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Advanced landfill leachate treatment using a two-stage UASB-SBR system at low temperature

Hongwei Sun, Qing Yang, Yongzhen Peng*, Xiaoning Shi, Shuying Wang, Shujun Zhang

Key Laboratory of Beijing Water Quality Science and Water Environment Recovery Engineering, Beijing University of Technology, Beijing 100124, China. E-mail: shw@emails.bjut.edu.cn

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Abstract

A two-stage upflow anaerobic sludge blanket (UASB) and sequencing batch reactor (SBR) system was introduced to treat landfill leachate for advanced removal of COD and nitrogen at low temperature. In order to improve the total nitrogen (TN) removal efficiency and to reduce the COD requirement for denitrification, the raw leachate with recycled SBR nitrification supernatant was pumped into the first-stage UASB (UASB1) to achieve simultaneous denitrification and methanogenesis. The results showed that UASB1 played an important role in COD removal and UASB2 and SBR further enhanced the nutrient removal efficiency. When the organic loading rates of UASB1, UASB2 and SBR were 11.95, 1.63 and 1.29 kg COD/(m^3·day), respectively, the total COD removal efficiency of the whole system reached 96.7%. The SBR acted as the real undertaker for NH_4^+-N removal due to aerobic nitrification. The system obtained about 99.7% of NH_4^+-N removal efficiency at relatively low temperature (14.9–10.9°C). More than 98.3% TN was removed through complete denitrification in UASB1 and SBR. In addition, temperature had a significant effect on the rates of nitrification and denitrification rather than the removal of TN and NH_4^+-N once the complete nitrification and denitrification were achieved.

Key words: landfill leachate; two-stage UASB-SBR; advanced nitrogen removal; low temperature; nitrification; denitrification

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Introduction

Landfill leachate which contains high concentrations of organics and nitrogen is primarily generated from the leaching of municipal solid waste and need to be treated before discharge. In recent years, various combined processes, such as anaerobic and aerobic biological system (Kettunen et al., 1996; Im et al., 2001; Ahn et al., 2002a; Ağdağ and Sponza, 2005; Chen et al., 2007; Liang and Liu, 2008; Peng et al., 2008), coagulation-flocculation, chemical and electrochemical oxidation (Chiang et al., 2001; Ahn et al., 2002b; Haapea et al., 2002; Zhang et al., 2009) have been applied in the treatment of landfill leachate. Among these, the anaerobic and aerobic systems have been proved to be one of the most efficient processes for simultaneous ammonium and organics removal from landfill leachate (Ağdağ and Sponza, 2005; Chen et al., 2007; Peng et al., 2008).

Most of the ammonium and organics can be removed from leachate via anaerobic and aerobic system, but total nitrogen (TN) removal in the subsequent anoxic-aerobic reactor is limited due to the deficient carbon source for denitrification. So far, the simultaneous and advanced nitrogen and organics removal from landfill leachate using a two-stage upflow anaerobic sludge blanket (UASB) and sequencing batch reactor (SBR) system is not been reported. To our knowledge, this is the first report on advanced landfill leachate treatment in a two-stage UASB-SBR system.

This work aims to: (1) present a two-stage UASB-SBR system as a feasible process for advanced treatment of landfill leachate, (2) achieve advanced nitrogen removal from landfill leachate in the subsequent SBR at low temperature, and (3) investigate the effects of temperature on the rates of nitrification and denitrification.

1 Materials and methods

1.1 Experimental set-up and operation procedure

Figure 1 shows the experimental treatment system, which consist of two-stage UASB and a SBR. The working volumes of UASB1, UASB2 and SBR were 3, 4.5, and 9 L, respectively. The upper part of the UASB reactor was designed for good separation of gas, liquid and solid. The temperatures in UASB1 and UASB2 were maintained by a heater and thermostat at (30 ± 2)°C and (35 ± 2)°C, respectively. The SBR was operated at the ambient temperature (20.7–10.9°C).

