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Achieving nitritation in a continuous moving bed biofilm reactor at different temperatures through ratio control

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HIGHLIGHTS

- A ratio control strategy was used to remain stable nitritation in MBBR.
- Oxygen-limiting conditions in biofilm reactor were determined in this study.
- Nitritation was recovered in low temperature of 6 °C through ratio control.
- Stable nitritation was achieved without complete wash-out of NOB.
- Choice of partial or full nitritation was recommended.

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ABSTRACT

A ratio control strategy was implemented in a continuous moving bed biofilm reactor (MBBR) to investigate the response to different temperatures. The control strategy was designed to maintain a constant ratio between dissolved oxygen (DO) and total ammonia nitrogen (TAN) concentrations. The results revealed that a stable nitritation in a biofilm reactor could be achieved via ratio control, which compensated the negative influence of low temperatures by stronger oxygen-limiting conditions. Even with a temperature as low as 6 °C, stable nitritation could be achieved when the controlling ratio did not exceed 0.17. Oxygen-limiting conditions in the biofilm reactor were determined by the DO/TAN concentrations ratio, instead of the mere DO concentration. This ratio control strategy allowed the achievement of stable nitritation without complete wash-out of NOB from the reactor. Through the ratio control strategy full nitritation of sidestream wastewater was allowed; however, for mainstream wastewater, only partial nitritation was recommended.

1. Introduction

Nitritation receives increasing interest due to its associated economic savings (e.g. organic carbon source and aeration energy) compared to classical nitrogen removal technologies (Turk and Mavinic, 1987). To achieve nitritation, several operational factors have been adopted, such as low dissolved oxygen (DO) (Hulle et al., 2010), high pH (Villaverde et al., 1997), high free ammonia (FA) (Hulle et al., 2010), high free nitrous acid (FNA) (Gabarro et al., 2012), high temperature, and suitable sludge retention time (Hulle et al., 2010). Recently, an oxygen-limiting ratio control (DO/TAN) strategy was successfully applied to biofilm airlift reactors to obtain full nitritation (almost 100% ammonia conversion to nitrite) under stable operating conditions (Carrera et al., 2010).

In theory and practice, nitritation with batch influent can easily be achieved compared to continuous influent (Zheng et al., 2016; Julio et al., 2009). With continuous influent, the closer the system is to plug-flow, the easier it is to obtain nitritation. In other words, the closer the system is to complete mixing of the liquid phase, the narrower the range of conditions under which nitritation is obtained (Julio et al., 2009). Plug-flow reactors perform better since the higher substrate concentration in the bulk liquid along the influent of the plug-flow reactor increases conversion although at the same time increasing any inhibition effects due to higher TAN concentrations (Julio et al., 2009; Watten and Sibrell, 2006). Therefore, it is both necessary and meaningful to test the applicability of ratio control in the continuous complete mixed moving bed biofilm reactor (MBBR). Undoubtedly, temperature is one of the main influencing factors for achievement and stable operation of nitritation. However, several studies have pointed out that the effect of temperature on nitritation in a biofilm reactor was limited

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Nomenclature

MBBR	moving bed biofilm reactor
DO	dissolved oxygen
TAN	total ammonia nitrogen
AOB	ammonia oxidizing bacteria
NOB	nitrite oxidizing bacteria
FA	free ammonia
FNA	free nitrous acid
HRT	hydraulic retention time
TNN	total nitrite nitrogen
C	concentration
T	actual temperature
NAR	nitrite accumulation rate
OUR	oxygen uptake rate
r	production rate
SOUR	specific oxygen uptake rate
$D_{NH_4^+}$	diffusivity coefficients for ammonium
D_{O_2}	diffusivity coefficients for oxygen
γ_{O_2/NH_4^+}	ratio of the stoichiometric coefficients of ammonium and oxygen
NRR	nitrogen removal rate
$\mu^T_{\max,AOB(NOB)}$	maximum specific growth rate of AOB (NOB) at T in K
T_0	temperature at which $\mu^T_{\max,AOB(NOB)}$ has been reported
$E_{a,AOB(NOB)}$	free energy of AOB (NOB)
R	ideal gas constant

where competition for oxygen drives nitritation (Julio et al., 2009; Eduardo et al., 2015). Even so, nitritation with a temperature below 10 °C has not drawn much attention, especially in MBBR through ratio control. So far, most studies focus on nitritation as a treatment strategy of the sidestream (reject water) (Albert et al., 2010; Achlesh et al., 2013). Nitritation within the mainstream is comparatively difficult to achieve. Research on nitritation with a low-strength influent is beneficial for the application of nitritation. Considering economy and practicality, it is not recommended to elevate the temperature of the mainstream in a wastewater treatment plant. Therefore, an exploration of effective control methods to maintain the stable nitritation under low temperature for the treatment of the mainstream is crucial.

