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Performance study of the reduction of excess sludge and simultaneous removal of organic carbon and nitrogen by a combination of fluidized- and fixed-bed bioreactors with different structured macroporous carriers

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Abstract

Aiming for the reduction of excess sludge and the simultaneous removal of organic carbon and nitrogen, a new two-stage bioreactor system constructed by combining three-phase fluidized-bed (TFB) and sludge-reduction fixed-bed bioreactor (SFB) processes with different structured porous carriers was proposed. In this system, wastewater was first treated in the TFB bioreactor, in which the organic and nitrogenous compounds were simultaneously removed, and then the excess sludge produced in the TFB and residual organic substances flowed into the SFB for further degradation of suspended solids (SS) and nutrient removal. During a 470-day continuous operation, the average COD removal ratio reached about 95% at the influent COD of 500–600 mg/L. The removal ratio of T-N could reach up to 28–55% and was carried out through both microbial growth and simultaneous nitrification and denitrification (SND). The SS from TFB could be reduced in the following fixed-bed from 160 mg/L to 28 mg/L with two SFBs without the settling tank. Therefore, the simultaneous removal of organic carbon and nitrogen with an on-site reduction of excess sludge could be achieved in this two-stage bioreactor.

Keywords: Fluidized-bed bioreactor; Fixed-bed bioreactor; Porous carriers; Excess sludge reduction; Wastewater treatment; Nitrogen removal

1. Introduction

Nowadays, effective biological wastewater treatment and excess sludge reduction are becoming important issues for water pollution protection. Among the various biological wastewater treatment technologies, the three-phase fluidized-bed bioreactor (TFB) using porous microbial carriers has received much attention in recent years. The large surface area of porous carriers, such as polyurethane foam in a TFB, can ensure a high biomass concentration and efficient immobilization of slow-growing nitrifiers that enable the simultaneous removal of organic carbon and nitrogen to occur [1–4]. Meanwhile, since the immobilized microbes are used in this system, sludge yield is widely observed to be relatively lower compared to the traditional activated sludge process.

However, the TFB using porous carriers still often leads to the effluent containing suspended sludge due to the detachment of retained microbes from the carriers and their growth in the bioreactor. The microbial detachment from the carriers in a TFB is a complicated and inevitable process caused by erosion, abrasion, and sloughing [5]. In fact, such detachment is also necessary for the fluidized-bed reactors to maintain high organic removal efficiency [6]. Many researchers have thus focused on the detachment of the biofilm in TFB [7–9].

As a result, even though the yield of the sludge in the TFB with porous carriers is relatively smaller than that of the activated sludge, the suspended sludge formed in the TFB will also become the excess sludge which would need further treatment. Considering this problem, Miyanaga et al. [3] constructed a hybrid system consisting of a TFB with porous carriers and submerged microfiltration (MF) membrane which can retain the suspended sludge into the system. The amount of excess sludge generated in the hybrid system can be reduced to about one-fourth of that in the single TFB. However, the utilization of the membrane still has the typical problems of a membrane biore-

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actor, such as membrane fouling and the complicated operation in membrane reverse washing during the treatment.

In our previous study, a new fixed-bed bioreactor capable of repeatedly coupling aerobes and anaerobes by using porous carriers made of small stone particles [10] and alternative aeration along the flow direction in the reactor was constructed, and it successfully realized the significant reduction of excess sludge during the biological wastewater treatment [11]. Since the size of the porous carriers is large enough (around 10 cm in diameter), the sludge-reduction fixed-bed bioreactor (SFB) can be ran satisfactorily without any sludge blocking during the wastewater treatment. This bioreactor has been successfully applied to the treatment of inosine wastewater in pilot scale in China [12]. The possible mechanisms of on-site sludge reduction in such kind of reactor have been discussed in our previous work [11]. The solubilization and degradation of over-growing aerobes by the anaerobes after moving into the anaerobic regions, decoupling of the microbial anabolism and catabolism of aerobes, and the existence of a complex microbial community with more metazoan in the bioreactor are the most important factors for the wastewater treatment and excess sludge reduction. However, in this bioreactor with on-site sludge reduction, nitrification seems to be a limiting step in nitrogen removal, especially at a short hydraulic retention time (HRT), even though the alternative formation of aerobic and anaerobic environments along the reactor can benefit the occurrence of simultaneous nitrification and denitrification [1]. The possible reason for this phenomenon may be the formation of soluble microbial products (SMP) that can inhibit nitrification after the sludge is degraded to release SMP [13]. Thus, a combination of the TFB and SFB using the respective structured porous carriers can be expected to reach the simultaneous removal of COD and nitrogen from the wastewater, as well as initiate sludge reduction at the same time.

