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The performance of biological anaerobic filters packed with sludge-fly ash ceramic particles (SFCP) and commercial ceramic particles (CCP) during the restart period: Effect of the C/N ratios and filter media

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ABSTRACT

Two lab-scale upflow biological anaerobic filters (BAF) packed with sludge-fly ash ceramic particles (SFCP) and commercial ceramic particles (CCP) were employed to investigate effects of the C/N ratios and filter media on the BAF performance during the restart period. The results indicated that BAF could be restarted normally after one-month cease. The C/N ratio of 4.0 was the thresholds of nitrate removal and nitrite accumulation. TN removal and phosphate uptake reached the maximum value at the same C/N ratio of 5.5. Ammonia formation was also found and excreted a negative influence on TN removal, especially when higher C/N ratios were applied. Nutrients were mainly degraded within the height of 25 cm from the bottom. In addition, SFCP, as novel filter media manufactured by wastes–dewatered sludge and fly ash, represented a better potential in inhibiting nitrite accumulation, TN removal and phosphate uptake due to their special characteristics in comparison with CCP.

1. Introduction

Biological anaerobic filters (BAF) are based on the immobilization of microorganisms on a support. This type of reactor has been widely applied due to its capacity for retaining bacteria attached to the media, easy acclimatization and anti-variation of the influent (Umana et al., 2008). The selection of biofilm support is considered to be one of the most significant aspects in the BAF design. Many materials such as refractory brick, special ceramic, polyurethane foam, PVC, (Picanco et al., 2001), zeolite (Nikolaeva et al., 2002), glass (Show and Tay, 1999), carbon filter, rock wool, loofah sponge and other materials (Yang et al., 2004) have been employed for the attachment and growth of anaerobic biomass. It can be summarized that the characteristics of the bed materials for immobilization have shown a significant influence on the reactor performance in all cases. For example, the reactor packed with high media porosity obtained better organics removal efficiency compared with that using non-porous supports (Show and Tay, 1999). It is notable that some filter media are derived from wastes such as waste tyre rubber (Reyes et al., 1999; Umana et al., 2008) and grain–slag (Yu et al., 2008), which provide us a new attempt of treating waste with waste.

In the present paper, sludge-fly ash ceramic particles (SFCP), as novel media made from wastes, were used for the supports of anaerobic biomass. This type of media has been successfully utilized in a biological aerobic filter (Han et al., 2009). The results indicated that the average consumed volumetric loading rates for CODcr, NH_4^+–N and TN with 200% recirculation were 4.06, 0.36 and 0.29 kg $(m^3\ d)^{-1}$, respectively, suggesting that the SFCP system had a remarkable superiority to that employing sand as support media (Ha and Ong, 2007). Thus, the applicability of SFCP in an anaerobic filter system would be an interesting exploration. Based on the characteristics of anaerobic filters, microorganisms can exist in the long run without any feed water. The BAF performance during the restart period was mainly investigated in terms of the nitrogen and orthophosphate uptake under different C/N ratios. In order to compare the effect of bed materials on the restart performance, commercial ceramic particles (CCP) were also employed due to their similar ceramic properties with SFCP.

2. Experimental

2.1. Methods

SFCP as novel media of BAF consist of two waste materials (dewatered sludge and fly ash) and clay with a mass ratio of 1:1:1; dewatered sludge was taken from Jinan Wastewater Treatment Plant and fly ash was obtained from Jinan Haihua Filter Material Plant, Shandong Province of China. The composition of three raw materials is as shown in Table 1. CCP were only made from clay. SFCP and CCP were prepared as follows: first, raw materials

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Table 1
The composition of raw materials (%).

Raw materials	SiO_2	Al_2O_3	MgO	CaO	Fe_2O_3, Na_2O, K_2O	Loss on ignition
Dewatered sludge	31.3	0.13	1.30	4.03	–	63.2
Clay	69.3	14.3	2.69	1.99	2.47	9.25
Fly ash	57.5	24.4	1.60	6.00	7.12	3.38

Table 2
The comparison on characteristics between SFCP and CCP.

Filter material	Total porosity (%)	Pore size distribution (μm)	Particle diameter (mm)	Bulk density (g cm^{-3})	Apparent density (g cm^{-3})	Total surface area (m^2 g^{-1})
SFCP	37.7	0.5–1.0	3–6	1.32	2.11	8.99
CCP	24.7	0.5–1.0	3–5	1.89	2.51	3.05

were mixed in a muller and transported into a rotational disk, and then tap water was injected to make powdered materials become particles with a similar diameter. Second, semi-manufactured SFCP were diverted to the front of a rotary kiln to finish desiccation and fired with a high temperature of 1100 °C. Finally, filter media were obtained and cooled off after screen separation. The characteristics of SFCP and CCP are specified in Table 2.

