Bioresource Technology 189 (2015) 266–272

Contents lists available at ScienceDirect

Bioresource Technology

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

Enhanced biological denitrification in the cyclic rotating bed reactor with catechol as carbon source

Gholamreza Moussavi [a,*], Seyed Javad Jafari [a], Kamyar Yaghmaeian [b,c]

[a] Department of Environmental Health Engineering, Faculty of Medical Sciences, Tarbiat Modares University, Tehran, Iran
[b] Department of Environmental Health Engineering, School of Public Health, Tehran University of Medical Sciences, Tehran, Iran
[c] Center for Water Quality Research, Institute for Environmental Research, Tehran University of Medical Sciences, Tehran, Iran

HIGHLIGHTS

- The denitrification was evaluated in the CRBR using toxic carbon source.
- Optimum media filling ratio in the CRBR was found to be 30%.
- Minimum rotational speed of media in the CRBR was 20 rpm.
- CRBR reduced nitrate to the discharge limit at loading rate of 58 g/m^3 h.
- CRBR attained the denitrification at a rate much greater than that in conventional bioreactors.

ARTICLE INFO

Article history:
Received 13 February 2015
Received in revised form 5 April 2015
Accepted 6 April 2015
Available online 9 April 2015

Keywords:
Biological denitrification
Cyclic bioreactor
Rotating bed
Toxic carbon source
Filling ratio

ABSTRACT

The performance of CRBR in denitrification with catechol carbon source is presented. The influence of inlet nitrate concentration, hydraulic retention time (HRT), media filling ratio and rotational speed of media on the performance of CRBR was investigated. The bioreactor could denitrify over 95% of the nitrate at an inlet concentration up to 1000 mg NO_3^-/L and a short HRT as low as 18 h. The optimum media filling ratio at which the maximum denitrification was achieved in the CRBR was 30% and the contribution of media at this condition was around 36%. The optimum ratio of media filling at which the maximum denitrification was 20 rpm and the contribution of rotational speed under this condition was around 17%. According to the findings, the CRBR is a high rate bioreactor and thus serves as an appropriate technology for denitrification of wastewaters containing a high concentration of nitrate and toxic organic compounds.

1. Introduction

Several industry activities including the production of plastics, synthetic fibers, minerals, nitrogen-based fertilizers, metal finishing and explosive industries generate effluents with a high concentration of nitrate (NO_3-N > 1000 mg/L) (Cyplik et al., 2012). Discharging nitrate to the receiving water bodies imparts several environmental and health-related serious problems. Biological denitrification is the most appropriate technology for eliminating nitrate from the waste streams due to its unique features including high efficiency, environmental friendliness, cost-effectiveness, simplicity in design and operation, and high flexibility (Foglar et al., 2005). Biological denitrification is a respiratory anoxic process during which heterotrophic bacteria utilize organic substances as carbon sources and nitrate as an external electron acceptor, and thus reduce it to nitrogen gas through the following sequence:

$$NO_3^- \rightarrow NO_2^- \rightarrow NO(g) \rightarrow N_2O(g) \rightarrow N_2(g) \quad (1)$$

The main parameter affecting the success and efficacy as well as the cost-effectiveness of the denitrification is the source of organic carbon for preceding the reduction of nitrate (ÆsØy et al., 1998; Obaja et al., 2005). Adding an external carbon source and using the organic compounds present in the waste streams are two of the main strategies frequently applied for supplying the source of carbon for denitrification (Modin et al., 2007; Obaja et al., 2005). The later is technically and economically the most accepted strategy because of its lower cost (Obaja et al., 2005) due to utilizing the organic content of the wastewater stream.

Many of the nitrate-laden industrial effluents or industries close to the plant discharging nitrate-laden wastewater contain a high concentration of organic compounds, which can be reused as a

* Corresponding author. Tel.: +98 21 82883827; fax: +98 21 82884580.

http://dx.doi.org/10.1016/j.biortech.2015.04.019
0960-8524/

source of carbon for the denitrification. Therefore, reusing an organic-laden effluent generated in or fairly close to the denitrification plant as the resource of organic carbon for nitrate reduction process eliminates the need for the external carbon source to be added to the denitrification process. The added value of adopting this strategy is simultaneous treatment of the reused waste stream for organics in the denitrification plant, which eliminates the separate treatment process. The main critical concern for adopting this strategy is the point that the organic substances in the reused stream might be inhibitors and/or toxic, which may hinder microbial metabolism including the denitrification process.

Accordingly, the critical point to take advantage of using an internal waste stream as a carbon source for denitrification in the industrial field is the development of a bioreactor and an acclimatized biomass to be capable of running the denitrification at the presence of inhibitory/toxic organic carbon source. To date, the denitrification has been conducted in various suspended and attached growth bioreactors, mainly using different biogenic organic carbon sources. Table 1 illustrates the summary of the denitrification in the selected published literature. As seen in Table 1, denitrification using toxic organic compounds is very limited. Table 1 reveals that the conventional bioreactors have to be operated at a low inlet nitrate loading rate and/or low toxic organics in order to attain a sufficient nitrate reduction rate (NRR), resulting in the increase of the size and cost of the denitrification processes.

