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Review

Oxygenic denitrification for nitrogen removal with less greenhouse gas emissions: Microbiology and potential applications

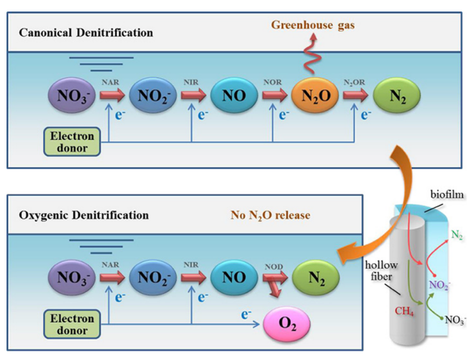
Zhanfei He [a,b], Yudong Feng [a], Shijie Zhang [a], Xiaonan Wang [c], Shuyun Wu [a,b], Xiangliang Pan [a,b,*]

[a] *College of Environment, Zhejiang University of Technology, Hangzhou, China*
[b] *Key Laboratory of Microbial Technology for Industrial Pollution Control of Zhejiang Province, Zhejiang University of Technology, Hangzhou, China*
[c] *Xinjiang Key Laboratory of Environmental Pollution and Bioremediation, Xinjiang Institute of Ecology and Geography, Chinese Academy of Sciences, Urumqi, China*

HIGHLIGHTS

- O2DN is a novel nitrogen removal process with less GHG emissions.
- Responsible microorganisms and mechanisms of O2DN are reviewed.
- Potential applications of O2DN in wastewater treatment are discussed.
- Benefits, limitations and unsolved problems of O2DN are presented.

GRAPHICAL ABSTRACT



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ABSTRACT

Nitrogen pollution is a worldwide problem and has been extensively treated by canonical denitrification (CDN) process. However, the CDN process generates several issues such as intensive greenhouse gas (GHG) emissions. In the past years, a novel biological nitrogen removal (BNR) process of oxygenic denitrification (O2DN) has been proposed as a promising alternative to the CDN process. The classic denitrification four steps are simplified to three steps by O2DN bacteria without producing and releasing the intermediate nitrous oxide (N_2O), a potent GHG. In this article, we summarized the findings in previous literatures as well as our results, including involved microorganisms and metabolic mechanisms, functional genes and microbial detection, kinetics and influencing factors and their potential applications in wastewater treatment. Based on our knowledge and experience, the benefits and limitations of the current O2DN process were analyzed. Since O2DN is a new field in wastewater treatment, more research and application is required, especially the development of integrated processes and the quantitative assessment of the contribution of O2DN process in natural habitats and engineered systems.

Contents

* Corresponding author at: College of Environment, Zhejiang University of Technology, Hangzhou, China.
E-mail address: panxl@zjut.edu.cn (X. Pan).

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1. Introduction

The increasing nitrogen pollution has become a significant worldwide environmental problem. Many waters are suffering potential risks of toxic algal blooms and red tides due to receiving a lot of nitrogen and phosphorus pollutions from anthropogenic activities, such as fertilizer application and livestock production (He et al., 2015c; Wang and Chu, 2016). Nitrogen pollution *per se* and toxins produced from the toxic algal blooms are threatening human health and ecosystem sustainability (Habermeyer et al., 2015; Song et al., 2017). For nitrogen pollution control, different technologies have been developed and applied in wastewater treatment, including physical, chemical and biological methods (Wang and Chu, 2016). Among them, biological nitrogen removal (BNR) process is a hot topic due to its low cost and high efficiency (Chen et al., 2016; He et al., 2015f; Li et al., 2016). Canonical denitrification (CDN) (Fig. 1), using reducing substances as electron donors and energy source to reduce nitrate/nitrite to nitrogen, has been worldwide applied in wastewater treatment plants (WWTP) for high loading rates and convenient operations (Rissanen et al., 2017). Furthermore, several novel BNR processes have been proposed over the last decades, such as anaerobic ammonium oxidation (anammox) (Kartal et al., 2010) and oxygenic denitrification (O2DN) (Ettwig et al., 2010). The O2DN process utilizes methane or other alkanes as electron donors to reduce nitrate/nitrite into nitrogen. Molecular oxygen (O_2) is intracellularly produced in the novel denitrification pathway of O2DN process and consumed in the aerobic oxidation of methane or other alkanes (Ettwig et al., 2010; Zedelius et al., 2011).

