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Advanced treatment of landfill leachate using anaerobic–aerobic process: Organic removal by simultaneous denitritation and methanogenesis and nitrogen removal via nitrite

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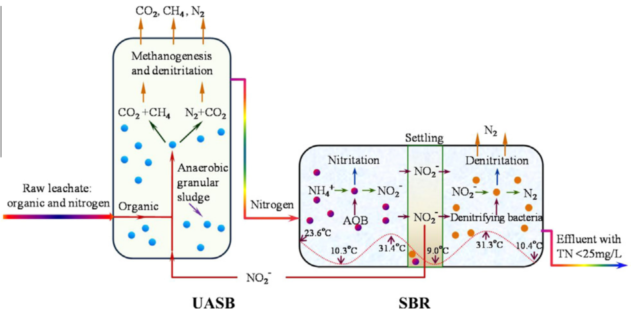
HIGHLIGHTS

- Advanced treatment of landfill leachate was achieved in an anaerobic–aerobic system.
- Simultaneous denitritation and methanogenesis was obtained to enhance TN removal.
- Nitritation was achieved at low temperatures by FA inhibition and process control.
- Process control can avoid excess aeration, allowing FA to continue to inhibit NOB.
- The dominant AOB explains essentially the stable nitritation at low temperatures.

GRAPHICAL ABSTRACT



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ABSTRACT

A novel biological system coupling an UASB and a SBR was established to treat landfill leachate. In order to enhance organics and nitrogen removal, simultaneous denitritation and methanogenesis (SDM) was performed in the UASB. Free ammonia (FA) inhibition on nitrite-oxidizing bacteria (NOB) and process control was used to achieve nitrite pathway in the SBR. Results over 623 days showed that the maximum organic removal rate in the UASB and the maximum ammonium oxidization rate in the SBR was 12.7 $kgCOD/m^3$ d and 0.96 kgN/m^3 d, respectively. The system achieved COD, TN, and NH_4^+–N removal efficiencies of 93.5%, 99.5%, and 99.1%, respectively. By using FA inhibition coupled with process control, the nitrite pathway was started-up in the SBR at low temperatures (14.0–18.2 °C) and was maintained for 142 days at temperatures below 15 °C (the lowest level was 9.0 °C). The predominant ammonia-oxidizing bacteria (AOB) explains essentially stable nitritation obtained.

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1. Introduction

Municipal landfill leachate is generated during the decomposition of municipal solid waste (MSW) in landfills. 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, as well as a significant amount of inorganic salts, toxic pollutants, and heavy metals (Renou et al., 2008; Irene and Lo, 1996). If not treated safely, landfill leachate can be a major source of environmental pollution.

In order to reduce the negative impacts of leachate on the environment, many combined physical, chemical, and biological processes are suited to treating leachate, including anaerobic and aerobic biological treatments (Wei et al., 2012; Kargi and Yunus Pamukoglu, 2003) and physicochemical and electrochemical oxidation methods (Kurniawan et al., 2006; Zhang et al., 2009). Various physicochemical techniques, such as air stripping, adsorption, coagulation–flocculation, membrane filtration, electrochemical oxidation, and so on, have been extensively used to treat leachate due to their advantages including plant simplicity, smaller footprint, lower sensitivity to temperature, and higher resistance to toxic agents. But these benefits are counteracted by remarkable shortcomings such as higher energy consumption, operational costs, and post-treatment costs for concentrated liquor.

Among these, joining anaerobic and aerobic biological treatments (Peng et al., 2008; Ağdağ and Sponza, 2005; Im et al., 2001) are effective and competitive because they can produce good effluent quality, offer organic and nitrogen removal, and they are cost effective, simple, and do not transfer pollution. Therefore, the biological approach that combines anaerobic and aerobic system has been recommended as a feasible method for removing organics and nitrogen from landfill leachate. However, when considering mature leachate, the major weakness of anaerobic–aerobic technology is that it is difficult to satisfactorily remove total nitrogen (TN) due to the lack of carbon source for denitrification. The highest removal efficiency of TN was 81–93% in the two-stage UASB and anoxic–oxic (A/O) reactor by Peng et al. (2008). However, the final effluent TN of the system was always kept within the range of 170–250 mg/L, which could not meets the stringent discharge standards of landfill leachate.

In previous studies (Peng et al., 2008; Andalib et al., 2008) that used an anaerobic–aerobic biological system for treating landfill leachate, simultaneous denitrification/denitritation and methanogenesis (SDM) was successfully performed in the anaerobic reactor, which enhanced TN and COD removal. The maximum NO^{-}_{x}–N reduction efficiency and rate in the anaerobic reactor were above 99% and 3.0 kg NO^{-}_{x}–N/m^3 d, respectively.

To treat landfill leachate in a more economic and sustainable way, researchers (Wang et al., 2013; Peng et al., 2008) have recently introduced a method for removing nitrogen via the nitrite pathway because this pathway has distinct advantages over the nitrate pathway. 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) (Ganigué et al., 2007; Kim et al., 2006). Therefore, FA inhibition is an effective way to remove nitrogen from landfill leachate via the nitrite pathway.

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 (Hellinga et al., 1998). For this reason, nitritation is easily achieved at high temperatures. Interestingly, several studies have also shown that nitritation can be achieved and maintained at low temperatures. For example, Yang et al. (2007) treated municipal wastewater in a pilot-scale sequencing batch reactor (SBR) and Qiao et al. (2010) 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). Furthermore, the study by Qiao et al. accomplished a high rate of nitritation at a temperature range of 10–20 °C. However, limited study reported nitritation was successfully started up at low temperatures (11–16 °C) using a pilot-plant SBR to treat municipal wastewater (Gu et al., 2012).

In general, process control has proven useful for improving the performance and efficiency of biological nitrogen removal (BNR) processes, especially when these processes employed the nitrite pathway (Zanetti et al., 2012). On the other hand, process control has been found effective for achieving nitritation in SBRs treating domestic wastewater (Guo et al., 2009; Wang et al., 2008). Moreover, previous studies (Gu et al., 2012; Yang et al., 2007) have also shown that the nitrifying bacterial population could be optimized through long-term application of process control, which implicates AOB, rather than NOB, as the dominant nitrifying bacteria involved in nitritation.

The specific objectives of this study were threefold. First, the long-term performance of a biological system consisting of an upflow anaerobic sludge bed (UASB) and a sequencing batch reactor (SBR) to simultaneously remove organics and nitrogen from landfill leachate was investigated, Second, an effective method for rapidly achieving and stably maintaining nitritation in an SBR at low temperatures was developed, Finally, the microbial spatial distribution and the morphology of AOB and NOB in the sludge flocs in the SBR was analyzed by using fluorescence in situ hybridization (FISH) and scanning electron microscopy (SEM).

2. Methods

2.1. A lab-scale biological system

Fig. 1 shows the experimental system, which includes a feed tank, an UASB, an equalization tank, and a SBR. The UASB reactor had a working volume of 3 L, an inner diameter of 50 mm, and a height of 1500 mm. The SBR had an effective volume of 9 L. 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 (9.0–32.1 °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 rpm.

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 UASB was operated in a simultaneous anaerobic and anoxic mode for the removal of COD and NO^{-}_{x}–N. The SBR was fed with the UASB effluent, and it was operated under alternating aerobic and anoxic conditions. 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