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Enhanced nitrification at short hydraulic retention time using a 3-stage biological aerated filter system incorporating an organic polishing reactor

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ABSTRACT

In this work, a 3-stage biological aerated filter (BAF) system was proposed for the enhancement of nitrification at short hydraulic retention time (HRT). This was done by incorporating an intermittent aeration reactor, as an organic polishing reactor, into a conventional 2-stage pre-denitrification/nitrification BAF system. Laboratory experiments were performed at three different HRTs (i.e., 3, 2 and 1 h). Experimental results clearly showed that NH_4-N removal of a conventional BAF system severely deteriorated in the presence of even a very small amount of organic matter at the short HRT of 1 h. Moreover, nitrite accumulation was observed at this HRT. This means that organic matter could be a limiting factor in nitrification at short HRTs. These problems were effectively controlled in the 3-stage BAF system. When the HRT of a conventional BAF system was reduced from 2 to 1 h, NH_4-N removal decreased in from 96.6% to 74.0%. In contrast, for the experimental 3-stage BAF system, NH_4-N removal remained high over 94% at the HRT of 1 h. This was because the polishing reactor eliminated organic matter before it could enter the nitrification reactor. Finally, this organic polishing reactor contributed to the higher removal of T-N and T-P.

1. Introduction

The biological aerated filter (BAF) system was developed in the 1980s and 1990s as a novel wastewater treatment system due to its advantages relative to other systems [1]. Conventionally, BAF is submerged media wastewater treatment reactors that combine biological treatment and biomass separation by depth filtration [2]. BAF also offers a small footprint alternative to conventional oxic processes and can be operated at high loadings of biochemical oxygen demand (BOD) compared with activated sludge processes. Furthermore, in a single BAF operation unit, carbonaceous BOD removal, filtration of solids and nitrification can be achieved simultaneously [3]. In recent years, BAF has been applied effectively for the removal of nitrogen with a pre-denitrification configuration [4–6].

Although BAF system has many advantages, it must be properly modified to perform nitrification at shorter hydraulic retention time (HRT) because the operation of BAF system over long HRTs reduces the quantity of wastewater which can be treated. This limitation is a serious concern for countries like South Korea, where available land is very limited and there is a serious need to treat wastewater with a short HRT. Moreover, more stringent effluent criteria for total nitrogen (T-N) were applied to treatment of sewage wastewater in South Korea in 2012. This means that BAF system badly needs to be modified to nitrify nitrogen (NH_4-N) well; even under extreme conditions, such as very short HRT.

In previous BAF studies, it was reported that nitrification performance noticeably deteriorated as the HRT decreased [7–11]. It is obvious that this is due to the increase in organic and ammonia nitrogen loads that typically result from an increase in HRT. Specifically, nitrification performance in a BAF system would be critically affected by the organic matter content when the BAF system is operated at very short HRT. Qiu et al. [10] clearly showed that up to 50% ammonia nitrogen had been removed when influent COD loading was below 6 kg/m^3 d. Ji et al. [12] also reported that NH_4-N removal in the BAF systems decreased 3% following an increase in organic loading from 0.39 to 1.56 kg COD/m^3 d,

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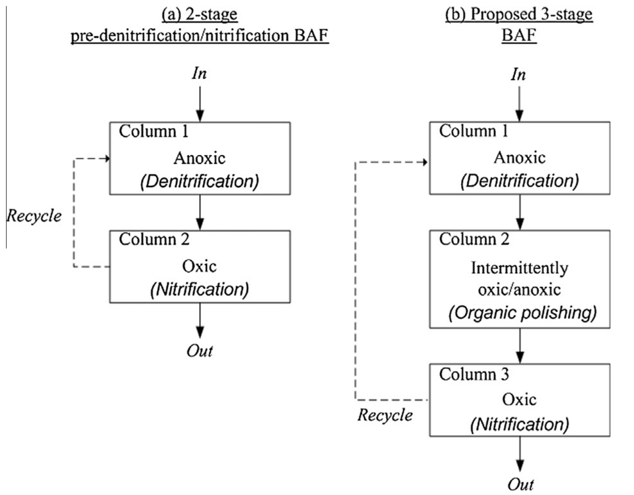

Fig. 1. Comparison of operational concepts of: (a) conventional 2-stage pre-denitrification/nitrification BAF system and (b) the proposed 3-stage BAF system. The functions of each column are indicated in parentheses.

corresponding to an HRT range of 2.15–5.73 h. In a similar way, Jie showed that the rate of nitrification decreased with increasing organic concentration of nitrifying biofilms [13].

Therefore, it was urged that existing BAF systems be modified for enhanced nitrification performance at short HRT by controlling organic matter entering nitrification reactor. However, to the best of our knowledge, such an attempt has not been made previously even though it has been reported that even a small quantity of organics may be critical in nitrification using BAF systems at short HRT. The operation of BAF system at short HRT was just applied to the treatment of primary treated wastewater or municipal wastewater for tertiary nitrification alone [14–16].

