Pagilla et al., 2011). Pagilla et al. (2011) conducted laboratory scale sequencing batch reactor (SBR) activated sludge process experiments to investigate the effect of influent nitrogen composition on microbial DON production. Three different synthetic wastewater

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http://dx.doi.org/10.1016/j.watres.2016.01.041
0043-1354/

samples were prepared in different nitrogen compositions (nitriloacetic acid + ammonium, ammonium only, and amino acid mixture + ammonium). They observed about 1–2 mg/L DON production in the effluent even though there was no organic nitrogen introduced in the influent feed solution (ammonia only feed) of the reactor. The nitrifier growth rate constant in the system was the highest (between 0.91 and 1.14 day^{-1}) and lowest (0.82 day^{-1}) for the influent samples contained nitriloacetic acid + ammonium, and ammonium only, respectively. They found very little (negligible) colloidal organic nitrogen in the effluent of the SBR contradicting the full-scale plant observations (Pagilla et al., 2008; Sattayatewa et al., 2010). They explained that partial breakdown of influent suspended solids in full-scale plants could be the source of effluent colloidal organic nitrogen.

Sattayatewa et al. (2009) investigated the biodegradability and bioavailability of the final effluent DON from a 4-stage Bardenpho nitrogen removal plant in the presence and absence of effluent nitrate. They inoculated the samples with either mixed culture bacteria (from mixed liquor suspended solids) or algae and bacteria together. The incubation period was 40 days for BDON (bacteria only seed) and 14 days for algae-bacteria seeded samples. Effluent DON bioavailability for three algae-bacteria seeded samples in the presence of nitrate was 40%, 34%, and 28% and it was higher when DON was the only nitrogen source (nitrate absence by ion exchange pretreatment), which was 48%, 57%, and 35%. Effluent DON bioavailability for bacteria only seeded samples was 41%, 42%, and 43% in the presence of nitrate, and 46%, 57%, and 45% in the absence of nitrate. They concluded that DON can be an alternative nitrogen source in the absence of nitrate. There was no significant difference between bacteria seeds and algae-bacteria seeds with respect to amount of DON utilization.

Khan et al. (2009) developed a procedure that can be routinely used at wastewater utilities for quantifying BDON in treated effluent. The BDON procedure adopts the concepts of two existing bioassay methods in the wastewater field, 5-day biochemical oxygen demand (BOD_5) and biodegradable dissolved organic carbon. The procedure is based on DON reduction during incubation and relies on the use of a mixed culture inoculum, which is agreeable with treatment plant conditions. An acclimated mixed liquor suspended solids (MLSS) inoculum and an incubation period of 20 days were found to be adequate for BDON exertion. The procedure provided reliable BDON results for standard samples with DON greater than 0.40 mg N/L with an average detection limit of 0.31 mg N/L.

The availability of the BDON procedure (Khan et al., 2009) allows the nutrient removal field to move forward in answering the most practical and vital question regarding the biodegradability of DON. What is a way to minimize effluent BDON or DON biodegradability? Solids retention time (SRT), the main control parameter for activated sludge process, is known to affect effluent quality particularly collective organic parameters such as BOD_5 and chemical oxygen demand (COD). However, the effects of SRT on effluent DON and BDON are not known. SRT is not the only key parameter, but biokinetic parameters such as ammonification and hydrolysis rates also affect the performance of a bioreactor in the removal of DON and BDON (Simsek et al., 2012, 2013). Therefore, understanding the role of biokinetic parameters on the performance of a bioreactor for DON and BDON removal at various SRTs will assist in proper design of the bioreactor.

The objectives of this study are to investigate whether effluent DON, BDON, and BDON/DON can be minimized by SRT and to evaluate the role of biokinetic parameters on the removal of DON and BDON at various SRTs through model simulations. Laboratory scale chemostat experiments were conducted to examine the effects of SRT (same as hydraulic retention time for chemostat reactors) on the concentrations of DON and BDON in treated wastewater. Actual primary treated wastewater was used to feed the chemostat reactor which was operated at different SRTs ranging from 0.3 to 13 days. All major dissolved inorganic nitrogen species and TDN, soluble COD (SCOD), and soluble BOD_5 ($SBOD_5$) concentrations were measured continuously for the chemostat influent and effluent samples. DON and BDON for the chemostat influent and effluent samples were determined from the TDN and dissolved inorganic nitrogen species data and a bioassay procedure (for BDON). Model development and biokinetic parameter calibrations were performed under steady state conditions. Individual influent fractionation was performed for each SRT during the model development. An iterative step calibration process was performed by adjusting the kinetic parameters for BOD_5 and COD, followed by the kinetic parameters for nitrogen species for each SRT.

2. Materials and method

2.1. Sample source, preparation, and storage

Primary treated wastewater was collected (grab sample) from the Moorhead Wastewater Treatment Facility (WWTF) (Moorhead, MN, USA) and was used as influent for a chemostat reactor. This facility uses a high purity oxygen activated sludge (HPO-AS) process with a SRT of 3 days and moving bed biofilm reactor (MBBR) for biological treatment and has an average capacity of 15,000 m^3 $day^{-1}$with a peak flow of 38,000 m^3 day^{-1}. A portion of the primary treated wastewater (about 5 gallons) was placed in a refrigerator (at 4 °C) within 20 min after the collection and used to feed the chemostat reactor. The rest of the wastewater was stored in another refrigerator at 4 °C for future use within 3–4 days.

The chemostat reactor was seeded with MLSS taken from an aeration tank of the same facility at the beginning of each SRT studied. Also, MLSS was used to seed BOD and BDON samples. Instead of going to the treatment plant daily to obtain fresh MLSS for seeding BOD and BDON samples, 2 L of MLSS were placed in a container and were aerated and fed with primary wastewater daily. Every 3–4 days, this MLSS was discarded and new MLSS was obtained from the treatment plant.

2.2. Experimental setup and operation

The chemostat reactor was made of plexiglass. The working volume of the reactor was 10 L with a height of 17 cm, a width of 20 cm, and a length of 30 cm. The reactor was operated at a constant temperature of 25 °C (room temperature). At the beginning of the chemostat operation, 5 L of sample and 5 L of fresh MLSS were used to fill the reactor for each SRT. Immediately after, the influent (primary treated wastewater) is fed to the inlet of the reactor using a peristaltic pump (Masterflex L/S, Cole-Parmer, USA).

The peristaltic pump was calibrated for a desired flow rate prior to the experiment and it was checked and adjusted daily to maintain the same flow rate. Continuous and uniform aeration was provided with three bubble diffusing stones to achieve complete mixing. The air flow rate was regulated to ensure sufficient DO being supplied as well as a complete mixing condition. Occasional monitoring indicated a DO level of 5.0 mg/L in the reactor. The chemostat reactor was operated at 9 different SRTs of 0.3, 0.7, 2, 3, 4, 5, 7, 8, and 13 days with no recirculation and re-inoculation resulting in hydraulic retention times being the same as SRTs. SRTs between 0.7 and 2.0 days are common for full scale WWTPs (Khan et al., 1998b). SRTs between 0.7 and 1.0 days were applied in WWTPs to control foaming nuisance in warm weather conditions, while SRTs as low as 0.4 days were used in high purity oxygen activated sludge process treating warm wastewater (Eckenfelder