In addition, following the discovery of anaerobic ammonia oxidation (anammox) (Strous et al., 1999) and its later application, a two-step treatment consisting of nitritation plus anammox to autotrophically denitrify to nitrogen gas has probably become the most advanced and economical alternative for nitrogen removal (Henze et al., 2008; Van der Star et al., 2007). In a two-step system, nitritation is alternative with activated sludge, granular and biofilm reactors, and others. In summary, nitritation with granular and biofilm reactors has less effect on the subsequent anammox process compared to nitritation with activated sludge, i.e., no sludge settling is needed (Eduardo et al., 2015; Ma et al., 2011; Malovanyy et al., 2015).

In this study, a MBBR that utilized ratio control obtained nitritation of a low-strength ammonium concentration wastewater. Here, the main goals were to (i) decouple oxygen-limiting conditions from low DO concentrations, (ii) test the feasibility of ratio control, allowing the achievement and maintenance of nitritation in MBBR, and then explore the range of operating conditions, (iii) explore the nitritation performance of MBBR through ratio control at different temperatures, especially for temperature below 10 °C.

2. Materials and methods

2.1. Reactor set-up

A cubic reactor (about 180 × 120 × 260 mm) with working volume of about 4.4 L was used (see a detailed diagram in Fig. 1). The reactor was placed in a temperature control cabinet in which water temperature could be controlled according to requirements (26, 16, and 6 °C). Compressed air was supplied through an air diffuser placed at the bottom of the reactor. The DO concentration in the bulk liquid was measured via an online electrode. The aeration rate was manually controlled to maintain DO concentration at different set-point values. The hydraulic retention time (HRT) was adjusted via influent pump to obtain different setting TAN concentrations in the effluent. No pH adjustment was carried out in the reactor and in the effluent it ranged between approximately 7.3 and 7.4. Pall rings were used as biomass carriers. The volume of the carriers was approximately 22% of the working volume of the reactor. Inoculated activated sludge used for biofilm culturing was taken from the aeration tank of a wastewater treatment plant, which had a good nitrification performance, and its f (MLVSS/MLSS) and SVI were approximately 0.75 and 90, respectively.

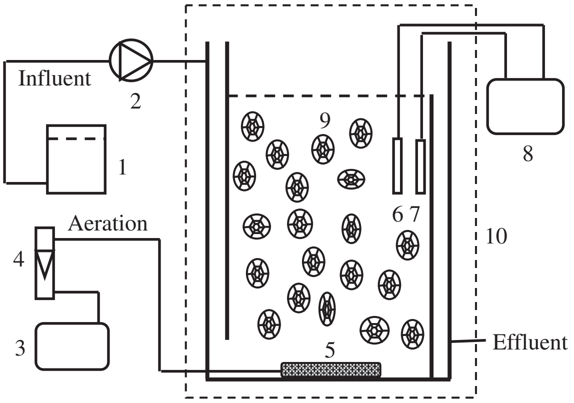

Fig. 1. Schematic diagram of the MBBR showing peripheral instrumentation: (1) Influent tank; (2) influent pump; (3) air pump; (4) air flowmeter; (5) air diffusor; (6) DO electrode; (7) pH electrode; (8) WTW; (9) pall ring; (10) temperature control cabinet. DO: dissolved oxygen.

2.2. Wastewater

The MBBR was fed with synthetic wastewater, which contained approximately 5 mg COD/L, added as CH_3COONa; 2.5 mg P/L, added as KH_2PO_4; 60 mg NH_4^+-N/L, added as NH_4Cl. $NaHCO_3$ was added for alkalinity, which was approximately 720 mg/L. The pH of the influent ranged between 7.7 and 7.8. The synthetic wastewater contained 1 mL of trace elements solution per L of influent (Guerrero et al., 2011).

2.3. Analytical methods

All samples were filtered with a 0.45 μm filter prior to analyzing. NH_4^+-N, NO_2^--N, NO_3^--N, MLSS, MLVSS, and alkalinity were measured according to standard methods (APHA, 1998). Biofilms were respectively detached from pall rings by ultrasound (45 kHz, 120 W, 2–3 min) and subsequently centrifuged (10000g, 15 min) for MLSS and MLVSS measurements. The detached pall rings were