In order to solve this problem, we propose a refined 3-stage BAF system by modifying the 2-stage pre-denitrification/nitrification BAF system (see Fig. 1a), within which both nitrification and denitrification are possible [17]. To control the organic matter entering the nitrification reactor in the proposed 3-stage BAF system, an organic polishing reactor was incorporated into the 2-stage pre-denitrification/nitrification BAF system (see Fig. 1b). Fig. 1b shows the operational concept of the proposed 3-stage BAF process and compares it with that of the 2-stage pre-denitrification/nitrification BAF system in Fig. 1a. The anoxic column of the 3-stage BAF system functions to denitrify nitrified wastewater, which is recycled from the oxic column. In the intermittent aeration column, part of the substrate in the influent is adsorbed onto the biomass attached to the media, and accumulated within bacterial cells. These play the role of organic polishing; thus minimizing the amount of organics that are introduced into the oxic column. After that, the ammonia-rich liquid streams go to the next oxic column where fast nitrification occurs without interference from organic matter. This configuration of the proposed system would maximize nitrification efficiency at short HRT by eliminating organics entering the nitrification reactor.

In this manner, the experimental plan was designed to evaluate the performance of the process proposed in this study. The evaluations were mainly focused on nitrification by comparing two systems at HRTs of 3, 2 and 1 h.

2. Materials and methods

2.1. System setup and operation

The experimental work was performed using two lab-scale BAF systems. One was a conventional 2-stage pre-denitrification/nitrification BAF system (hereafter called "Control") as shown in Fig. 1a. The other was the proposed 3-stage BAF system, for which an intermittent aeration reactor functioned as an organic polishing reactor, was incorporated into the "Control" reactor (see Figs. 1b and 2) for the purpose of enhancing the performance of biological nitrification. The 3-stage BAF system was composed of three upflow biofilter columns connected in series. Each column was 1.90 m in height and 0.9 m in diameter. The anoxic, intermittent and oxic columns were packed with expanded polystyrene (EPS) media (approximately 2 to 3 mm in diameter and over 2000 m^2/m^3 average specific surface area) to a depth of about 0.90, 0.45 and 0.90 m, respectively. Therefore, the effective volumes of the anoxic, intermittent and oxic columns were 6, 3 and 6 L, respectively. The density of the packing media was 15 kg/m^3. In the oxic column, air-flow through diffusers at the bottom of the column was provided to maintain a dissolved oxygen (DO) concentration of 5 ± 0.5 mg/L. In contrast, DO was not provided in the anoxic columns. In the intermittently aerated column, oxic and anoxic conditions alternated. A 1:1 h time-ratio

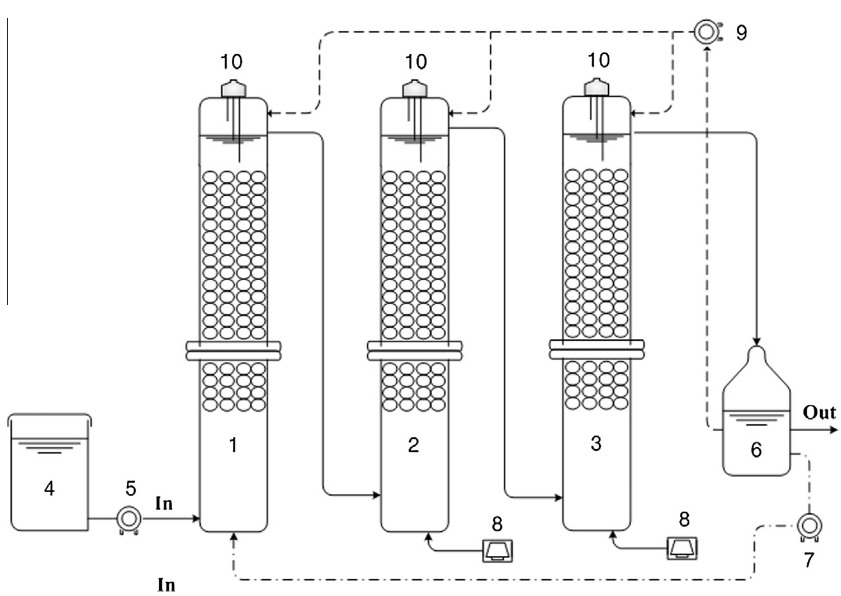

Fig. 2. Schematic of the 3-stage BAF system proposed in this work: (1) anoxic column; (2) intermittent aeration column; (3) oxic column; (4) influent wastewater tank; (5) influent pump; (6) effluent storage tank; (7) recycle pump; (8) air blower; (9) backwashing pump; (10) level switch.