Bioresource Technology 219 (2016) 762–767

Contents lists available at ScienceDirect

Bioresource Technology

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

Short Communication

Effect of filling fraction on the performance of sponge-based moving bed biofilm reactor

Xinbo Zhang [a], Xun Chen [a], Chunqing Zhang [a], Haitao Wen [a], Wenshan Guo [b], Huu Hao Ngo [b,*]

[a] Department of Environmental and Municipal Engineering, Bioprocess Centre For Sustainable Environment, Tianjin Key Laboratory of Aquatic Science and Technology, Tianjin Chengjian University, Jinjing Road 26, Tianjin 300384, China
[b] Centre for Technology in Water and Wastewater, School of Civil and Environmental Engineering, University of Technology Sydney, Sydney, NWS 2007, Australia

HIGHLIGHTS

- The filling fraction exhibited significant effect on TN removal and SND performance.
- DNR was affected more obviously than NR by the filling fractions.
- The difference between NR and DNR decreased with the filling fraction increasing.
- DNR is the controlling factor that affecting nitrogen removal performance of MBBR.
- The carriers showed the largest amount of biomass in the 20% filling fraction MBBR.

ARTICLE INFO

Article history:
Received 6 July 2016
Received in revised form 10 August 2016
Accepted 11 August 2016
Available online 11 August 2016

Keywords:
Sponge based moving bed biofilm reactor
Sponge carrier
Simultaneous nitrification and denitrification
Filling fraction

ABSTRACT

Cubic-shaped polyurethane sponges (15 × 15 × 15 mm) in the form of biofilm carriers were used in a moving bed biofilm reactor (MBBR) for treating synthetic domestic wastewater. Results indicated there was no significant difference in total organic carbon (TOC) and ammonia (NH_4^+-N) removal at different filling fractions. Three reactors exhibited high removal efficiencies of over 93% TOC and 95% NH_4^+-N on average at an HRT of 12 h and aeration flow of 0.09 m^3/h. However, total nitrogen (TN) removal and simultaneous nitrification and denitrification (SND) increased with increasing the filling fraction. TN removal averaged at 77.2, 85.5% and 86.7% in 10%, 20% and 30% filling fraction reactor, respectively. Correspondingly, SND were 85.5 ± 8.7%, 91.3 ± 9.4% and 93.3 ± 10.2%. Moreover, it was observed that sponge carriers in the 20% filling fraction reactor achieved the maximum biomass amount per gram sponge, followed by the 10% and 30% filling fraction reactors.

1. Introduction

With governments around the world implementing increasingly stringent effluent quality requirements and eutrophication controls, conventional pollutants as well as nutrients must be removed more efficiently. Therefore, advanced attached growth reactors such as the moving bed biofilm reactor (MBBR) have been developed for treating wastewater. To a large extent these have achieved a high degree of operational efficiency. The MBBR process was developed on the basis of conventional activated sludge and the best features of the biofilter process in Norway in the late 1980s and early 1990s (Ødegaard et al., 1994; Chen et al., 2008). Compared to the suspended biomass process, MBBR has certain advantages such as higher biomass concentration, higher chemical oxygen demand loading, strong tolerance to loading impact, longer sludge age, lower hydraulic retention time (HRT), higher volumetric removal rates, no sludge recirculation, relatively small area requirements and no sludge bulking problem (McQuarrie and Boltz, 2011; Leyva-Díaz et al., 2013).

The MBBR process has proved to be a very simple and efficient technology in municipal and industrial wastewater treatment strategies. In 2009 there were more than 600 MBBRs operating in 50 countries (Chen et al., 2015). Successful treatment is achieved by having the biomass grow on buoyant carriers that are slightly less dense than water and moving freely in the reactor's water. Consequently, the biofilm carriers in the MBBR play a major role in governing microbial attachment, as well as the type of reactor operation and process effectiveness. To date, various carriers have been introduced in the MBBR process, including polyethylene plastics, polyurethane sponge, polyvinyl alcohol gel, biodegradable polymer, granular activated carbon, polymer foam pads, nonwoven

---

* Corresponding author.
E-mail address: ngohuuhao121@gmail.com (H.H. Ngo).

http://dx.doi.org/10.1016/j.biortech.2016.08.031
0960-8524/

media, etc., (Rouse et al., 2007; Bertin et al., 2010; Guo et al., 2010; Nguyen et al., 2010; Chu and Wang, 2011a; Wu et al., 2012).

Of all the types of carriers, the sponge carrier is considered to be an ideal one for the attached growth media, in that it has a high porosity for microbial immobilization with the ability to deposit biomass on the sponge surface and inside the sponge pores (Guo et al., 2010). Nguyen et al. (2010) studied the effects of sponge size and type on treatment efficiency under aerobic conditions. Their results revealed there was no significant difference in the organic and nutrient removal rates between sponge types. Chu and Wang (2011b) used MBBRs filled with 20% sponge carriers to treat wastewater with a low C/N ratio, concluding that total organic carbon and ammonium removal efficiencies were 90% and 65% at an HRT of 14 h, respectively. Luo et al. (2014) investigated the removal of micropollutants in a sponge-based moving bed bioreactor. It emerged that polyurethane sponge indicated varying sorption capacities for micropollutants with a removal efficiency of 25.9% (carbamazepine) to 96.8% (b-Estradiol 17-acetate) on average in the MBBR. In addition, as studied by Luo et al. (2015), the hybrid moving bed biofilm reactor–membrane bioreactor (MBBR–MBR) system filled with sponge cubes could effectively remove 80% of all hydrophobic compounds ($\log D > 3.2$) among the selected micropollutants at the HRTs of 24 h in the MBBR and 6 h in the MBR unit. Although some other studies have assessed the performance of sponge-based MBBR (Ngo et al., 2008; Nguyen et al., 2010; Chu and Wang, 2011a), to date, the effect of filling fraction on the nitrification and denitrification capacity of sponge-based MBBR has not yet been investigated. Further investigation on attached-growth biomass (AGBS) functions in biocarriers is thus necessary for developing an efficient bioprocessing operation.

