Journal of Environmental Management 192 (2017) 302–308

Contents lists available at ScienceDirect

Journal of Environmental Management

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

Research article

Embedding constructed wetland in sequencing batch reactor for enhancing nutrients removal: A comparative evaluation

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ARTICLE INFO

Article history:
Received 25 December 2016
Received in revised form
25 January 2017
Accepted 31 January 2017

Keywords:
Green bio-sorption reactor (GBR)
Alum sludge
Constructed wetland
Activated sludge
Aesthetic value
Simultaneous nitrification and denitrification (SND)

ABSTRACT

In the present study, a novel green bio-sorption reactor (GBR) was firstly proposed and preliminarily investigated by embedding constructed wetland (CW) into the aeration tank of the conventional activated sludge (CAS). This integrated novel system owns the striking features of adding carriers of wetland substrate (i.e. the dewatered alum sludge in this case) in CAS for robust phosphorus adsorption and enriching the biomass. Meanwhile, the "green" feature of this GBR imparted aesthetic value of CW to the CAS system. The preliminary 3-month trial of GBR based on a sequencing batch reactor (GB-SBR) with diluted piggery wastewater demonstrated an average removal of 96%, 99% and 90% for BOD, TP and TN, respectively. The comparison with moving bed biofilm reactor (MBBR) and integrated fixed-film activated sludge (IFAS) reflected the advantages of GBR over purification performance, aesthetic value and potential carbon sink. Moreover, the carriers used in the GBR are dewatered alum sludge which is in line with the policy of "recycle, reuse and reduce". Overall, this GBR undoubtedly offered a more sustainable and economical solution for retrofitting the aging CAS.

1. Introduction

Water scarcity has been an urgent issue for most regions of the world due to the widespread water pollution (Liu et al., 2017). The release of nutrients and trace but toxic substances from the effluent of wastewater treatment plant (WWPTs) into rivers and lakes could induce eutrophication and expose detrimental effect on aquatic organisms (Wang and Wang, 2016). In order to achieve water reclamation and reuse from wastewater, wastewater treatment technologies need to be intensified. In addition, most current WWTPs are also confronting growing connected population and rising quantity of wastewater, thus needing urgency to be upgraded (Zhang et al., 2016a).

Many techniques, such as membrane bioreactor (Hazrati and Shayegan, 2011), granular sludge system (Awang and Shaaban, 2016), and biofilm reactor (Kim et al., 2010; Zhang et al., 2016b), have been proposed and employed to retrofit WWTPs. However, they are restricted by either the expensive materials or infant stage. Among these, biofilm reactors are the most frequently used process to retrofit municipal WWTPs. So far, the most representative biofilm reactors include fluidized bed reactor (FBR) (Islam et al., 2014), moving bed biofilm reactor (MBBR) (Javid et al., 2013; Barwal and Chaudhary, 2014), and integrated fixed-film activated sludge system (IFAS) (Veuillet et al., 2014; Malovanyy et al., 2015).

These biofilm reactors would undoubtedly intensify the nitrification efficiency with the carriers. Moreover, many authors alleged that the biofilm reactor could avail of the advantage of simultaneous nitrification and denitrification (SND) (Lim et al., 2012) to improve TN removal. However, SND efficiency was always restricted by the insufficient organic (Lim et al., 2012). This is due to partially the intrinsic drawback of wastewater and partially the pre-anaerobic configuration which uptake a large quantity of organic (Erdal et al., 2000). From the technical point of view, the biofilm reactor could couple with step feeding, multiple aerobic-anoxic stages and culturing denitrifying phosphorus bacteria (DPBs) to achieve satisfied TN removal (Table S1). The performance of these systems, however, is sensitive and vulnerable.

As such, a novel idea to combine alum sludge-based constructed wetland (CW) (Zhao et al., 2010; Hu et al., 2012) and conventional

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http://dx.doi.org/10.1016/j.jenvman.2017.01.080
0301-4797/

activated sludge (CAS) was proposed to gain the advantages of both the processes, achieving an enhanced nutrient removal and effluent quality. The basic configuration is to embed the CW into the aeration tank of the CAS, thus given the name of green bio-sorption reactor (GBR). Here, "Green" implies wetland/plant while "Bio-sorption" represents the novel wetland substrate. In the present study, a lab-scale sequencing batch reactor (SBR) was retrofitted to a GBR (GB-SBR) in order to demonstrate its performance. Attention was also paid on the comparison of GB-SBR with other biofilm reactors. The *pros* and *cons* were comparatively analyzed and discussed.

2. Material and methods

2.1. Apparatus setup and operation

A commercial polythene tank (L × W × H: 54.5 × 35.0 × 42.0 cm) was configured as an SBR system with liquid working volume of 54 L (Fig. 1a). Dewatered alum sludge (Babatunde et al., 2009) (5 kg in weight with particle size around 2 × 2 × 2 cm) was filled into a meshed rectangular cage (20 × 16 × 30 cm) with planting vegetation on its top, which simulated an alum sludge-based CW. Two these CWs were then placed and hung in the SBR as "floating" CW. Air diffusers were placed in a line at the bottom of the SBR and connected to an air compressor. A mixer was also installed in order to promise homogenizing the suspended sludge and wastewater.