In this study, a TFB with polyurethane particles connected with an SFB using the porous carriers made of small stone particles [10] was constructed. The performance of this reactor system was examined in terms of COD removal ratio, nitrogen removal ratio, and changes in phosphorus and SS concentrations through the continuous treatment of an artificial sewage. Transformations of soluble components and SS along the flow direction were also discussed.

2. Materials and method

2.1. Experimental apparatus and procedure

The reactor system consisted of two parts, a TFB connected with an SFB, as shown in Fig. 1. Depending upon the experimental necessity, the TFB had a volume of either 8 L or 16 L and was obtained by controlling the outlet position. Porous 15-mm polyurethane cubes (average pore size: 1.47 mm; density: 30 kg/m^3) were placed in the TFB with a final packing ratio of 12.5% (v/v) [1]. Air was supplied by a sparger at the bottom of the reactor. The second part, the SFB, was one or two-sequential fixed-bed reactor(s) with the respective sizes of 0.5 m (L) × 0.4 m (W) × 0.3 m (H) and 0.5 m (L) × 0.4 m (W) × 0.25 m (H) (H: effective height, i.e., liquid level). About 60 macroporous stone carriers with a 10 cm diameter spherical structure (porosity: 40%) called Jarikko [10] were fully packed in each SFB with the total porosity of about 60%. The carriers were made by small stones with a diameter of 1.5–2.5 cm adhered by an adhesive agent into the above spherical porous carriers. A baffle plate was set in the middle of each SFB to extend the water flow distance to 1.0 m in each SFB. At the bottom of each SFB, aeration tubes were settled every 0.5 m along the flow direction, i.e., at position 0.5 m and 1 m, to form an alternative appearance of aerobic and anaerobic regions. The size of opening in the aeration tubes was 2–3 mm in diameter, through which the bubbles could be formed. As shown in Fig. 2, the DO concentration at the aerobic regions could be maintained between 3 mg/L and 4 mg/L, while the DO concentration was below 1.5 mg/L at the surface of the anaerobic regions.

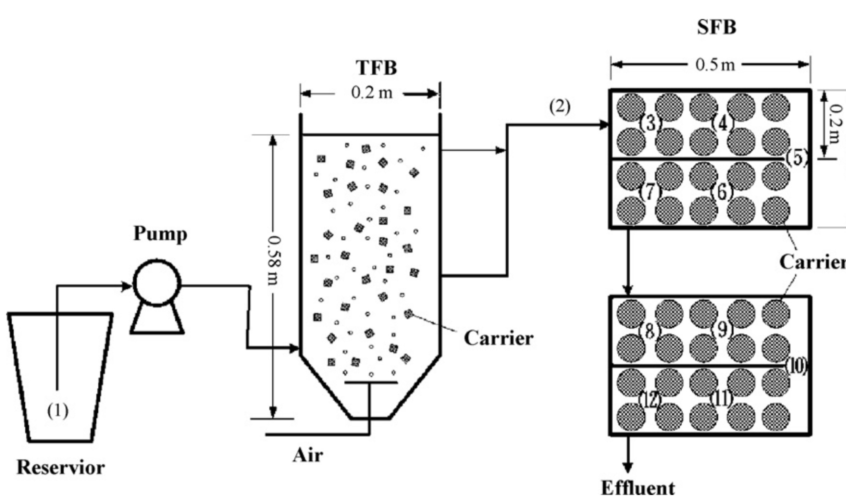

Fig. 1. Schematic diagram of the reactor system consisting of TFB and SFB. TFB, the side view of the three-phase fluidized-bed bioreactor; SFB, the top view of the sludge-reduction fixed-bed bioreactor; The following are the sampling sites along the flow direction: 1, artificial wastewater reservoir; 2, TFB effluent; 5, 7, 10, and 12, aeration positions by air spargers; 3, 4, 6, 8, 9, and 11, non-aeration regions.