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Short Communication

Optimization of three-stage Anammox system removing nitrogen from landfill leachate

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HIGHLIGHTS

- The mature landfill leachate used in this study was real instead of synthetic.
- Effect of feeding mode and influent organics on Anammox was investigated.
- Continuous feeding mode reduced inhibition of high influent substrates on Anammox.
- A dose of COD improved nitrogen removal, and should be maintained below 800 mg/L.

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ABSTRACT

Advanced nitrogen removal had been realized from mature landfill leachate via three-stage anaerobic ammonium oxidation (Anammox) system during the previous study. However, the Anammox system was influenced by factors such as influent nitrite and organic concentrations and needed to be optimized. To optimize the Anammox system, this study investigated Anammox Sequence Batch Reactor (ASBR) with different feeding modes and influent organic concentrations. The results showed that with influent ammonia and nitrite concentrations of 250 ± 20 and 320 ± 20 mg/L, respectively, a continuous feeding mode reduced the adverse effect of high influent nitrite concentration on Anammox. A small amount of organics improved rather than inhibited nitrogen removal. However, as influent COD increased (from 600 ± 50 to 800 ± 50 mg/L), Anammox was gradually inhibited. Influent organics concentration should be kept below 800 mg/L, which facilitated Anammox.

1. Introduction

Landfill leachate contains a large amount of organics and inorganics, including high ammonia concentrations. Wide variations in leachate composition make it difficult to treat (Renou et al., 2008). Biological processes and Phytoremediation coupled with biological processes are usually used to treat leachate due to their simplicity and high cost-effectiveness (Yabroudi et al., 2013; Wang et al., 2013; Pant and Adholeya, 2010). The traditional or modified nitrification–denitrification process is a biological process that can remove the nitrogen from the early-age or middle-age leachate because of high COD/TN (C/N) ratio (Wang et al., 2013; Zhu et al., 2013; Peng et al., 2008). However, advanced nitrogen removal from mature leachate is difficult with traditional biological processes, because of high ammonia concentrations (usually >1000 mg/L), low organics concentration (usually <3000 mg/L), and low C/N ratio (usually <3) (Kulikowska and Klimiuk, 2008).

Anaerobic ammonium oxidation (Anammox) is a novel cost-effective process with great potential (Mulder et al., 1995; Kartal et al., 2010). It is suitable for treating mature landfill leachate, because it does not need external carbon sources (Liang and Liu, 2008; Sri Shalini and Joseph, 2012). Until now, Anammox studies have focused on nitrogen removal in an upflow anaerobic sludge blanket (UASB) (Liu et al., 2010; Ni et al., 2012; Tang et al., 2010); it was found that sludge could run off in the continuous flow process. SBR is suitable for enriching Anammox because of its efficient biomass retention and high stability over a long operating period.

Some factors, however, can adversely impact Anammox, including high nitrite concentrations. Strous et al. (1999) demonstrated that Anammox was inhibited when the nitrite concentration reached 100 mg/L. Carvajal-Arroyo et al. (2013) demonstrated that if the nitrite concentration exceeded 210 mg/L, the Anammox

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bacteria was completely inhibited. Thus, short-term feeding would inhibit the Anammox bacteria and reduce nitrogen removal efficiency. Besides, the organics in the influent can also influence Anammox. Ni et al. (2012) studied Anammox using artificial wastewater and found that low COD concentration didn't affect nitrogen removal; however, high COD concentration suppressed Anammox activity and reduced bacteria populations when COD exceeded 400 mg/L. Li et al. (2011) found that nitrogen removal was inhibited during domestic wastewater treatment when influent COD concentration was 50 mg/L. As such, Anammox needs to control the influent COD concentration.

In a previous study, advanced nitrogen removal from mature landfill leachate was achieved using a three-stage Sequence Batch Reactor (SBR) process (Miao et al., 2014). The three-stage SBR process ran more than 300 days. With influent total nitrogen (TN) and COD concentrations of 3000 ± 100 and 2200 ± 100 mg/L, respectively, TN removal efficiency exceeded 90%. During the three-stage process, the influent of the Anammox SBR (ASBR) was comprised of mixed effluents from the pretreatment SBR and nitritation SBR, based on a NO_2^--N/NH_4^+-N ratio of 1.3. ASBR was operated in a modified mode with continuous feeding (5 h), alleviating the nitrite inhibition effect on Anammox. The continuous feeding mode duration and the influent COD concentration are the most important parameters in the Anammox process. Therefore, this study focused on choosing the appropriate feeding duration and influent COD concentration to optimize the three-stage SBR process.