Consequently, the objective of this study is to evaluate the effect of filling fraction on the sponged aerated-MBBRs in terms of: (i) the organic and nitrogen removals; (ii) nitrification rate and denitrification rate performance; and (iii) biomass growth on sponge carriers.

2. Materials and methods

2.1. Synthetic wastewater

The experiments were conducted with synthetic wastewater. The composition of synthetic wastewater in this study was referred to the study of Lee et al. (2003). It consisted of around 100–118 mg/L total organic carbon (TOC), 13–18 mg/L NH_4^+-N, 2.7–3.5 mg/L total phosphorus, 0.3–1.2 mg/L NO_3^--N, 0.02–0.28 mg/L NO_2^--N and of a trace nutrient solution containing the following (mg/L): $MgSO_4{\cdot}7H_2O$, 5.07; $CaCl_2{\cdot}2H_2O$, 0.368; $MnCl_2{\cdot}7H_2O$, 0.275; $ZnSO_4{\cdot}7H_2O$, 0.44; $CoCl_2{\cdot}6H_2O$, 0. 42; $CuSO_4{\cdot}5H_2O$, 0.391; $FeCl_3$, 1.45; $Na_2MoO_4{\cdot}2H_2O$, 1.26; yeast extract, 30. The synthetic wastewater was used to simulate middle strength domestic wastewater. Based on the component of the synthetic wastewater, TOC/TN (C/N) ratio of the influent in the experiments was 6.5 ± 0.5.

2.2. MBBR experimental set-up and operation

Three bench-scale MBBRs of 12 L were employed with a cubic-shaped polyurethane sponge (15 × 15 × 15 mm) serving as biofilm carriers. Sponges with a density of 28 kg/m^3 with 90 cells per 25 mm were purchased from Joyce Foam Pty, Australia. Average specific surface area of a sponge cube was 0.846 m^2/g. Following this, three reactors were filled with non-acclimatized sponge carriers at the filling fraction of 10% (R1), 20% (R2), and 30% (R3), and began by inoculating activated sludge with the initial mixed liquor suspended solids (MLSS) of 2.8 g/L. The activated sludge derived from a secondary sedimentation tank at a local municipal wastewater treatment plant, located in Tianjin, China. Firstly, the sponge carriers were acclimatized to the synthetic wastewater for 15 days, with the hydraulic retention time (HRT) and the aeration flow set at 24 h and 0.09 m^3/h, respectively. Three reactors were then operated continuously in parallel with HRT of 12 h and an aeration flow of 0.09 m^3/h. The dissolved oxygen (DO) concentration in R1, R2 and R3 ranged from 5.0 to 6.5 mg/L. The pH was adjusted to around 7.0 with $NaCO_3$ or H_2SO_4 every day.

2.3. Analytical methods

TOC in the influent and effluent was measured using a TOC analyzer (TOC-VWP, Shimadzu, Japan). NH_4^+–N, NO_2^-–N and NO_3^-–N were examined with an ion chromatograph analyzer (ICS-1500, THEMORS, US). The analysis of MLSS and mixed liquor volatile suspended solids (MLVSS) was done according to Standard Methods (APHA, 2005). AGBS and volatile attached-growth biomass (VAGBS) in each sponge carrier were obtained by hand squeezing. In the meantime the sponge was rinsed with ultrapure water. Total nitrogen (TN) removal efficiency, simultaneous nitrification and denitrification (SND), nitrification rate (NR) and denitrification rate (DNR) were calculated using (1)–(4):

$$\text{TN removal efficiency} = \left(1 - \frac{[NH_4^+-N]_{eff} + [NO_2^--N]_{eff} + [NO_3^--N]_{eff}}{[NH_4^+-N]_{inf} + [NO_2^--N]_{inf} + [NO_3^--N]_{inf}}\right) \times 100 \tag{1}$$

$$SND = \left(1 - \frac{[NO_2^--N]_{eff} + [NO_3^--N]_{eff} - [NO_2^--N]_{inf} - [NO_3^--N]_{inf}}{[NH_4^+-N]_{inf} - [NH_4^+-N]_{eff}}\right) \times 100 \tag{2}$$

$$NR = \frac{[NH_4^+ - N]_{inf} - [NH_4^+ - N]_{eff}}{VS \times T} \tag{3}$$

$$DNR = \frac{[NH_4^+-N]_{inf} - [NH_4^+-N]_{eff} + [NO_2^--N]_{inf} + [NO_3^--N]_{inf} - [NO_2^--N]_{eff} - [NO_3^--N]_{eff}}{VS \times T} \tag{4}$$

where $[NH_4^+–N]_{inf}$, $[NO_2^-–N]_{inf}$ and $[NO_3^-–N]_{inf}$ are NH_4^+–N, NO_2^-–N and NO_3^-–N concentrations in the influent (mg/L), $[NH_4^+–N]_{eff}$, $[NO_2^-–N]_{eff}$ and $[NO_3^-–N]_{eff}$ are NH_4^+–N, NO_2^-–N and NO_3^-–N concentrations in the effluent (mg/L), T is the HRT of the reactors during the operation (h), VS is the sum of MLVSS and VAGBS concentra-