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Long-term nitritation performance of ammonium-rich landfill leachate☆

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ABSTRACT

This study presents a biological system combined upflow anaerobic sludge bed (UASB) with sequencing batch reactor (SBR) to treat ammonium-rich landfill leachate. The start-up and operation of the nitritation at low temperatures were investigated. The synergetic interaction of free ammonia (FA) inhibition on nitrite-oxidizing bacteria (NOB) and process control was used to achieve nitritation in the SBR. It is demonstrated that nitritation was successfully started up in the SBR at low temperatures (14.0 °C–18.2 °C) by using FA inhibition coupled with process control, and then was maintained for 482 days at normal/low temperature. Although ammonia-oxidizing bacteria (AOB) and NOB co-existed within bacterial clusters in the SBR sludge, AOB were confirmed to be dominant nitrifying population species by scanning electron microscopic (SEM) observation and fluorescence in situ hybridization (FISH) analysis. This confirmation not only emphasized that cultivating the appropriate bacteria is essential for achieving stable nitritation performance, but it also revealed that NOB activity was strongly inhibited by FA rather than being eliminated altogether from the system.

1. Introduction

This leachate is characterized by small amounts of biodegradable organics; high concentrations of ammonia, chemical oxygen demand (COD), and suspended solids (SS); low ratios of B/C and C/N [1,2]. If not treated safely, landfill leachate can be a major source of environmental pollution.

To treat landfill leachate in a more economic and sustainable way, researchers [3–5] have recently introduced a method for removing nitrogen via the nitrite pathway because this pathway has distinct advantages over the nitrate pathway [6,7]. In order to establish the nitrite pathway, stable nitritation (ammonia being oxidized to nitrite) must be achieved in nitrification.

It has been widely reported that a high concentration of free ammonia (FA) can promote nitrite accumulation by selectively inhibiting the activity of nitrite oxidizing bacteria (NOB) but not ammonia oxidizing bacteria (AOB) [8]. Therefore, FA inhibition is an effective way to remove nitrogen from leachate via the nitrite pathway.

Moreover, process control has been found effective for achieving nitritation in SBRs treating domestic wastewater [9–11]. Previous literatures [12–14] have also reported that the nitrifying bacterial population can be optimized through long-term application of process control, which implicates AOB, rather than NOB, as the dominant nitrifying bacteria involved in nitritation.

Temperature is typically an important parameter for achieving nitritation. High temperatures will cause AOB to outcompete NOB because they grow faster than NOB at temperatures higher than 25 °C, leading to nitrite accumulation [15]. For this reason, nitritation is easily achieved at high temperatures. Interestingly, several studies [13,14,16] have also shown that nitritation can be achieved and maintained at low temperatures. For example, Yang *et al.* [13] treated municipal wastewater in a pilot-scale sequencing batch reactor (SBR) and Qiao *et al.* [16] treated high-ammonium wastewater in a swim-bed reactor; both studies reported that nitritation was initiated at normal temperatures (above 20 °C) and maintained at low temperatures (blow 20 °C). To the best of our knowledge, however, only Gu *et al.* [14] successfully started up nitritation at low temperatures (11 °C–16 °C) using a pilot-plant SBR to treat municipal wastewater.

In this research, we established a biological system coupled upflow anaerobic sludge bed (UASB) and sequencing batch reactor (SBR) to treat ammonium-rich landfill leachate. Based on the achievement of simultaneous removal of organics and nitrogen from leachate, we expect to develop a novel method for starting up and maintaining nitritation at low temperatures. Moreover, microbial spatial distribution and the morphology of nitrifying bacteria population in the sludge flocs were analyzed.

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2. Materials and Methods

2.1. Experimental lab-scale reactor

Fig. 1 shows the two-component lab-scale system, which includes an UASB and a SBR. The working volumes of UASB and SBR were 3 L and 9 L, respectively. The SBR contained three sidewall ports in which sensors for dissolved oxygen (DO), pH, and oxidation–reduction potential (ORP) were inserted. An equalization tank was designed to adjust the conflict between continuous effluent in the UASB and intermittent influent in the SBR.

The temperature of the mixed liquor in the UASB was maintained at 30 °C ± 2 °C using a heating water jacket and a temperature control system. The SBR was operated at room temperature (9.0 °C–32.1 °C). DO was supplied by an air compressor through a porous diffuser installed at the bottom of the SBR. Complete mixing was provided by a mechanical stirrer rotating at a speed of 40 $r \cdot min^{-1}$.

2.2. Operational procedures

A wastewater mixture, consisting of the raw landfill leachate and SBR-nitrified supernatant (SNS), was continuously pumped into the UASB using peristaltic pumps. The SBR was fed with the UASB effluent. Each cycle of the SBR consisted of 2-min feeding, aerobic reaction, 30-min settling, 15-min SNS recycling anoxic reaction, 30-min settling, 10-min decanting, and idling period. The duration of the aerobic and anoxic reactions were controlled by monitoring characteristic points on DO, pH, and ORP profiles.