* Corresponding author. E-mail: pyz@bjut.edu.cn

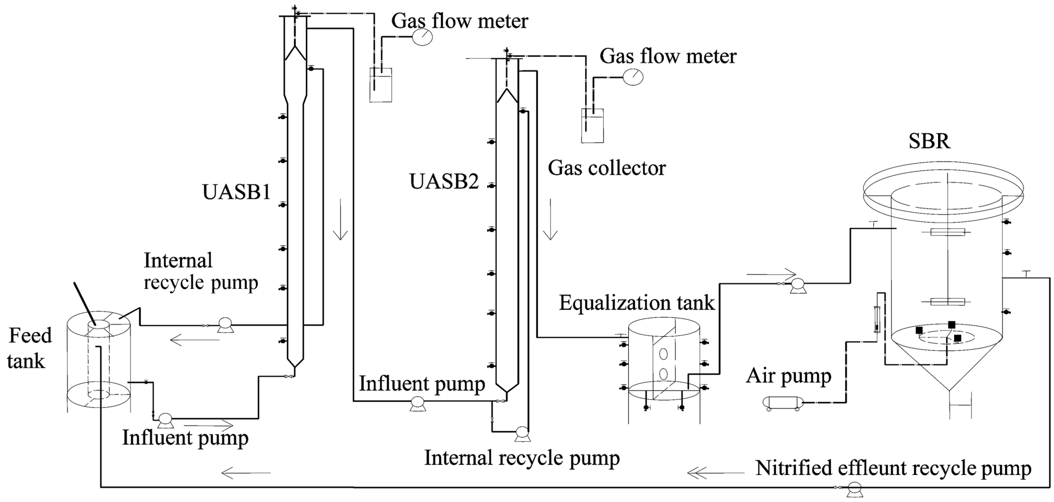

Fig. 1 Schematic diagram of the two-stage UASB-SBR system.

The influent of UASB1 was a mixture of raw leachate and returned SBR nitrification supernatant (SNS) with a recirculation ratio of 200%. The effluent from UASB1 was pumped into UASB2. The effluent of UASB2 was used as the influent of SBR. The SBR was operated with a cycle time of 24 hr consisting of transient filling, 16 hr aeration, 0.5 hr settling, 0.5 hr supernatant recycling, 6 hr anoxic mixing (add external carbon source), 0.5 hr settling and 0.5 hr discharging.

The hydraulic retention time (HRTs) in UASB1, UASB2 and SBR were 1.0, 1.5 and 1.5 days, respectively. The dissolved oxygen (DO) during aerobic phase of SBR was kept below 1.0 mg/L. It should be noted that the completion of nitrification and denitrification was indicated through the application of real-time control (Li and Bishop, 2002; Wang et al., 2004; Yang et al., 2007; Qureshi et al., 2008) .

1.2 Characteristics of landfill leachate

Landfill leachate was sampled every month from Beijing Liulitun Municipal Solid Waste Sanitary Landfill, China. Its characteristics were: COD 7856–22,500 mg/L, NH_4^+-N 738–1287 mg/L, TN 839–1390 mg/L, pH 7.1–8.5, black and brown color, and strong smelling.

1.3 Sludge

Granulated anaerobic sludge from Haerbin beer wastewater treatment plant in Heilongjiang, China was seeded in the UASB reactors. The aerobic activated sludge taken from Jiuxianqiao Municipal Wastewater Treatment Plant in Beijing was seeded in SBR. The mixed liquor suspended solids was maintained at the concentration of 2500–3500 mg/L in SBR during the experimental period.

1.4 Analyses

Ammonium, NO_3^--N, NO_2^--N and COD were measured according to the standard methods (APHA, 1995). TN was analyzed by using TN/TOC analyzer (Multi N/C3000, AnaltikjenaAG, Germany). DO, pH, ORP and temperature were monitored by using pH/Oxi 340i analyzer (WTW Company, Germany).

