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Effects of packing rates of cubic-shaped polyurethane foam carriers on the microbial community and the removal of organics and nitrogen in moving bed biofilm reactors

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HIGHLIGHTS

- ▶ Three MBBRs with 20%, 30% and 40% packing rates of PUF cubes were constructed.
- ▶ Packing rates of the PUF had little influence on the COD removal efficiency.
- ▶ Ammonium removal was affected by the packing rates.
- ▶ Microprofiles revealed that dense biofilm limits the DO and nitrate diffusion.
- ▶ The structure of the microbial community was influenced by the packing rates of PUF.

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ABSTRACT

The effects of packing rates (20%, 30%, and 40%) of polyurethane foam (PUF) to the removal of organics and nitrogen were investigated by continuously feeding artificial sewage in three aerobic moving bed biofilm reactors. The results indicated that the packing rate of the PUF carriers had little influence on the COD removal efficiency (81% on average). However, ammonium removal was affected by the packing rates, which was presumably due to the different relative abundances of nitrifying bacteria. A high ammonium removal efficiency of 96.3% at a hydraulic retention time of 5 h was achieved in 40% packing rate reactor, compared with 37.4% in 20% packing rate. Microprofiles of dissolved oxygen and nitrate revealed that dense biofilm limits the DO transfer distance and nitrate diffusion. Pyrosequencing analysis of the biofilm showed that *Proteobacteria*, *Bacteroidetes* and *Verrucomicrobia* were the three most abundant phyla, but the proportions of the microbial community varied with the packing rate of the PUF carriers.

1. Introduction

With the rapid rate of urbanization and enactment of more stringent legislation, wastewater treatment plants are increasingly required to improve treatment capacity and efficiently eliminate organic substrates and nitrogen from wastewater. One of the solutions is the application of moving bed biofilm reactors (MBBR), which combine the advantages of both the activated sludge process and a biofilm reactor by incorporating free-floating carriers that provide large surface areas for biomass growth with no need for biomass recycling. Typical advantages of the MBBR system are the low head loss, absence of filter channeling, lack of prerequisite periodic backwashing, and provision of a large surface area for colonization and high specific biomass activity (McQuarrie and Boltz, 2011; Odegaard, 2006). To date, MBBRs have been successfully employed to treat sewage and industrial wastewater and upgrade small wastewater treatment plants (Loukidou and Zouboulis, 2001; Yang et al., 2009).

One of the key elements of the MBBR is the microbial carrier, which traditionally has a high specific area, surface roughness, high strength, porosity, and durability. Carriers are where the microorganisms accumulate to form a biofilm and enhance process effectiveness (Leenen et al., 1996). Biofilm carriers have included

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granular activated carbon, sand, diatomaceous earth, and polyethylene (Odegaard et al., 2000). The PUF carrier, which has a high porosity, is an ideal microbial carrier that promotes microbial self-immobilization and is characterized by good mechanical strength and low cost (Guo et al., 2010; Jun et al., 2003; Moe and Irvine, 2000). The rapid and stable attachment of microorganisms to the PUF carrier surface is the most important factor for the successful application of MBBR processes (Chae et al., 2008). The effects that size and type of PUF carrier have on treatment efficiency have been investigated (Nguyen et al., 2010; Xing et al., 2000). The results showed that cubic-shaped media of dimension 1.5–2 cm have the best performance in terms of both biomass growth and pollutant removal. Another advantage of PUF carriers is the simultaneous removal of carbonaceous and nitrogenous substances due to the limitation of dissolved oxygen (DO) diffusion in the cubic biofilm, which can be satisfactorily controlled by designing the size of the cubes. Around 40% total nitrogen removal was achieved in treating artificial sewage at a hydraulic retention time (HRT) of 4 h (Xing et al., 1995).

In biofilm systems, treatment performance mainly depends on the surface area available for biofilm growth, which is related to the characteristics and packing rates of the carriers. The study by Guo et al. (2010) demonstrated that the packing rate of PUF carriers had significant effects on phosphorus removal that were greater than its effects on organics or nitrogen removal. A reactor filled with 20% PUF carriers could achieve 99% total phosphorus (TP) removal with a short retention time in a fixed-bed biofilter during batch tests. Chu and Wang (2011) found that an MBBR filled with 20% PUF carriers demonstrated good performance in total organic carbon and ammonium removal. The packing rates of a LINPOR® process are generally reported in the range of 10–30% of the reactor volume (Morper and Wildmoser, 1990; Morper, 1994). Since the packing rates of microbial carriers will affect the organics and nitrogen removal efficiencies as well as the magnitude of the investment, a systematic study on the effects of packing rates on treatment performance in continuous MBBRs is needed.

