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Reactor performance and microbial ecology of a nitritation membrane bioreactor

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ABSTRACT

Partial nitritation is an indispensable pretreatment for anaerobic ammonium oxidation process. However, the nitritation is limited by the low growth rates of ammonia-oxidizing bacteria (AOB). In this study, a membrane bioreactor (MBR) was operated for 300 days to assess its nitritation performance and the shift of microbial community. Results showed that the reactor obtained satisfying nitritation after a startup period of 50 days, which finally achieved ammonium conversation rates of about 0.8 kg N/m^3/d. The apparent half-saturation constant (K_m) and maximum ammonium oxidation rate (r_{max}) of the AOB-enriched culture were determined to be 6.1 mg N/L and 1.1 kg N/g-VSS/d, respectively. In addition, lower fouling rates were found in the initial operating days that the reactor was fed with lower ammonium loads (day 0–day 150). However, the increased ammonium loads (>0.6 kg N/m^3/d) in the following 150 days resulted in increases in extracellular polysaccharides, leading to much higher fouling rates. 16S rRNA high-throughput sequencing analysis showed clear changes in the microbial community populations during the MBR operation. Results also showed that ordinary heterotrophic organisms and nitrite-oxidizing bacteria were successively inhibited; finally *Nitrosomonas* dominated in the nitritation MBR, with relative abundance of 40–46%. Moreover, the AOB-enriched culture was of higher microbial diversity than the seeding sludge. This study could not only improve our understanding of the bacterial community dynamics in nitritation processes, but also provide more alternatives for MBR applications.

1. Introduction

Anaerobic ammonium oxidation (ANAMMOX) process has attracted increasing attention for nitrogen removal, because of its ability to achieve high nitrogen removal rates [1,2]. The ANAMMOX-based processes can even achieve satisfying performance at full-scale applications [3], where the wastewater compositions are far more complex than that used in laboratory-scale studies. However, the occurrence of ANAMMOX reaction requires a proportion of nitrite nitrogen and ammonium nitrogen of ca. 1.32 in the feed solution, i.e., part of ammonium in the wastewater should be converted to nitrite for the uptake by ANAMMOX bacteria. Thus, the completion of ANAMMOX-based processes is generally accompanied by the nitritation process, which oxidizes ammonium into nitrite by ammonia-oxidizing bacteria (AOB) [3].

Different to conventional nitrification–denitrification process, the nitritation–ANAMMOX process requires enrichment of AOB and inhibition of nitrite-oxidizing bacteria (NOB) [4]. However, the low proliferation rates of AOB limit the nitritation process largely. Thus, attempts have been made to develop new reactors or optimize operating conditions of the currently existing reactors. In recent years, membrane bioreactors (MBRs), which can decouple hydraulic retention time (HRT) and solids retention time (SRT) with the help of membrane separation, have shown great potentials for the startup and long-term operation of nitritation process [5–7]. For instance, Zhang et al. [6] achieved ammonia oxidization efficiency of 95% in an MBR at 30 °C, and they reported a nitrite/total nitrogen (TN) ratio in the treated water as high as 0.95. In addition, Xue et al. [5] also achieved successful nitritation in a MBR at the influent ammonium concentration of 600 mg N/L. These previous efforts have largely increased our knowledge on nitritation processes, and indicated that nitritation process is an economically and technically feasible pre-treatment for ANAMMOX processes. However, there are still some ambiguous issues dealing with nitritation MBRs or AOB. First, it is of some importance to understand the membrane permeability in nitritation-based MBRs, as membrane fouling is ubiquitous in MBRs [8–11]. Second, the activity and metabolism of AOB should be further

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clarified in order to elevate our understanding of nitritation process. Third, there are sparse attempts to reveal how the AOB are enriched during the reactor operation, which in fact is of high significance for the startup and optimization of nitritation-based reactors. Therefore, it is of high significance to explore the nitritation-based MBRs systematically.

Nitritation performance is crucially determined by the bacterial dynamics in the reactors, such as species and relative abundance of AOB. Thus, it is necessary to track the AOB dynamics during the startup and operation of nitritation reactors. Despite of its significance, the AOB dynamics have not been fully revealed, possibly because of the limitations of conventional molecular methods such as the low sequencing depth [12]. The successful application of high-throughput sequencing technologies have made it possible to explore the microbial community dynamics with sufficient sequencing depth [13]. Importantly, the high-throughput can make the sequencing much more times-saving and cost-effective [14,15], as compared with conventional sequencing methods. Thus, it can facilitate a comparative analysis among several samplings. It has been shown that the high-throughput sequencing can provide significant information dealing with the population diversities of activated sludge [16]. So far, there are sparse investigations revealing the microbial dynamics during the startup and operation of nitritation MBRs. The high-throughput sequencing study can hopefully update our understanding of nitritation process.

In this study, the nitritation performance of a MBR operated with increasing ammonium loads was explored. The ammonium, nitrite and nitrate in the feed wastewater and effluent were monitored regularly for over 300 days. The ammonium oxidation kinetics of AOB-enriched culture was examined in terms of specific oxygen uptake rates (SOUR) and ammonium half-saturation constant. Finally, the shift of microbial community populations during the MBR operation was examined using 16S rRNA high-throughput sequencing.