Two lab-scale upflow BAF were set-up as shown in Fig. 1: the cylindrical reactors made from polymethyl methacrylate had a diameter of 100 mm and a working volume of 3 L with a height of 1.6 m. SFCP (9 L) and CCP with an average grain diameter of 3–5 mm were filled in the column, respectively. At the top of the column, there was a buffer zone with a height of 35 cm to stop media being washed away during the backwashing operation. On each pillar, five sampling ports were located at a height of 25, 45, 65, 85 and 105 cm from the bottom flange. The influent was fed into the column with a feed pump and the inlet with a diameter of 1 cm was designed at 5 cm from the reactor base; the effluent from two columns was collected by an effluent tank. In addition, an aging biofilm outfall with a diameter of 2 cm was located under the column base.

During the restart period, the feeding solution was confected by sodium acetate trihydrate ($NaAc{\cdot}3H_2O$), potassium nitrate (KNO_3) and potassium biphosphate (KH_2PO_4). They were employed as single carbon source, nitrogen source and phosphorous source, respectively. It should be noted that the synthetic wastewater was not prepared in the form of a concentrate solution of acetate, nitrate and phosphate. For every batch experiment, the mass of KNO_3 and KH_2PO_4 used for feed water were invariable, while $NaAc{\cdot}3H_2O$ was quantified precisely on the basis of some C/N ratio.

CODcr concentration was obtained by calculating the mass of $NaAc{\cdot}3H_2O$ based on the fact that CODcr content of acetate is 0.47 mg CODcr/mg $NaAc{\cdot}3H_2O$ from the investigation of Ha and Ong (2007) and Isaacs and Henze (1995). In addition, the following parameters were determined: ammonia (NH_3-N), nitrite (NO_2^--N), nitrate (NO_3^--N) and orthophosphate (PO_4^{3-}-P). These determinations were carried out according to standard methods (State Environmental Protection Administration of China, 2002). In this article, total nitrogen (TN) was expressed as the sum of ammonia, nitrite and nitrate and organic nitrogen was negligible during the whole experiments. Temperature and pH were monitored routinely throughout the trials. The system was operated at a heating-control laboratory, where temperature ranged from 20 to 22 °C.

2.2. Inoculation, start-up and restart

The reactors were inoculated in July, 2008. First, biofilm cultured under the aerobic condition for two weeks was injected into the columns; and then, the BAF system was operated for one more week under the oxygen-controlled mode. Finally, inoculated biofilm could grow on the surface of the supports and begin to proliferate under the anaerobic condition. During the start-up, two reactors underwent a one-month acclimation period with the aim of improving biomass concentration. Hydraulic residence time (HRT) of 3.0 h was chosen with a C/N ratio of 3.0, corresponding to the influent NO_3^--N concentration of 35 mg L^{-1}. Phosphorous was added as a nutrient in the form of KH_2PO_4 with a concentration of 5 mg L^{-1}. In order to determine the steady-state conditions, the same feeding solution was provided continuously and the effluent nitrate was measured every day. When the effluent value was stable, the start-up period was considered to be finished. In addition, at the inoculation period, backwashing cycles were not

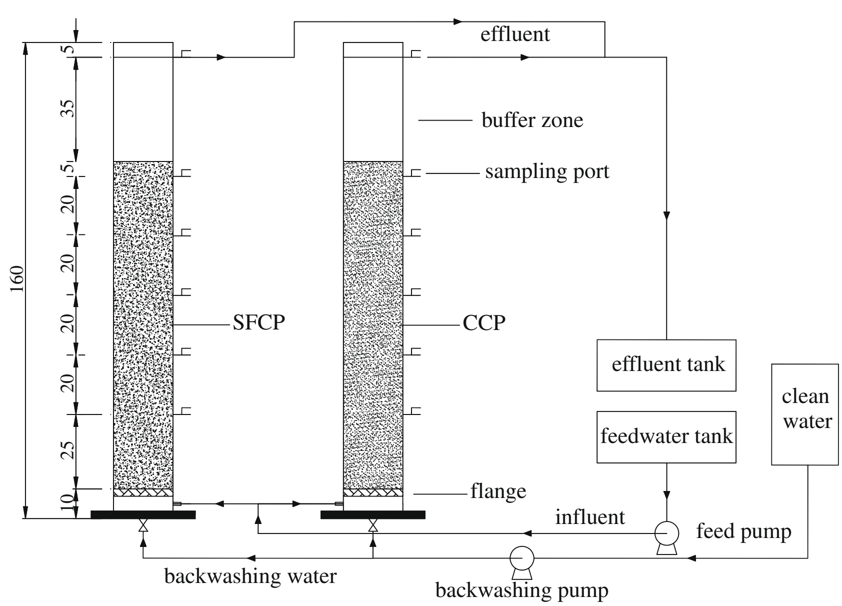

Fig. 1. Schematic diagram of experimental set-up (dimensioning unit: cm).