2 Results and discussion

2.1 COD removal in two-stage UASB-SBR system

The COD removal in the two-stage UASB-SBR system is shown in Fig. 2. During the experimental periods, the average organic loading rates (OLRs) of UASB1, UASB2 and SBR were 11.95, 1.63 and 1.29 kg COD/(m^3·day), respectively. Due to the dilution of returned SNS, the influent COD concentration of UASB1 was decreased from 11,950.2 to 4165.2 mg/L. The effluent COD concentration of UASB1 was less than 939.5 mg/L. The NO_3^--N contained in the returned SNS was about 80–100 mg/L, while NO_3^--N concentration in UASB1 effluent was less than 1.3 mg/L all the time. Simultaneous denitrification and methanogenesis were successfully achieved in UASB1, and the average NO_3^--N removal rate was 0.64 kg N/(m^3·day).

As mentioned above, it was found that most of the COD was removed in UASB1 by denitrification and methanogenesis, and the contribution of two biological reactions to COD removal were 5.6%–6.6% and 94.5%–93.4% by

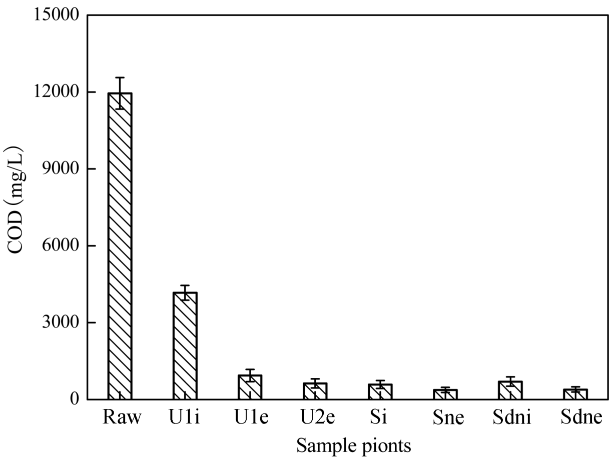

Fig. 2 Variation of COD concentration in two-stage UASB-SBR system. Raw: raw leachate; U1i: UASB1 influent; U1e: UASB1 effluent; U2e: UASB2 effluent; Si: SBR influent; Sne: SBR nitrification effluent; Sdni: SBR denitrification influent; Sdne: SBR denitrification effluent.

calculation, respectively, according to the stoichiometry of denitrification (Tchobanoglous et al., 2003).

The residual COD remaining in UASB1 effluent was further eliminated in UASB2 by methanogenesis and SBR through aerobic biodegradation. The COD concentration in the final effluent of the system was 375.7 mg/L, and the residual COD was mainly non biodegradable organics from the leachate. The total COD removal efficiency reached 96.7%, indicating the achievement of advanced COD removal in the two-stage UASB-SBR system. The contributions of UASB1, UASB2 and SBR to total COD removal were 77.4%, 7.4% and 6.0%, respectively. Therefore, UASB1 played the most important role in COD removal, and UASB2 and SBR further enhanced the nutrient removal efficiency and ensured the excellent effluent.

2.2 Nitrogen removal in two-stage UASB-SBR system

The nitrogen removal in two-stage UASB-SBR system was also monitored during the operation (Fig. 3). As shown in Fig. 3a, the influent NH_4^+-N concentration of UASB1 was significantly low compared with the raw leachate. It is mainly owing to the dilution effect rather than any biological reaction. The average NH_4^+-N concentration in raw leachate was 982.6 mg/L, while the NH_4^+-N concentration in the influent of UASB1, in the effluent of UASB1 and UASB2 were recorded as 338.9, 300.5 and 290.5 mg/L, respectively. In other words, the NH_4^+-N removal efficiencies of UASB1 and UASB2 were 11.3% and 3.3%, respectively. No significant NH_4^+-N removal was observed in UASB reactors. The low NH_4^+-N removal efficiency could be attributed to the utilization of NH_4^+-N through the assimilation of anaerobic bacteria as reported in some other publications (Kennedy and Lentz, 2000; Chen et al., 2007).