In order to initiate the reactor/GB-SBR, 20 L activated sludge collected from one WWTP in Dublin city, was seeded into the reactor. The sludge content in the reactor's operation was controlled at 2000 mg L^{-1} by discharging 300 mL mixed liquor every day. The reactor was operated in SBR mode with four stages of filling, alternating oxic bubbling and anoxic mixing, settling and draining (Fig. 1b and Table S2) and controlled automatically by timers. At the beginning of each cycle, the same volume of drained wastewater in the last cycle (33 L) was filled into the reactor by a peristaltic pump with an exchange ratio of 0.6.

The performance of GB-SBR was monitored every two days based on the influent/effluent quality of COD, BOD_5, TN, NH_4^+-N, NO_x^--N (NO_2^- and NO_3^-), and TP. In order to understand the pollutants evolution in each stage, the pollutants evolution of a typical cycle was tracked in the 20th day of the operation period. The cycle monitors were started after introducing the wastewater into the GB-SBR and samples were collected at the end of each stage and filtered through 0.45 μm membrane filter and then analyzed for SCOD, TN, NH_4^+-N, NO_x^--N, and TP.

2.2. Batch test for nitrification/denitrification rate

In the GB-SBR system, the biomass existed in two categories, i.e. suspended sludge and biofilm (on the surface of the alum sludge). In order to clarify the scheme of SND in the present GB-SBR, the nitrification and denitrification rates (R_N and R_D) were tested, respectively, in terms of biofilm only (R_{N-B} and R_{D-B}), suspended-sludge only (R_{N-S} and R_{D-S}) and biofilm-suspended-sludge together (R_{N-M} and R_{D-M}).

For R_{N-B} and R_{D-B}, the alum sludge particles of around 100 g were randomly taken from the GB-SBR at the end of experiment and filled into a small cage (Liu et al., 2016). Then, the cage was rinsed for several times one day before the test to remove the residual substrates on the surface of the used alum sludge and eliminate storage effect. The cage was then immersed into the beaker with solution prepared according to Table 1. In terms of R_{N-S} and R_{D-S}, 500 mL suspended sludge was sampled from the GB-SBR and 400 mL supernatant was replaced by the same amount of medium (Table 1). The R_{N-M} and R_{D-M} were conducted in GB-SBR directly with the initial condition in Table 1.

In order to keep complete mixture, the ready beakers were then placed on the magnetic stirrer. For R_N ($R_{N-B,}$ R_{N-S} and R_{N-M}) test, oxygen concentration (DO) was kept at 4 mg L^{-1} in ambient temperature by an air compressor. For R_D ($R_{D-B,}$ $R_{D-S,}$ and R_{D-M}) test, nitrogen gas was employed to flush the reactors (beaker and GB-SBR) to obtain anoxic condition. Samples were collected every 30 min for 3 h. All the samples were filtered through 0.45 μm membrane filters for analyzing NO_3^--N, alkalinity and/or COD, NO_3^--N. All the tests were conducted independently in duplicate.

2.3. Wastewater and analytical methods

Piggery wastewater (Hu et al., 2012), collected from an animal

Table 1
Medium preparation for R_N and R_D tests.

No.	N (mg/L)	Alkalinity	COD	Trace elements	DO	Sludge
ex-situ (600 mL beaker with 500 mL working volume)						
R_{N-B}	40 (NH_4^+-N)	400 mg/L	No	Yes[a]	4 mg/L	Biofilm
R_{N-S}						SS
R_{D-B}	40 (NO_3^--N)	No	400 mg/L	Yes	–	Biofilm
R_{D-S}						SS
In-situ (GB-SBR)						
R_{N-M}	40 (NH_4^+-N)	400 mg/L	No	Yes	4 mg/L	Mixed
R_{D-M}	40 (NO_3^--N)	No	400 mg/L	Yes	–	

[a] Trace elements solution was prepared according to Nguyen et al. (2010).

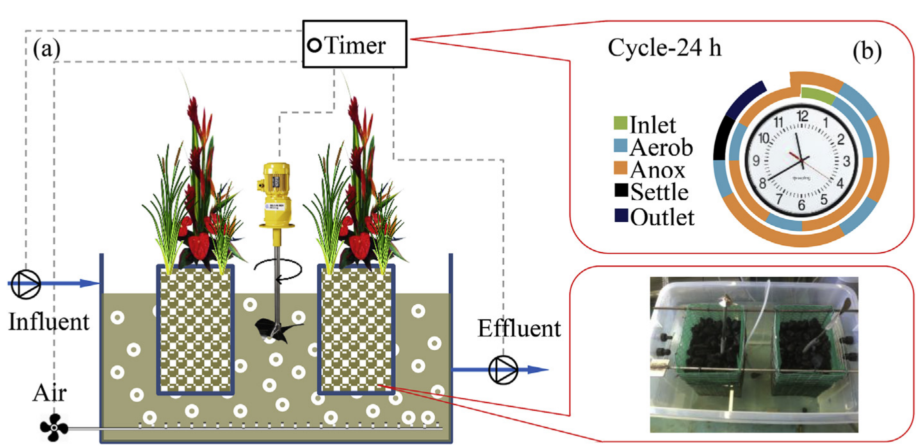

Fig. 1. Schematic description of alum sludge-based GB-SBR in lab-scale (a), and the time distribution of one cycle of GB-SBR operation (b).