Generally, packing rates of carriers affect the energy consumption and the cost of MBBRs. For highly porous PUF carriers, the packing rate can be expected to be lower than the conventional carriers for MBBRs. The objectives of this study were thus to systematically investigate the effects of the packing rate of PUF carriers on organics and nitrogen removal in MBBRs. Three packing rates of 20%, 30% and 40% were chose to construct three reactors in parallel according to our previous experience for the future application. The relationship between the chemical oxygen demand (COD) volume loading of carriers and the amount of attached biofilm was identified. We also used a microelectrode to measure the DO and nitrate microprofiles in biofilms with different densities. The diversity of microbial communities in biofilms with different packing rates was analyzed by using a pyrosequencing method. This study will contribute insights into developing MBBRs filled with PUF carriers for domestic wastewater treatment in practical applications.

2. Methods

2.1. Experimental setup and carriers

Three MBBRs with 20% (reactor 1), 30% (reactor 2), and 40% (reactor 3) packing rates of PUF cubes were assembled. The reactors were made of polymethyl methacrylate. Each reactor contained a 6-L aeration zone and a 1-L setting zone (Fig. 1). The bottom of the reactor was designed in triangular form to prevent settlement of the carriers. Air was injected through small holes (1.0 mm) in a pipe located on the bottom of the reactor. The sup-

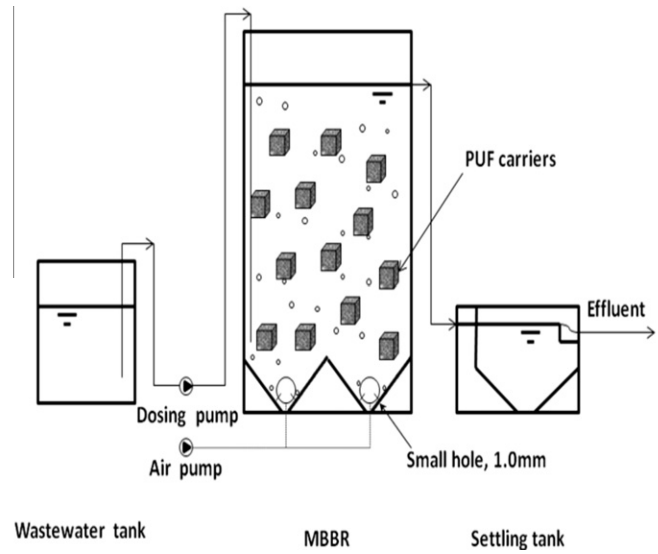

Fig. 1. Schematic diagram of the laboratory apparatus.

plied airflow rate was controlled at 200 L/h (0.56 vvm), 300 L/h (0.83 vvm), and 400 L/h (1.11 vvm) in reactors 1, 2, and 3, respectively, to keep the carriers floating and mixing well in the reactors. The DO concentration in the three reactors was 4–6 mg/L. All the other operating conditions for the three reactors were kept the same. The reactors were operated at 16.8–31.9 °C from April to October, 2011. The PUF carriers were cubic in shape with an average length of 1.5 cm per side and an average pore size of 1.47 mm. The bulk density and specific surface area were 25 kg/m^3 and 1120 m^2/m^3, respectively.

2.2. Wastewater and experimental procedures

Synthetic wastewater was prepared by dissolving glucose, NH_4Cl, KH_2PO_4, and trace elements in tap water. It consisted of 280–320 mg COD/L, 25 ± 3.0 mg NH_4–N/L, 5 ± 0.4 mg TP/L, and 0.1% (V/V) of a trace nutrient solution containing the following (g/L): $MgSO_4·7H_2O$, 2.5; $CaCl_2$, 1.5; $FeSO_4·7H_2O$, 0.28. The pH value was 7.7 ± 0.2.

Wastewater was continuously fed to the reactors using a peristaltic pump. The operation of the three MBBRs was started by inoculating activated sludge taken from an oxic tank at the Gaobeidian municipal wastewater treatment plant, Beijing, China. The initial sludge concentration was 3.0 g total suspended solids (TSS)/L. The MBBRs were in continuous operation in parallel for 6 months. During the start-up period of 30 days, the HRT was set at 24 h, and then reduced to 5 and 7 h for the following 175 days of operation in reactor 1, 3 and 3, respectively. The excess sludge in the settling tank was not returned to the aeration tank, but was discharged every week. The treatment performance was monitored by following NH_4–N, COD, and pH values in the effluent two to three times a week. A relative standard deviation was 1–5% for the analysis of the water quality.

2.3. Measurement of DO and nitrate profiles in the carriers using a microelectrode

Vertical profiles of DO and nitrate within the biofilms and carriers were measured using DO and nitrate liquid-membrane microelectrodes, which gave valuable information about transformations and the location of activities. Samples of PUF carrier with biofilm were taken from the three reactors and placed in a cell (Fig. 2),