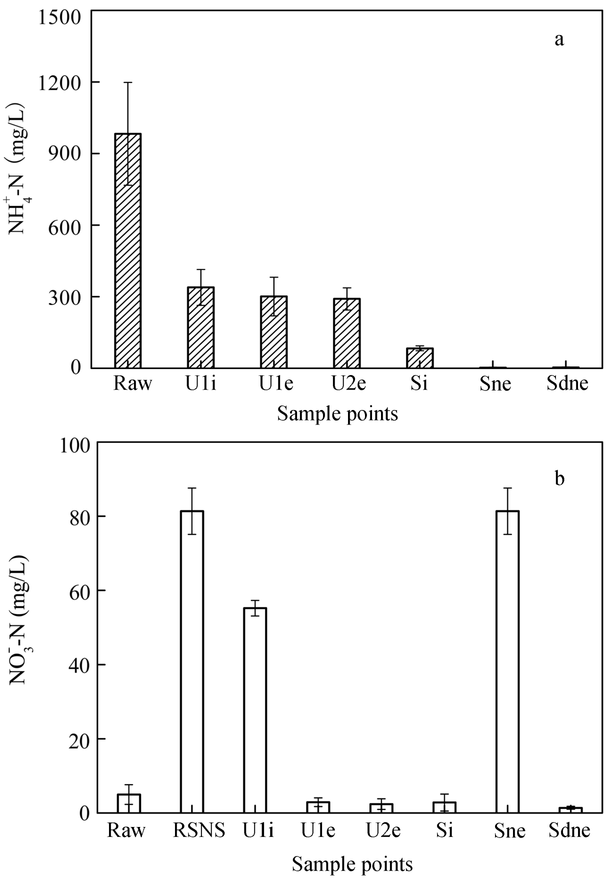

Fig. 3 Variations of the NH_4^+-N (a) and NO_3^--N (b) concentration in two-stage UASB-SBR system. Values are expressed as mean ± standard deviations (n = 17). RSNS: recycled SBR nitrification supernatant.

During the subsequent SBR aerobic periods, about 99.6% NH_4^+-N in UASB2 effluent was oxidized to NO_3^--N. The NO_3^--N produced was reduced to N_2 in the following SBR anoxic step and UASB1. As shown in Fig. 3b, when the average NO_3^--N concentration in the returned SNS was 81.2 mg/L, the effluent NO_3^--N concentrations of SBR and UASB1 were less than 1.3 and 1.1 mg/L, respectively. The denitrification efficiencies of NO_3^--N in both reactors were above 98.8%. These results clearly showed that SBR acted as the real undertaker for NH_4^+-N removal due to aerobic nitrification in this system. In addition, the final effluent concentrations of NH_4^+-N and NO_3^--N were 2.9 and 1.1 mg/L, respectively, indicating that advanced nitrogen removal from landfill leachate via nitrate pathway was achieved in the two-stage UASB-SBR system.

2.3 Advanced nitrogen removal in SBR at low temperature

Figure 4 shows the typical variations of TN, NH_4^+-N, NO_3^--N and NO_2^--N during nitrification and denitrification processes in an SBR cycle at four different temperatures. At 14.9,14.1,13.5 and 11.05°C, complete nitrification and denitrification were obtained with a longer HRT and the effluent TN concentrations were 4.13, 5.7, 14.1 and 16.5 mg/L, respectively. The TN removal efficiencies were maintained above 95.4%, 93.9%, 83.7% and 86.7%, respectively. These results indicated that advanced nitrogen removal was achieved in SBR at low temperature.