The UASB–SBR system was operated for 623 days. The experiment was divided into three periods according to the nitrogen removal pathway in the SBR. In Period I (0–115 days), nitrogen removal was performed via the nitrate pathway. In Period II (116–141 days), nitrogen removal was initiated via the nitrite pathway at low temperatures. In Period III (142–623 days), the nitrite pathway was maintained at normal and low temperatures.

Table 1 summarizes the detailed operational conditions of the UASB–SBR system during the whole experimental period. After inoculation, the UASB was fed with a mixture of the raw leachate and the returned SNS at suitable ratios. For the first 89 days of operation, raw leachate was diluted by tap water to acclimate the inoculated sludge to leachate. The designed dilution ratios were 5, 3, 2, and 1.5. Subsequently, raw leachate was not diluted. During the first 89 days, the influent COD of the UASB gradually increased due to the decrease of the dilution ratios. The influent biodegradable COD was removed by denitrification and methanogenesis in the UASB.

The low effluent COD of the UASB benefited the rapid nitrification of the ammonia in the SBR.

2.3. Landfill leachate

The landfill leachate was taken from the Liulitun municipal landfill site in Beijing, China. The leachate samples were collected monthly, transported to the laboratory, and then stored at 4 °C. Characteristics of the leachate are described in Table 2.

2.4. Inoculums

The UASB was inoculated with anaerobic granulated sludge taken from a methanogenic reactor of a wastewater treatment plant of Harbin brewery (located in Heilongjiang province, China). The SBR was seeded with aerobic activated sludge taken from a Municipal Wastewater Treatment Plant (located in Beijing, China), where the oxidation ditch process was employed. The concentrations of mixed liquor suspended solids (MLSS) in the SBR were 1340–4400 $mg \cdot L^{-1}$.

2.5. Analyses

COD, BOD_5, NH_4^+–N, NO_3^-–N, NO_2^-–N, MLSS, TS, and alkalinity were examined according to the Standard Methods [17]. TN was analyzed using a multi N/C 3000 analyzer (Analytik Jena AG, Germany). DO, pH, and ORP were continuously detected using pH/oxi-340 analyzer (WTW Company, Germany).

2.6. Microbiology analysis

Fluorescence in situ hybridization (FISH) was performed as specified by Amann [18]. Specific oligonucleotide probes used in this experiment were EUBmix for detecting all bacteria; NSO1225 specific for ammonia-oxidizing β-proteobacteria; NIT3 specific for *Nitrobacter*; and Ntspa662 specific for *Nitrospira*. FISH images were captured using an OLYMPUS-BX52 fluorescence microscope (Japan). The quantitative analysis of FISH images was performed using Leica QW in quantitative microscopy software, where the relative abundance of the target bacteria was determined in triplicate as the mean percentage of all bacteria.

Scanning electron microscopy (SEM) was used to observe the morphological characteristics of the dominant nitrifying bacteria

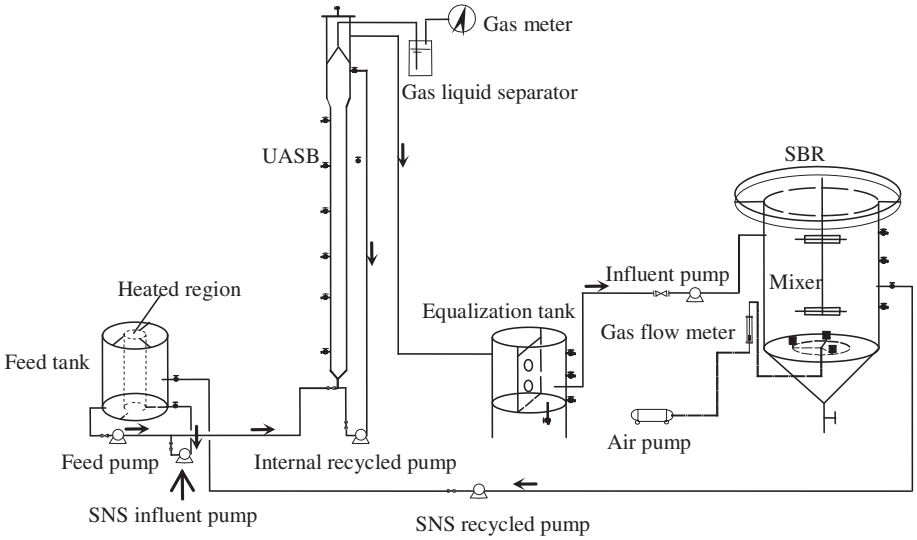

Fig. 1. Schematic diagram of the UASB–SBR biological system.