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Operation of partial nitrification to nitrite of landfill leachate and its performance with respect to different oxygen conditions

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ABSTRACT

The coupled system of partial nitrification and anaerobic ammonium oxidation (Anammox) is efficient in nitrogen removal from wastewater. In this study, the effect of different oxygen concentrations on partial nitrification performance with a sequencing batch reactor (SBR) was investigated. Results indicate that, partial nitrification of landfill leachate could be successfully achieved under the 1.0–2.0 mg L^{-1} dissolved oxygen (DO) condition after 118 d long-term operation, and that the effluent is suitable for an Anammox reactor. Further decreasing or increasing the DO concentration, however, would lead to a decay of nitrification performance. Additionally, the MLSS concentration in the reactor increased with increasing DO concentration. Respirometric assays suggest that low DO conditions (<2 mg L^{-1}) favor the ammonia-oxidizing bacteria (AOB) and significantly inhibit nitrite oxidizing bacteria (NOB) and aerobic heterotrophic bacteria (AHB); whereas high DO conditions (>3 mg L^{-1}) allow AHB to dominate and significantly inhibit AOB. Therefore, the optimal condition for partial nitrification of landfill leachate is 1.0–2.0 mg L^{-1} DO concentration.

1. Introduction

Leachates are defined as the aqueous effluent generated as a consequence of rainwater percolation through wastes, biochemical processes in waste's cells and the inherent water content of wastes themselves, which may contain large amounts of organics (biodegradable, but also refractory to biodegradation), ammonium, inorganic salts, and in some cases, heavy metals [1,2]. Factors that affect the quality of leachates include age, waste type, site geochemical properties, and regional climate [3]. The composition of landfill leachates, in particular, varies greatly depending on the age of the landfill. [4]. In young landfills, leachate is characterized by high concentrations of biodegradable matters, the largest group of which are volatile fatty acids (VFAs). However, much of landfill leachate is composed of recalcitrant organic molecules with increasing landfill age because VFAs are gradually converted to biogas. As a result, this type of intermediate leachate is characterized by high COD (2000–20,000 mg L^{-1}), low BOD_5 (500–1000 mg L^{-1}) and fairly high NH_3-N (1000–4000 mg L^{-1}) [5,6]. Therefore, nitrogen removal from landfill leachates by conventional biological nitrification/denitrification is difficult owing to low biodegradable organic matter content and high ammonium concentration. Recently, some new processes and operational strategies such as partial nitrification/denitrification and anaerobic ammonium oxidation (Anammox) have arisen in order to remove nitrogen compounds in wastewaters. These process is based on the facts that, since nitrite can be partially produced by ammonia-oxidizing bacteria (AOB) using ammonium, and subsequently, heterotrophic denitrifying bacteria would use nitrite as terminal electron acceptor to form nitrogen gas (Eq. (1)) [7], or Anammox bacteria (AAOB) would convert ammonium with nitrite to nitrogen gas (Eq. (2)) [8]

$$2NO_2^- + 6H^+ + 6e^- \rightarrow N_2 + 2OH^- + 2H_2O \qquad (1)$$

$$NH_4^+ + 1.31NO_2^- + 0.066HCO_3^- + 0.13H^+ \rightarrow 1.02N_2 + 0.26NO_3^- + 0.066CH_2O_{0.5}N_{0.15} + 2.03H_2O \qquad (2)$$

Partial nitrification with Anammox saves up to 40% of the oxygen supply for nitritation without the carbon requirement and with minimal sludge production [9,10]. Thus, the coupled

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system is suitable for the treatment of landfill leachate with low biodegradable organic matter and high ammonium concentration. Feeding an Anammox reactor requires an influent composed by a 1:1 ammonium-to-nitrite molar ratio. A number of strategies have been suggested to achieve partial nitrification, including reactors' selective NOB washout at elevated temperatures (30–40 °C) [11]; NOB inhibition at the free ammonia (FA) concentration of 10–150 mg L^{-1} [12]; and DO control at low concentrations favoring AOB growth [13]. Among these strategies, the easiest to manipulate is bulk DO concentration in the reactor by changing the superficial air velocity or by partial recirculation of the off-air. Manipulation of the oxygen concentration seems to be the most practical method to obtain partial nitrification [14].

The majority of studies have confirmed that low DO concentrations (<2 mg L^{-1}) are effective in achieving partial nitrification [15,16]. However, the wastewater treated in these previous investigations was predominantly synthetic or domestic-type wastewater with low organic matter content (COD = 100–200, BOD = 50–100 mg L^{-1}), such that litter competition exists between the nitrifying bacteria and the heterotrophic bacteria more akin to "pure culture. High COD concentrations in which biodegradable organic content exceeds 500 mg L^{-1} favor the development of AHB, which grow much faster than autotrophs and outcompete them for oxygen and nutrients. As a result, the autotrophic nitrifying bacteria are easily overgrown by heterotrophs, which eventually cause the nitrification efficiency to decrease [17,18]. Available literature about nitrogen removal of landfill leachate in lab-scale reactor is focused on operations at higher DO concentrations (>2 mg L^{-1}) [15,19,20]. Consequently, a question might be introduced if the partial nitrification process can conduct at a low DO (<2 mg L^{-1}) condition to treat high organic wastewater like landfill leachate. On the other hand, although many studies have successfully achieved stable partial nitrification using synthetic or domestic-type wastewater under low DO concentration (<2 mg L^{-1}), detailed investigations of nitrification with respect to further increasing the DO concentrations post-startup are largely absent from the literature. Given that the competition between the nitrifying and the heterotrophic bacteria could be enhanced under high DO conditions, particularly with high organic matter content, it needs to be investigate nitrification performance as well as organic matter content removal under higher DO concentrations.