2. Methods

2.1. Experimental setup operational procedure

The three-stage SBR system, which includes the pretreatment SBR, nitritation SBR, and ASBR, was comprised of polymethyl methacrylate. The total working volume capacity is 33 L, distributed as 10 L for pretreatment SBR, 10 L for nitritation SBR, and 13 L for ASBR. The pretreatment SBR and nitritation SBR were equipped with pH meters, mechanical stirrers, and air diffusers. The ASBR was equipped with a pH meter and a mechanical stirrer. During the aeration period, aeration intensity was maintained at 100 L/h. The temperatures in the pretreatment SBR and nitritation SBR were maintained at 35 and 25 °C, respectively, using a temperature controller.

In the three-stage SBR system, the influent was mixture of raw landfill leachate and effluent of ASBR. The pretreatment SBR and nitritation SBR were operated using a traditional mode: filling-aeration-settle-decant (5 h). The ASBR influent was comprised of mixed effluents from the pretreatment SBR and nitritation SBR, based on a NO_2^--N/NH_4^+-N ratio of 1.3 (Fig. 1). ASBR was operated using a modified mode: continuous feeding (5 h) and stirring until the reaction was complete. The Anammox's terminal point was determined using the pH profile. The exchange volumetric rate of ASBR was 38%.

2.2. Influent and seed sludge

The mature landfill leachate collected from the Liulitun Municipal Solid Waste (MSW) Sanitation Landfill Site (Beijing, China) was used as the feeding solution. The main characteristics of the landfill leachate were as follows: COD 3000 ± 1000 mg/L, BOD_5 100 ± 50 mg/L, NH_4^+-N 3000 ± 100 mg/L, NO_3^--N 1 ± 0.5 mg/L, NO_2^-N 1 ± 0.5 mg/L, alkalinity 7000 ± 100 mg/L, pH 8.0 ± 0.2.

The mixed liquor suspended solids (MLSS) of the pretreatment SBR, nitritation SBR, and ASBR were 4000 ± 100 mg/L, 3000 ± 100 mg/L, and 3000 ± 100 mg/L, respectively.

2.3. Experimental procedure

Based on the three-stage SBR process, this study examined the effect of feeding duration and influent COD concentration on Anammox. Table 1 presents the experimental procedure.

2.4. Analytical methods

The pH and temperature were monitored using a pH/Oxi 340i analyzer (WTW Company, Germany). MLSS, NH_4^+-N, NO_3^--N, NO_2^--N and COD were measured according to the standard methods (APHA, 1995). Total nitrogen was analyzed with a TN/TOC analyzer (MultiN/C3000, AnaltikjenaA G, Germany).

2.5. Calculations

The nitrogen load rate (NLR) (kgN/m^3 d) and nitrogen removal rate (NRR) (kgN/m^3 d) were calculated using Eqs. (1) and (2), respectively:

$$\mathrm{NRR}\left(\frac{\mathrm{mg\ N}}{\mathrm{gVSS\ h}}\right)=\frac{NH_4^+\text{-}N_{inf}\left(\frac{mg}{L}\right)+NO_2^-\text{-}N_{inf}\left(\frac{mg}{L}\right)+NO_3^-\text{-}N_{inf}\left(\frac{mg}{L}\right)-NH_4^+\text{-}N_{eff}\left(\frac{mg}{L}\right)-NO_2^-\text{-}N_{eff}\left(\frac{mg}{L}\right)-NO_3^-\text{-}N_{eff}\left(\frac{mg}{L}\right)}{t(\mathrm{h})\cdot \mathrm{MLVSS}\left(\frac{g}{L}\right)} \tag{1}$$

$$\mathrm{NLR}\left(\frac{\mathrm{kg\ N}}{\mathrm{m^3\ d}}\right)=\frac{\left(NH_4^+\text{-}N_{inf}(mg/L)+NO_2^-\text{-}N_{inf}(mg/L)+NO_3^-\text{-}N_{inf}(mg/L)\right)\times V_{inf}(L)\times 10^{-6}}{V(m^3)\cdot t\left(\frac{1}{d}\right)} \tag{2}$$

In these equations, NH_4^+-N_{inf}, NO_2^--N_{inf}, NO_3^--N_{inf} and NH_4^+-N_{eff}, NO_2^--N_{eff}, NO_3^--N_{eff} are the nitrogen concentrations of ASBR influent and effluent (mg/L), respectively; V_{inf} is the volume of ASBR influent (L); V is the working volume of ASBR (L); MLVSS is the mixed liquor volatile suspended solid concentration of ASBR (gVSS); and t is the ASBR reaction time in hours.

3. Results and discussion

3.1. Effect of feeding mode on Anammox

The activity of Anammox bacteria could be influenced by nitrite, and the high influent nitrite concentration could inhibit Anammox. As such, when treating high-ammonia wastewater, such as landfill leachate, the traditional feeding mode (feeding in a short time) needs to be changed to reduce nitrite inhibition.