In addition to cost and efficiency, environmental concerns such as greenhouse gas (GHG) emissions have been raised in WWTP in recent years (Massara et al., 2017). GHG including carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) are released during wastewater treatment (Lijo et al., 2017). N_2O has gained particularly intense considerations during nitrogen removal process, since it has high greenhouse effect (265 times stronger than CO_2 per molecule) and long lifetime in the atmosphere (114 years) (IPCC, 2013). Moreover, N_2O is a significant ozone-depleting substance that destroys the ozone layer in the stratosphere (Portmann et al., 2012; Ravishankara et al., 2009). N_2O generation and emission mainly occur in the nitrification and denitrification processes *via* NH_2OH oxidation, nitrifier denitrification and canonical denitrification pathways (Massara et al., 2017). N_2O is an important intermediate product of the CDN process, and it will be released from reaction system when nitrous oxide reductase (N_2OR) is limited (Ni and Yuan, 2015). It was estimated that 17–42% of the N_2O emission was caused by the CDN process in WWTP (Kampschreur et al., 2009). N_2O emission from the CDN process varies largely depending on many factors, *e.g.* nitrogen loading rate, carbon source and operational condition (Adouani et al., 2015; Frison et al., 2015; Hu et al., 2013; Zhou et al., 2012; Zhu and Chen, 2011), and ranges from 0.25% to 3.5% of the nitrogen load in full-scale reactors (Pan et al., 2016; Sun et al., 2015) and up to 82% in a lab-scale batch reactor (Adouani et al., 2015).

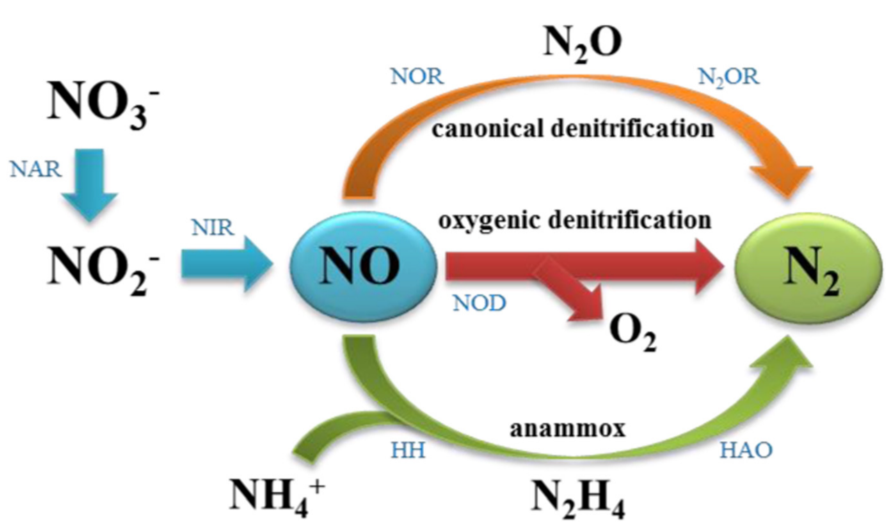

Fig. 1. Three known biological pathways for nitrogen removal, adapted from Strous et al. (2006), Ettwig et al. (2012) and Chen and Strous (2013). Abbreviations: NAR, nitrate reductase; NIR, nitrite reductase; NOR, nitric oxide reductase; N_2OR, nitrous oxide reductase; NOD, nitric oxide dismutase; HH, hydrazine hydrolase; HAO, hydroxylamine oxidoreductase.