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Partial nitritation of landfill leachate with varying influent composition under intermittent aeration conditions

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ABSTRACT

The start-up and operation of a partial nitritation sequencing batch reactor for the treatment of landfill leachate were carried out on intermittent aeration mode. Partial nitrite accumulation was established in 15 days after the mode was changed from continuous aeration to intermittent aeration. Despite the varying influent composition, partial nitritation could be maintained by adjusting the hydraulic retention time (HRT) and the air flow rate. An increase in the air flow rate together with a decrease in air off duration can improve the partial nitritation capacity and eventually result in the development of granular sludge with fine diameters. A nitrogen loading rate of $0.71 \pm 0.14\,kg/m^3/d$ and a COD removal rate of $2.21 \pm 0.13\,kg/m^3/d$ were achieved under the conditions of an air flow rate of $19.36 \pm 1.71\,m^3$ air/m^3/h and an air on/off duration of 1.5 min/0.7 min. When the ratio of total air flux (TAF) to the influent loading rate (ILR) was controlled at the range of 163–256 m^3 air/kg COD, a stable effluent NO_3^-–N/NO_x^-–N (NO_2^-–N plus NO_3^-–N) ratio below 13% was achieved. Interestingly, the effluent pH was found to be a good indicator of the effluent NO_2^-–N/NH_4^+–N ratio, which is an essential parameter for a subsequent anaerobic ammonium oxidation (Anammox) reactor.
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Keywords: Landfill leachate; Sequencing batch reactor; Partial nitritation; Intermittent aeration; Anammox; Granular sludge

1. Introduction

Combined partial nitritation (PN)–anaerobic ammonium oxidation (Anammox) processes advantageously support higher loading rates, lower oxygen requirements, and lower sludge yields than conventional nitrification–denitrification processes during nitrogen removal from ammonium-rich wastewater (Terada et al., 2011). This combined technique, either in a two-stage system (Fux et al., 2002; Gali et al., 2007; Liu et al., 2010; van der Star et al., 2007; van Dongen et al., 2001; Zhang et al., 2010) or in single reactor (Cema et al., 2006; Sliekers et al., 2002; Third et al., 2001; Vlaeminck et al., 2008), is generally considered more sustainable than conventional nitrification–denitrification process for treating strong nitrogenous wastewater (Van Hulle et al., 2010).

To date, mature landfill leachate (Wang et al., 2010; Xu et al., 2010) and sludge digester liquor (Joss et al., 2009; Vlaeminck et al., 2009) have been successfully treated using a one-stage PN/Anammox process. However, few reports are available on the treatment of nitrogenous wastewater with a high concentration of biodegradable organic compounds using a one-stage PN/Anammox process. Anammox biomass was reportedly inhibited by some biodegradable organic compounds, such as methanol and ethanol (Guven et al., 2005; Isaka et al., 2008). Therefore, most of the biodegradable organics must be removed before feeding the Anammox

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reactor. A PN unit that precedes the Anammox reactor cannot only partially oxidize ammonium to nitrite, but also remove the biodegradable organic fraction. Hence, a two-stage PN/Anammox process may be the preferred choice for sustainably treating strong nitrogenous wastewaters containing rich biodegradable organic matter.

Several studies (Ganigue et al., 2007, 2008, 2009, 2010; Liang and Liu, 2007; Vilar et al., 2010) on the treatment of landfill leachate using the PN process have been reported recently. In the tests carried out by Vilar et al. (2010), the start-up of the reactor was performed by shifting the feed from synthetic wastewater to landfill leachate; Ganigue et al. (2008) started-up the reactor by gradually increasing the feed percentage of landfill leachate. In operating the PN reactor, the alkalinity and pH must be controlled (Ganigue et al., 2009) and the ammonium loading rate must be adjusted to inhibit nitrite oxidation and partially oxidize ammonium to nitrite in order to achieve an adequate effluent NO_2^-–N/NH_4^+–N ratio (Liang and Liu, 2007). The proper and timely adjustment of key controlling parameters according to the influent characteristics is a challenge in operating the PN reactor, as this adjustment is required to closely monitor and control the system.

Our work focuses on the rapid start-up and operation of the PN reactor fed with raw landfill leachate with a variable influent composition. Specifically, this study seeks to achieve stable partial nitritation under different influent characteristics by adjusting the aeration duration, the air flow rate and the volumetric exchange ratio.