It is well-known that a longer HRT in SBR was better for achieving complete nitrification and denitrification at low temperature. The HRT increased gradually with the decrease of temperature, which implies that the rates of nitrification and denitrification decreased. The effects of temperature on the rates of nitrification and denitrification will be discussed in the following sections.

It is worth mention that nitrite accumulated obviously during the denitrification, and the maximum concentrations of nitrite accumulation were 21.5, 26.5, 37.8 and 34.9 mg/L, respectively, at 14.9, 14.1, 13.5 and 11.05°C (Fig. 4). The phenomenon had been observed in previous research works (Dawson and Murphy, 1972; Requa and Schoeder, 1973; Bdaszczyk et al., 1980; Betlach and Tiedje, 1981; Wilderer et al., 1987; Martienssen and Schöps, 1997; Sun et al., 2009). This result proved that nitrite accumulation was significantly correlated with the composition of the biocommunity of the denitrificants, which caused a lower reduction rate of nitrite than that of nitrate.

2.4 Effects of temperature on the rates of nitrification and denitrification

Figure 5 shows typical variations of nitrification rate (r_N), denitrification rate (r_{DN}) and removal efficiencies

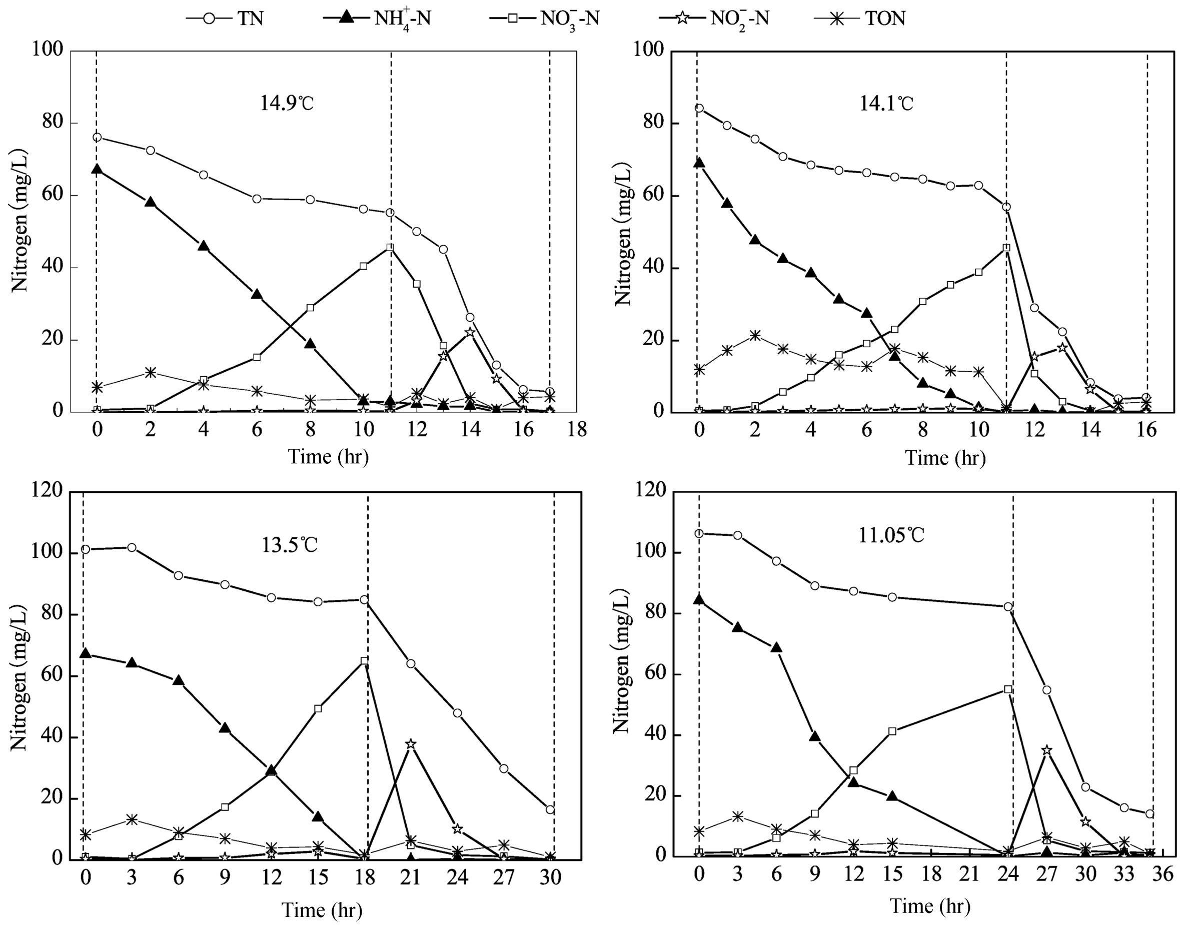

Fig. 4 Typical variations of total nitrogen (TN), total organic nitrogen (TON), NH_4^+-N, NO_3^--N and NO_2^--N during nitrification and denitrification processes of SBR cycle at four different temperatures.

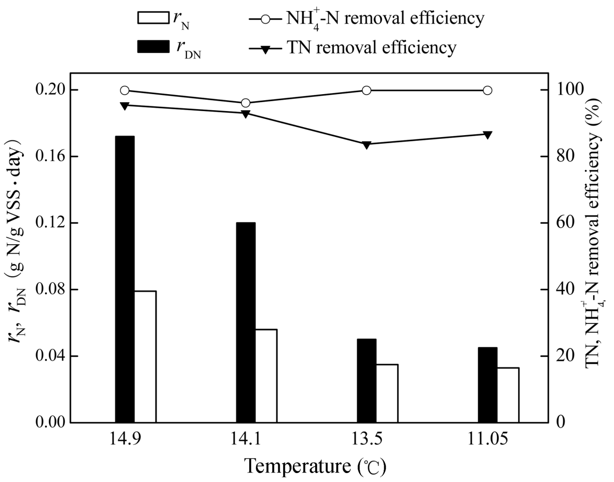

Fig. 5 Typical variations of nitrification rate (r_N), denitrification rate (r_{DN}) and removal efficiencies of TN and NH_4^+-N at four different temperatures.

