Bioresource Technology 152 (2014) 414–419

Contents lists available at ScienceDirect

Bioresource Technology

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

Floatation of granular sludge and its mechanism: A key approach for high-rate denitrifying reactor

Wei Li [a], Ping Zheng [a,*], Junyuan Ji [b], Meng Zhang [a], Jun Guo [c], Jiqiang Zhang [a], Ghulam Abbas [a,d]

[a] *Department of Environmental Engineering, Zhejiang University, Hangzhou 310058, China*
[b] *College of Environmental Science and Engineering, Ocean University of China, Qingdao 266100, China*
[c] *College of Environmental Science and Engineering, Tongji University, Shanghai 200000, China*
[d] *Department of Chemical Engineering, University of Gujrat, Gujrat, Pakistan*

HIGHLIGHTS

- A high-rate denitrifying automatic circulation (DAC) reactor was developed.
- Granule floatation was a limiting factor for performance of high-rate DAC reactor.
- The floating mechanism of denitrifying granule at high load was revealed.
- An evaluation model for physical characteristics of floated granules was proposed.

ARTICLE INFO

Article history:
Received 6 October 2013
Received in revised form 14 November 2013
Accepted 20 November 2013
Available online 28 November 2013

Keywords:
High-rate DAC reactor
Working performance
Granular sludge floatation
Floatation mechanism

ABSTRACT

A high-rate denitrifying automatic circulate (DAC) reactor has been developed recently, and it is promising to become an alternative in nitrogen removal from wastewaters. However, the performance of DAC reactor was disturbed by the floatation of granular sludge at high-loads. The results showed that: the floatation of granular sludge led to a serious biomass washout and a sharp decrease of biomass concentration. The floatation of granular sludge was ascribed to a low sludge density originated from the holdup of gaseous products. The average density and average gas holdup ratio of floated granular sludge were 913 kg m^{-3} and 11.8% (by volume), respectively. The floatation of granular sludge could disappear by releasing gas when sludge was in the state of elastic expansion, but it would become worse by holding gas when it entered the plastic expansion state. The plastic expansion of granules was significantly correlated with the less content of extracellular polymeric substances.

1. Introduction

Nitrogen and carbon-containing compounds are the major contaminants in wastewaters which cause serious environmental problems (Guo, 2007; Smith et al., 1999; Lettinga et al.,1980). Simultaneous elimination of nitrogen and carbon by biological denitrification (Cuervo-Lopez et al., 1999; Lew et al., 2012; Nancharaiah and Venugopalan, 2011) has become increasingly important in wastewater treatment (Gupta and Gupta, 2001; Reyes-Avila et al., 2004). Denitrifying reactor is a promising technology for denitrification and development of high-rate denitrifying reactor can improve denitrification technology. The denitrifying granular sludge reactor was reported in 1975 for the first time (Miyaji and Kato, 1975) and after that it became a focus of wastewater treatment due to its good performance and low cost. So far, the reported maximum nitrogen removal rate (NRR) and COD removal rate (ORR) in literature are 25 kgN m^{-3} d^{-1} (Bode et al., 1987) and 67.5 kg COD m^{-3} d^{-1} (Franco et al., 2006), respectively.

However, floatation of denitrifying activated sludge has been reported both in literatures and engineering applications (Cuervo-Lopez et al., 1999; Liu and Sun, 2011). And the floating sludge is more likely to be washed out from the reactor resulting in the deterioration of denitrification process, especially in high-rate reactor. Some researchers have reported that addition of enough Ca^{2+} to influent was an effective way to control the floatation of sludge (Jin et al., 2012b; Liu and Sun, 2011). However, this can cause sludge calcification and sludge activity decline in the end (Chen et al., 2010a). So far, most of the reported loads for denitrifying reactor are lower than 15 kgN m^{-3} d^{-1} (Franco et al., 2006; Isaka et al., 2012; Rabah and Dahab, 2004) and the key factors causing floatation of denitrifying granular sludge remain unclear. Until now, rare literature is available on the mechanism of floating denitrifying granular sludge and its effect on on the performance of reactor at nitrogen loading rate (NLR) greater than 25 kg m^{-3} d^{-1}.

* Corresponding author. Tel./fax: +86 57188982819.
E-mail address: pzheng@zju.edu.cn (P. Zheng).

0960-8524/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.biortech.2013.11.056

Nomenclature

EPS	extracellular polymeric substances	SDA	sludge denitrifying activity
GPR	gas production rate	SGPR	specific gas production rate
NLR	nitrogen loading rate	U_{up}	two-phase upflow velocity
NRR	nitrogen removal rate	VLR	volumetric loading rate
OLR	COD loading rate	ε_B	bed porosity
ORR	COD removal rate	ε_g	granular porosity
PN	extracellular proteins	ρ_l	liquid density, (1000 kg m^{-3})
PS	extracellular polysaccharide	ρ_g	density of granular sludge
Q_G	gas flow rate	ρ_{gc}	critical density for settling
Q_{in}	influent flow rate	ρ_s	solid density of granular sludge
R	recycling ratio	ρ_G	density of gas production
S_R	cross-sectional area of reactor	x_0	critical gas holdup for floating

Recently, a high-rate denitrifying automatic circulation (DAC) reactor has been successfully developed in laboratory. However, the performance of the DAC reactor decline at high NLR caused by the floatation of granular sludge. Taking DAC reactor and granular sludge as models, the mechanism of floating granular sludge has been investigated in order to carry forward the development and application of high-rate granular sludge bed reactor.