Therefore, the main aim of the present work is to investigate the performance of our recently developed cyclic rotating bed reactor, named CRBR (Aghapour et al., 2013) to denitrify a high concentration of nitrate using a toxic organic compound. Catechol was used as the model of the toxic organic carbon source. It has serious adverse effects on human and environmental health (Aghapour et al., 2013). CRBR is an integrated bioreactor in which both suspended biomass and a rotating media package are included in a cyclically operated single tank. The novelty of this work is the investigation of the efficacy of the CRBR system for biological denitrification using a toxic carbon source. The effect of inlet nitrate concentration, hydraulic retention time (HRT), media filling ratio and rotational speed of media package was evaluated on the denitrification process at the presence of catechol as the carbon source.

2. Methods

2.1. Wastewater preparation

Feed synthetic wastewater was prepared by dissolving sodium nitrate as the source of nitrate and catechol as the source of carbon source in tap water. To provide the nutrients required for microbial metabolism, the feed wastewater was supplemented with aliquots of the nutrient solution. The stock nutrient solution used in this work was composed of 120 g NH_4Cl, 15 g KH_2PO_4, 5 g K_2HPO_4, 10 g $NaHCO_3$, 12 g $(NH_4)_2HPO_4$, 10 g $CaCO_3$ dissolved in 1 litre of tap water, to maintain a COD/N/P ratio of 100:5:1 (Tchobanoglous and Burton, 1991). The NO_3^-/catechol mass ratio was kept constant at 2.5 throughout the experiment. The pH of the feed wastewater was set and maintained at 7.3 ± 0.3 throughout the bioreactor operation. All chemicals used in the study were of analytical grade.

2.2. Experimental setup

The experimental laboratory-scale CRBR setup consists of a glass cylindrical bioreactor with an inner diameter of 20 cm and a total height of 36 cm (25 cm fixed volume), a peristaltic feeding pump (WATSON MARLOW 101U/R), a media package composed of a perforated steel basket as a media support, a shaft and an electromotor (14 W), a supernatant decant system composed of an automatic time-controlled valve and a timer switch and other necessary accessories (Aghapour et al., 2013). The polyurethane foam (PUF) cubes (1 cm^3) with density of 35 kg/m^3 and specific surface area of 600 m^2/m^3 were used as media to support biomass and biofilm formation.

2.3. Reactor start-up and operation

The CRBR system contained a mixed microbial culture both as suspended biomass and as biofilm. The biomass and media containing a thin and active biofilm used in this work were obtained from the CRBR system efficiently treating a catechol-containing wastewater (Aghapour et al., 2013). The concentration of suspended biomass, measured as mixed liquor suspended solid (MLSS), at all experimental phases was kept constant at 3500 ± 300 mg/L via daily wasting the mixed liquor. It was observed in the scanning electron microscopy micrographs that a dense film of biomass evenly attached to the media. The bioreactor was operated cyclically; each operation cycle lasted 3 h and consisted of a reaction step (2 h), a settling step (0.75 h) and a decanting step (0.25 h). The synthetic wastewater was continuously fed into the bioreactor over the cycle and the effluent was discontinuously decanted at the decanting step. The media package was rotated during the reaction step and resulted in suspension of the biomass. The rotation of the package was stopped during the settling and decanting steps.

Table 1
Summary of the selected literature on biological denitrification.

Bioreactor	Source of carbon	NLR[a] (g NO_3^-/m^3 h)	NRE[b] (%)	NRR[c] (g NO_3^-/m^3 h)	References
Batch denitrifying reactor	Methane	8.2	100	8.2	Thalasso et al. (1997)
UASB	Acetate	20.8	95	19.7	Cervantes et al. (2001)
Continuous-flow stirred reactor	Methanol	19.2	100	19.2	Foglar and Briški (2003)
Attached growth reactor	Methane	52.3	91.2	47.7	Rajapakse and Scutt (1999)
Batch denitrifying reactor	Polylactic acid	34.5	81	28	Xu et al., 2011
Upflow anoxic bioreactor	Ethanol	57.5	80	46	Behera et al. (2007)
Packed-bed bioreactor	Biodegradable polymer	110	88.7	97.6	Shen et al. (2013a)
Bioreactor landfills	Landfill leachate	31.8	95	30.2	Sun et al. (2012)
Pack-bed bioreactor	Ethanol	26.9	95	25.6	Shen et al. (2013b)
Upflow sludge blanket reactor	Phenol	40	98.4	39.4	Eiroa et al. (2005)
Sequencing batch reactor	Phenol	37.6	92.6	34.8	Sarfaraz et al. (2004)
Cyclic rotating bed reactor	Catechol	57.7	95.1	54.9	Present work

[a] Nitrate loading rate.
[b] Nitrate reduction efficiency.
[c] Nitrate reduction rate.