2. Materials and methods

2.1. *Landfill leachate characteristics*

The landfill, which has been operating for 12 years, is located in Jiangmen, a city in southern China. The raw leachate generated from different landfill cells with different landfill ages was collected in three regulating reservoirs and was then transported to the laboratory for experiments. Leachate with different ages exhibit different compositions. The main physicochemical characteristics of the raw leachate used in each phase of the experiments are listed in Table 1.

2.2. *SBR system*

The working volume of the SBR varies from 3.0 L to 4.5 L, depending on the actual treatment capacity. The reactor was operated at a temperature of 29 ± 1 °C and in cycles of 24 h. Each cycle consisted of 1 h of feed, 22.4 h of intermittent aeration (air on/off), 0.5 h of settling and 0.1 h of draw. Aeration was maintained for 1.5 min and was followed by a variable period of non-aerated operation (Table 2). Sludge was not deliberately wasted and the sludge retention time (SRT) was approximately 28–42 days depending on the calculation of the reactor mixed liquid suspended solids (MLSS), the influent and effluent MLSS and the sludge wasted in occasional cases and in the MLSS measurements.

2.3. *Experimental procedure*

To start-up the PN reactor, 3.2 L of nitrifying activated sludge (MLSS 1200 mg/L) from the full-scale SBR operating at the same landfill site for landfill leachate treatment was used as the seed sludge. The operation of the reactor can be divided into five phases based on the influent composition, the alternating air on/off duration and the volumetric exchange ratio. The volumetric exchange ratio was calculated according to Wilderer et al. (2000). During the operation, the air flow rate and the volumetric exchange ratio were adjusted according to the observed influent composition and the treatment performance. The controlling parameters in different phases are listed in Table 2.

2.4. *Analytical methods*

The liquid and biomass samples were collected and analyzed regularly to evaluate the reactor performance. Measurements for MLSS, mixed liquid volatile suspended solids (MLVSS), sludge volumetric index (SVI), COD, ammonium, nitrates, nitrites, total nitrogen (TN) and alkalinity were carried out according to standard methods (China, 2002). As nitrite exerts a COD of 1.1 mg O_2/mg NO_2^-–N, the COD values were corrected accordingly. Free ammonia concentrations in the effluent were calculated according to Anthonisen et al. (1976). Dissolved oxygen (DO) and pH values were measured by a handheld oxygen meter (YSI 55, USA) and a pH meter (pHS-25, Rex Company, China), respectively. The particle size distribution of the biomass in the reactor was estimated according to Laguna et al. (1999). In this study, 150 ml of sludge was collected and then screened with five stainless steel sieves with pores size of 2.00, 1.00, 0.45, 0.30 and 0.11 mm. All sludge diameter measurements were made in duplicate. The images of the screened sludge were taken with a digital camera (Canon EOS 500 D, Japan).

The effluent nitrate percentage (effluent NO_3^-–N/NO_x^-–N (NO_2^-–N plus NO_3^-–N) ratio) was calculated according to Eq. (1).

$$\text{Effluent nitrate percentage (\%)} = \frac{NO_3^- - N_{effl.}}{NO_2^- - N_{effl.} + NO_3^- - N_{effl.}} \times 100 \quad (1)$$

where $NO_2^- - N_{effl.}$ and $NO_3^- - N_{effl.}$ are the concentrations (mg/L) of nitrite and nitrate nitrogen in the effluent, respectively.

The nitrogen loss in the reactor possibly due to denitrification was calculated according to Eq. (2), assuming that the stripping effect and the fraction assimilated into biomass were negligible.

$$\text{Nitrogen loss (\%)} = \frac{TN_{Ini.} - TN_{Fin.}}{TN_{Ini.}} \times 100 \quad (2)$$

where $TN_{Ini.}$ is the initial TN concentration in the bulk liquid when the feeding event in one cycle has finished (mg/L) and $TN_{Fin.}$ is the final TN concentration in the bulk liquid when the reaction has ended, which is equal to the effluent TN concentration (mg/L).

The influent loading rate (ILR) (kg COD/m^3/d) was defined as the sum of oxygen demand from the COD loading rate (kg COD/m^3/d) and the partial nitritation loading rate calculated from the ammonium loading rate (kg NH_4^+-N/m^3/d), as described in Equation 3. The multiplication factor of 1.80 (g COD/g N, which takes both PN and ANAMMOX biosyntheses into account and is adapted from Ahn (2006) and Van Hulle et al. (2010), please also refer to SI) is the theoretical oxygen

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