of TN and NH_4^+-N at four different temperatures. Compared the effect of temperature on r_N with r_{DN}, rates of nitrification and denitrification were both the fastest at 14.9°C and slowest at 11.05°C. In other words, r_N and r_{DN} both decreased with temperature decrease, which indicated that temperature was a significant factor to nitrification and dentirification. In contrast with r_N, the r_{DN} dropped sharply but was always relatively high. It suggested that r_{DN} was more sensitive to temperature and nitrification is rate-limiting step during nitrification and denitrification processes at low temperature.

Additionally, the removal efficiencies of TN and NH_4^+-N remained above 83.7% and 96.0%, respectively (Fig. 5). It was therefore concluded that temperature would not affect the removal efficiencies of TN and NH_4^+-N when complete nitrification and denitrification were achieved.

3 Conclusions

In this study, the two-stage UASB-SBR system was found a feasible process for advanced treatment of landfill leachate. Raw leachate COD with an average concentration of 11,950 mg/L could be degraded to 375.7 mg/L. Raw leachate NH_4^+-N with an average concentration of 982.6 mg/L could be reduced to less than 2.9 mg/L. At 14.9, 14.1, 13.5 and 11.05°C, complete nitrification and denitrification in the SBR were successfully achieved, and the concentration of TN in the final effluent was below 20 mg/L. Temperature was a significant factor to nitrification and denitrification. Compared with nitrification rate, denitrification rate was more sensitive to temperature. However, the removal efficiencies of TN and NH_4^+-N were not affected by relatively low temperature.

Acknowledgments

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