International Biodeterioration & Biodegradation 103 (2015) 221–226

Contents lists available at ScienceDirect

International Biodeterioration & Biodegradation

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

Simultaneous biological nitrogen and phosphorus removal with a sequencing batch reactor–biofilm system

Jiang Yin, Panyue Zhang*, Fan Li, Gaopeng Li, Binghan Hai

Beijing Key Laboratory for Source Control Technology of Water Pollution, College of Environmental Science and Engineering, Beijing Forestry University, 35 Tsinghua East Road, Beijing 100083, China

A R T I C L E I N F O

Article history:
Received 11 January 2015
Received in revised form
16 February 2015
Accepted 16 February 2015
Available online 5 March 2015

Keywords:
Sequencing batch reactor–biofilm system
Activated sludge
Denitrification
Phosphate accumulating organisms
Denitrifying phosphate accumulating organisms

A B S T R A C T

To achieve simultaneous biological nitrogen and phosphorus removal, a pilot-scale sequencing batch reactor–biofilm (SBR–BF) system was explored. SBR–BF system was started up with two phases, which were anaerobic/aerobic and anaerobic/aerobic/anoxic, to enrich phosphate accumulating organisms (PAOs) and denitrifying phosphate accumulating organisms (DNPAOs), and to form system of suspended activated sludge and attached biofilm. Operation cycle of SBR–BF system was adjusted as fill 5 min, anaerobic 90 min, aerobic 210 min, anoxic 90 min, settle 30 min, draw 15 min and idle 40 min, and average removal of chemical oxygen demand, total nitrogen and total phosphorus respectively reached 95%, 94%, and 97% during stable operation for 3 months. Analysis of a typical wastewater treatment cycle testified that DNPAOs played an important role for phosphate uptake and denitrification under aerobic and anoxic conditions. The SBR–BF system not only provided good living conditions for PAOs, DNPAOs, nitrifying bacteria and denitrifying bacteria which had different generation times, but also prevented the competition for carbon source between different bacteria.

Introduction

Widespread water environment eutrophication leads to increasingly strict nitrogen and phosphorus discharge standards for wastewater treatment worldwide. Many technologies have been studied and used to effectively remove nitrogen and phosphorus (Gao et al., 2008; Donsì et al., 2009; Yang et al., 2010; Guadie et al., 2013; Jin et al., 2014; Wu et al., 2014). Among these technologies, sequencing batch reactor (SBR) is unique in its compact structure, flexible operation, and simple construction. All these characteristics make the SBR specially suitable for small-scale wastewater treatment plants. However, the SBR has an obvious drawback that it cannot simultaneously remove nitrogen and phosphorus with very high efficiency, because nitrification bacteria, denitrification bacteria, and P-removal bacteria are completely mixed in SBR system and compete with each other. On the other hand, a biofilm system provides different sub-zones for various types of bacteria so each can find its niche. Simultaneous nitrification, denitrification and phosphorus removal has been reported in biofilm systems (Rahimi et al., 2011; Duan et al., 2013a). However, diffusion limitation in the biofilm hinders the biological phosphorus removal (Meyer et al., 2005).

Therefore, a hybrid system combining SBR and biofilm (SBR–BF) was proposed to realize compact structure, flexible operation, and simultaneous nitrogen and phosphorus removal with high efficiencies (Lo et al., 2010). The SBR–BF can maximize the sludge retention time (SRT) in the biofilm and has a potential of operating the suspended activated sludge system with a relatively short SRT. Furthermore, in SBR–BF different bacteria with different SRTs can be developed in a single reactor, including ammonia oxidizing bacteria (AOBs), nitrite oxidizing bacteria (NOBs), phosphorous accumulating organisms (PAOs) and denitrifying phosphorous accumulating organisms (DNPAOs).

The existence of DNPAOs with different electron acceptors was testified (Ahn et al., 2002). As facultative anaerobic bacteria, DNPAOs can be enriched under anaerobic or anoxic conditions (Tsuneda et al., 2006; Ma et al., 2009). Under anaerobic condition, DNPAOs use energy released from hydrolysis of intracellular polyphosphate to transport volatile fatty acid across their cell membranes and to produce polyhydroxybutyrate (PHB), and phosphate is released in connection with storage of organic matters. Under anoxic condition, DNPAOs use nitrate and/or nitrite as electron acceptors for phosphate uptake and denitrification. Terada et al.

* Corresponding author.
E-mail address: panyue_zhang@bjfu.edu.cn (P. Zhang).

http://dx.doi.org/10.1016/j.ibiod.2015.02.019
0964-8305/

established a SBBR system and enriched DNPAOs in hollow fiber membrane by alterative anoxic/aerobic condition, and the chemical oxygen demand (COD), total nitrogen (TN) and total phosphorus (TP) removal respectively reached 99%, 96% and 90% after long operation (Terada et al., 2006).