2. Materials and methods

2.1. Setup and operation of the nitritation MBR

The experiments were conducted based on an aerobic MBR with an effective working volume of 5 L (see Fig. S1). A hollow fiber ultrafiltration membrane module (0.01 μm, 0.1 m^2, PVDF, Litree Corp., Suzhou, China) was submerged in the reactor. Seeding sludge was collected from a local wastewater treatment plant treating domestic wastewater and was used as the inoculation. The final concentration of the inoculation in the reactor was about 4000 mg/L. HRT of the reactor was set at about 10 h by fixing the membrane flux at 5 L/m^2 h (LMH). Except the sampling, no additional sludge was discharged from the reactor; that is, the reactor was operated at a prolonged SRT. During the entire

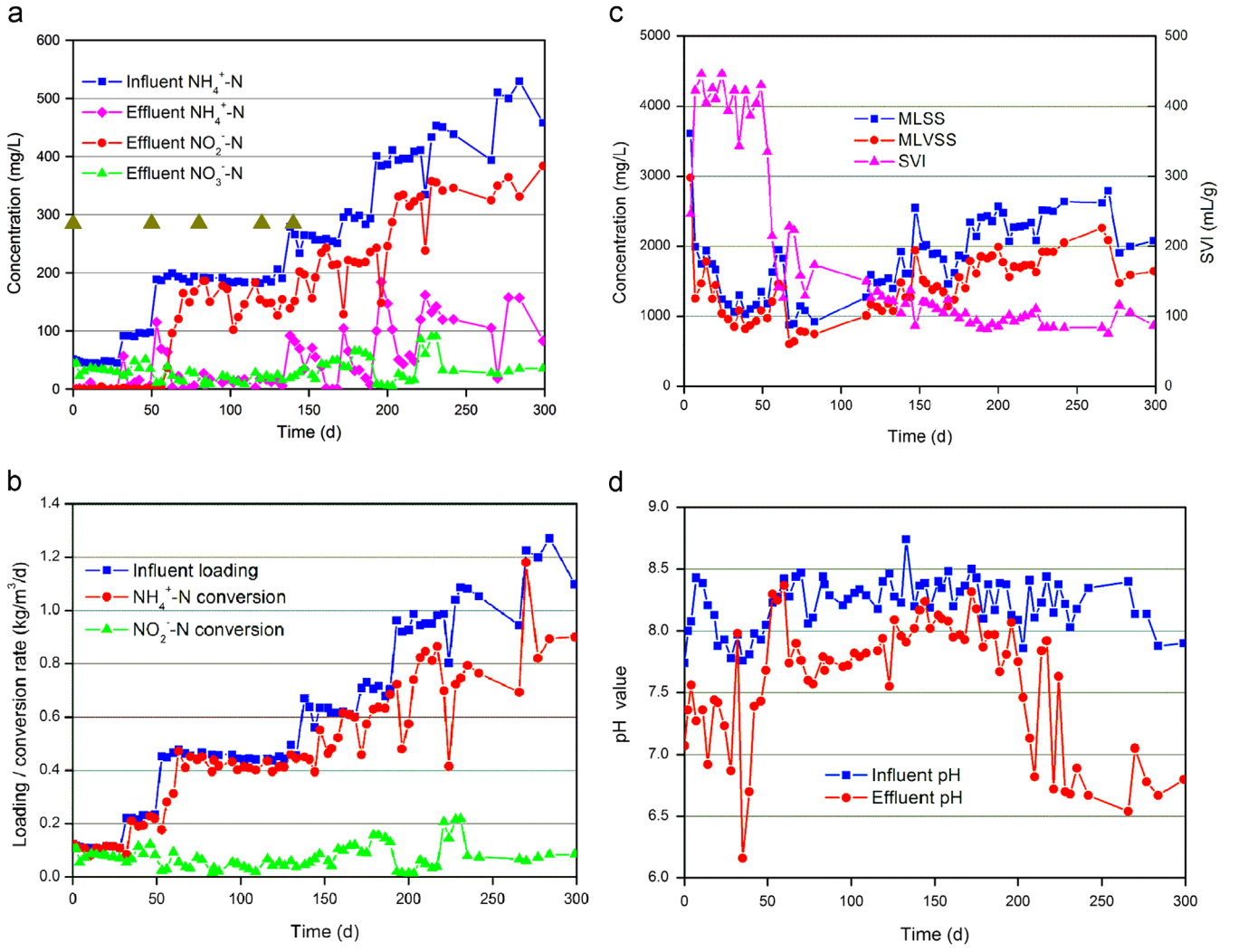

Fig. 1. Variations of nitrogen species (a), nitrogen conversation rates (b), sludge concentration and settlement ability (c) and pH during the MBR operation. The five larger triangles in Fig. 1a indicate the five samples collected for microbial community analysis (M1–M5).