2. Methods

2.1. Synthetic wastewater

The concentrations of sodium nitrate and methanol were 1 g NO_3^-–N L^{-1} and 5 g COD L^{-1}, respectively. Nitrogen to methanol ratio was 1:3.33 to keep the nitrogen as the limiting substrate. The other constituents of the mineral medium was (g L^{-1}): KH_2PO_3 0.05, $CaCl_2$ 0.4, $MgSO_4 \cdot 7H_2O$ 0.1 and 1 ml L^{-1} of trace elements solution. The trace elements solution contained (g L^{-1}): 5 EDTA, 5 $MnCl_2 \cdot 4H_2O$, 3 $FeSO_4 \cdot 7H_2O$, 0.05 $CoCl.6H_2O$, 0.04 $NiCl_2 \cdot 6H_2O$, 0.02 H_3BO_3, 0.02 $(NH_4)_6Mo_7O_2 \cdot 4H_2O$, 0.01 $CuSO_4 \cdot 5H_2O$ and 0.003 $ZnSO_4$. The pH of synthetic wastewater was in the range of 6.6–6.9 (Li et al., 2013).

2.2. Laboratory-scale DAC reactor

The experimental work was carried out in a plexiglass-made denitrifying automatic circulation (DAC) reactor. The schematic diagram of the reactor system is shown in Fig. 1. The lower part of DAC reactor is made of a 0.45 m high plexiglass-made tube with an inner diameter of 0.06 m and effective volume of 1.25 L. The top of DAC reactor was closed with a gas-collecting hood. The reactor was fed by a peristaltic pump (Lead Fluid, China).

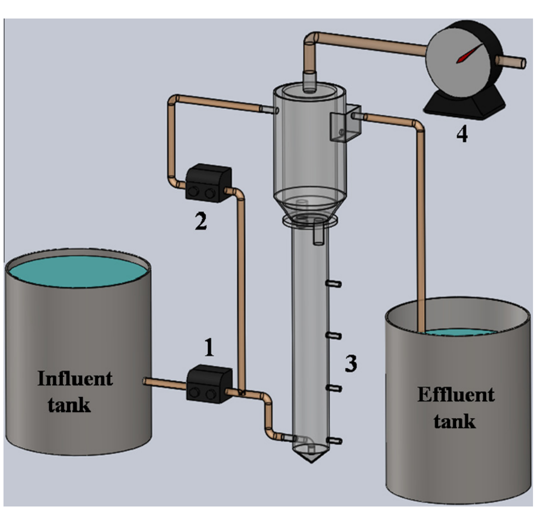

Fig. 1. DAC reactor system. (1, 2) Peristaltic pump, (3) DAC reactor, (4) Wet gas meter.

2.3. Reactor operation

The DAC reactor was initially inoculated with 1 L anaerobic granular sludge with VSS/SS content of about 70%. The reactor was set at NLR of 2 kg m^{-3} d^{-1} with a fixed effluent recycling ratio (recycling flow to inflow ratio) of 2.0. Both the synthetic wastewater and the recycling liquid were mixed in the manifold at the bottom of the reactor. The loading rate was increased by shortening hydraulic retention time (HRT) (Tang et al., 2011). Data was recorded after NLR reached up to 25 kg m^{-3} d^{-1}. The temperature was set at 30 ± 1 °C.

2.4. Analytical methods

The determination of pH, nitrate, nitrite, ammonium, suspended solids (SS) and volatile suspended solids (VSS) concentrations were carried out according to the Standard Methods (APHA, 2005).

2.4.1. Granular morphology

The digital macro photography was performed by SteREO Discovery stereomicroscopes (Carl Zeiss, Germany) or Digital single-lens reflex camera (Nikon, Japan). The digital macro photos were analyzed by Image Pro Plus 6.0 (Media Cybernetics, USA). The size of granular sludge was determined by QICPIC system (Sympatec, Germany).

2.4.2. Granular density (ρ_g)

Sucrose was used to make a series of solutions with densities of 1400, 1390, 1380…1020, 1010 g L^{-1}. Ethanol was used to make a series of solutions with densities of 990, 980, 970…920 g·L^{-1}, 910 g L^{-1}. The granular samples were added into each of the 50 ml graduated cylinders having sucrose or ethanol solutions of different densities (Lu et al., 2012). Under a quiescent condition, the granules moved up or down in the graduated cylinder depending on the density of the solution. Thus, the specific wet gravity of the granule was measured.

2.4.3. Granular porosity (ε_g)

The granular porosity was determined by size exclusion chromatography (Adav et al., 2008; Zheng and Yu, 2007). The experiment was performed at 4 °C to inhibit the sludge activity without affecting the granule characteristics (Alphenaar et al.,