More and more evidences have indicated that different bacteria for simultaneous nitrogen and phosphorus removal can be enriched in SBR–BF system. However, there are no sufficient study issued to treat different types of real wastewater with this system because of the fluctuant compositions of contaminants, and the studies on SBR–BF system configuration are also absent compared with the operational stability and nutrient removal. In this study, a SBR–BF system was started up to treat urban sewage. The anaerobic, aerobic and anoxic processes were optimized, and SBR–BF system was then operated stably under the optimal conditions. The operation cycle was further investigated to analyze the mechanisms of simultaneous biological nitrogen and phosphorus removal in the system.

Materials and methods

Startup and operation of SBR–BF system

The SBR–BF system used was located in the basement of an apartment block in south China. All wastewater produced in the building flowed into the SBR–BF system. The main pollutant compositions of wastewater were as follows: NH_4^+–N of 25–45 mg/L; TP of 8–15 mg/L; COD of 200–450 mg/L; pH of 7.2–7.6.

Fig. 1 shows the schematic diagram of the SBR–BF. The SBR–BF had a volume of 1 m^3, which was filled with polypropylene carriers (30% volume). A time controller was used for controlling the system operation. All experiments were conducted at ambient temperature (10–30 °C). The SRT was maintained at 20 d.

The SBR–BF was inoculated with 10 L common activated sludge from a local WWTP in Changsha, Hunan province, China. At the first week, the inoculated sludge was aerated without carbon substrate to inhibit the growth of heterotrophic bacteria; then the wastewater was added and the addition gradually increased, until the influent COD, NH_4^+–N and TP reached about 400, 35 and 13 mg/L, respectively. The system startup was divided into two phases (Table 1). The first phase included anaerobic and aerobic processes, in order to improve the PAOs growth and begin to form biofilm on the suspended carriers. In the second phase, anaerobic, aerobic and anoxic processes were conducted to increase the quantity of the DNPAOs and to form the uniform and compact biofilm. The

Table 1
Operation cycle for system startup (min).

	Anaerobic/aerobic	Anaerobic/aerobic/anoxic
Fill	5	5
Anaerobic	120	120
Aerobic	240	180
Anoxic	0	90
Settle	According to sedimentation of suspended activated sludge	According to sedimentation of suspended activated sludge
Draw	15	15
Idle	According to requirement	According to requirement

dissolved oxygen (DO) was respectively controlled below 0.2 mg/L, between 2 and 2.5 mg/L and below 0.5 mg/L in anaerobic, aerobic and anoxic process. The mixing speed of stirrer was 100 r/min. The pH of wastewater maintained within a range of 6.5–8.5.

After the startup of SBR–BF system, the anaerobic, aerobic and anoxic phases were respectively prolonged and detailed analyzed for the optimization of operation cycle. Then the SBR–BF system ran stably with optimum operation cycle for three months. The DO, pH and mixing speed of stirrer in the stable operation was similar as that in the startup phase.

The wastewater samples were regularly collected from the SBR–BF system to determine its quality. The sludge samples were regularly collected to test mixed liquid suspend solid (MLSS) and sludge volume index (SVI).

Analysis methods

The DO and pH of wastewater in the reactor were daily recorded with a portable dissolved oxygen/pH meter (HQ20, Hach, USA). The COD was measured with a COD speed measuring devices (CTL-12, Huatong Inc., China). The NH_4^+–N was measured by a spectrophotometer (8453, Agilent, USA) according to Nessler's reagent spectrometry, the NO_2^-–N and NO_3^-–N were respectively measured according to N-(1-naphthyl) ethylenediamine spectrophotometric method and phenol two sulfonic acid photometric method, and the TN was calculated as the sum of NH_4^+–N, NO_2^-–N and NO_3^-–N. The TP was analyzed according ammonium molybdate spectrophotometric method. The MLSS and SVI were measured according to APHA standard methods, respectively (Eaton et al., 2005).

The data were all the average of two or more replicates. Tukey's test was adopted to analyze the significance of data to ensure the level of significance above 95% ($P < 0.05$).

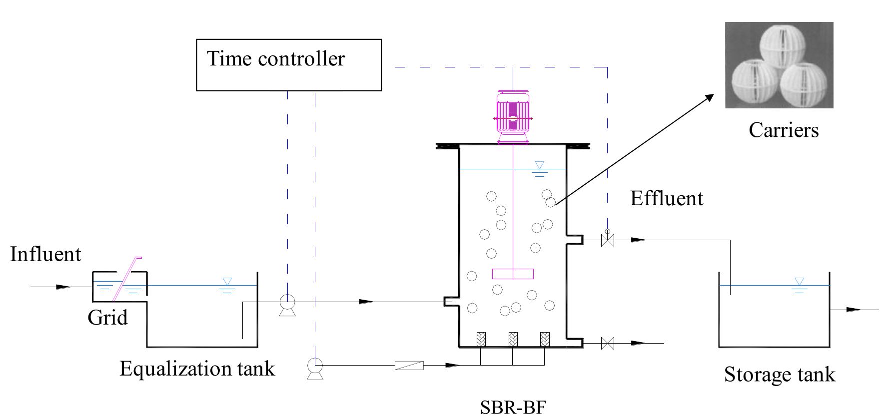

Fig. 1. Schematic diagram of wastewater treatment system.