Therefore, the aims of our study are to (1) investigate the feasibility of achieving long-term and stable partial nitrification of landfill leachate under low DO condition, (2) test the correlation between the performances of nitrogen removal and DO dynamic characteristics, and (3) determine the kinetic parameters of the nitrifying bacteria and AHB from respirometric assays.

2. Materials and methods

2.1. Experimental lab-scale reactor

The experiments were conducted in a 3 L sequencing batch reactor (SBR) as described previously [21]. Liquid temperature inside the SBR was maintained at (28 ± 1) °C with a thermostatic water jacket. Compressed air was supplied through an air diffuser placed at the bottom of the reactor. The DO concentration in the bulk liquid was measured on-line (HI 98186, HANNA, Italy) and controlled via a Programmable Logic Controller (PLC) to remain between 0.5 and 4.0 mg L^{-1} during the aeration period using ON/OFF control. pH was measured on-line (HI 98184, HANNA, Italy) and initially controlled at a maximum set-point value between 7.2 and 7.8 by adding 0.5 M Na_2CO_3 or 1 M HCl, depending on the applied nitrogen load. The SBR was carried out on an 12 h working cycle, consisting of an aerobic reaction phase of 690 min (feeding during the first 575 min), followed by a settling phase of 30 min and, afterwards, a drawing phase which was considered to occur in an instant. The volume exchange ratio (VEX, the volume added to the maximum reactor volume ratio) of each cycle was about 0.333, resulting in a hydraulic retention time (HRT) of 1.5 days. The sludge retention time (SRT) was not a controlled parameter of the system, and was calculated considering reactor MLSS and effluent suspended solids concentrations, presented during the whole study an average value of 10 days. With an SRT of 10 days, the corresponding mixed liquor concentration was within the range of 1400–2800 mg L^{-1}.

Table 1
Composition of the synthetic wastewater used in this study. Values are in mg L^{-1} except the pH.

Component	Concentration	Component	Concentration
$(NH_4)_2SO_4$	566	$FeSO_4·7H_2O$	10
KH_2PO_4	25	$ZnSO_4·7H_2O$	4.4
$KHCO_3$	125	$CoCl_2·6H_2O$	3.2
$CaCl_2·2H_2O$	300	$MnCl_2·4H_2O$	10.2
$MgSO_4$	200	$CuSO_4·5H_2O$	3.2
$NiCl_2·6H_2O$	19	EDTA	6.3
H_3BO_3	6	Glucose	625
pH	7.0–7.8		

2.2. Wastewater characteristics

The wastewater used in this study consisted of synthetic wastewater and raw leachate. The composition of the synthetic wastewater [21] was described in Table 1. The used raw leachate was collected from the Heimifeng MSW sanitation landfill site (Changsha, China) every 10 d, and stored at 4 °C. The average values of the principal chemical compounds concentration were summarized in Table 2.

2.3. Experimental procedure

The experiment was divided into two periods. In period I, the reactor was operated under low DO concentration (1.0–2.0 mg L^{-1}) condition to investigate the feasibility of achieving long-term stable partial nitrification to nitrite of landfill leachate. Mixed liquor of nitrifying sludge from our laboratory was used as inoculum for the SBR [21]. In the meantime, the leachate was diluted with synthetic wastewater (Table 1) and fed to the reactor to allow for adaptation to the real leachate over 118 days with decreasing dilution ratios.

In period II, the reactor was operated for 121 days under different concentrations of DO (0.5–1.0, 1.0–2.0, 2.0–3.0, 3.0–4.0 mg L^{-1}), during which the correlation between the performance of nitrogen removal and DO dynamic characteristics was tested. For all operations, the reactor was fed with raw leachate concentration with approximately 1300 mg NH_4^+-N L^{-1}. Partial nitrification was evaluated according to the ammonium oxidation rate and the concentrations of NH_4^+-N, NO_2^--N, NO_3^--N. Additionally, microbial oxygen utilization dynamics (AOB, NOB and AHB) with respect to different DO concentrations were also investigated.

Table 2
Characteristics of the raw landfill leachate from the Heimifeng municipal wastes landfill site of Changsha city. Values are in mg L^{-1} except the pH.

Compound	Average ± S.D.	Compound	Average ± S.D.
COD	3876 ± 661	NO_2^--N	0
BOD_5	548 ± 236	TKN	2018 ± 512.3
NH_4^+-N	1312 ± 417	Alkalinity	9618 ± 3502
NO_3^--N	0	pH	7.5–7.8