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Autotrophic nitrogen removal from sludge digester liquids in upflow sludge bed reactor with external aeration

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Abstract

The novel microbial process such as anaerobic ammonium oxidation (Anammox) and completely autotrophic nitrogen removal over nitrite (Canon) processes is promising biotechnology to remove nitrogen from ammonium-rich wastewater like anaerobic sludge liquid. In this research, a new Canon-type nitrogen removal process adopting upflow granular sludge bed configuration was investigated on its feasibility and process performance, using synthetic wastewater and sludge digester liquids. Air as an oxygen source was provided in an external aeration chamber with flow recirculation. In the first experiment using the synthetic wastewater (up to 110 mg NH_4–N L^{-1}), the ammonium removal was about 95% (92% for T–N) at HRT for 5 days. In the second experiment using the sludge digester liquids (438 $\pm$ 26 mg NH_4–N L^{-1}), the total nitrogen removal was 94 $\pm$ 1.7% at HRT for 7 days and 76 $\pm$ 1.5% at HRT for 5 days, respectively. Little nitrite and nitrate were observed in the effluent of both experiments. The process revealed quite lower oxygen (0.29–0.59 g O_2 g^{-1} N) and less alkalinity (3.1–3.4 g $CaCO_3$ g^{-1} N) consumption as compared to other new technology in microbial nitrogen removal. The process also offers the economical compact reactor configuration with excellent biomass retention, resulting in lower cost for investment and maintenance.

Keywords: Anammox; Canon; Hydroxylamine; Hydrazine; Granule; Nitrogen removal; Sludge digester liquids

1. Introduction

Generally, recycle water from sludge processing in municipal wastewater treatment plants is high in ammonium nitrogen and contains hardly any biodegradable organic contents. Nitrogen removal from the recycle water is therefore of concern in order to achieve a stable process performance, as well as to enhance the nitrogen removal efficiency in mainstream processes. Field surveys and mass balance analysis using operating data obtained from 79 plants in Korea revealed that the recycle water resulted in a considerable increase in loading into the mainstream, corresponding to 1–3% of the inflow and about 25% of nitrogen loading, respectively [1]. Particularly, it was noteworthy that in the case of anaerobic digester supernatant and the sludge filtrate, the flow rate was small (0.53% of the inflow), but it could cause about 20% increase in nitrogen loading of the mainstream due to the high nitrogen concentration (about 500–600 mg N L^{-1}).

The sludge digester supernatant has a very unfavourable characteristic (low COD:N ratio) for a classical nitrogen removal process, namely autotrophic nitrification/heterotrophic denitrification. However, novel autotrophic microbial processes such as single reactor system for high activity ammonia removal over nitrite (Sharon), anaerobic ammonium oxidation (Anammox) and completely autotrophic nitrogen removal over nitrite (Canon), etc., can be sustainable nitrogen elimination technologies [2–5].

Fux and Siegrist [3] demonstrated that the completely autotrophic nitrogen removal process including partial nitritation and Anammox (Eqs. (1) and (2)) is more economical and environmental than the classical nitrogen removal process. Both reactions (Eqs. (1) and (2)) can co-occur in a single reactor called the Canon process, as given by Eq. (3). This compact reactor configuration can result in lower investment and operating costs due to a lesser oxygen demand and not having an organic carbon demand. However, little practical experience is available for the Canon process as well as the Anammox process. The start-up period in a full-scale plant has not yet been demonstrated because the maximum specific growth rate of the Anammox bacteria is quite low. Factors such as adequate

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oxygen transfer rate and higher biomass retention, etc. should be critical parameters for success of the process [6].

$$\text{Nitritation}\quad NH_4^+ + 1.5O_2 \rightarrow NO_2^- + H_2O + H^+ \qquad (1)$$

$$\text{Anammox}\quad NH_4^+ + 1.32NO_2^- + H^+ \rightarrow 1.02N_2 + 0.26NO_3^- + 2H_2O \qquad (2)$$

$$\text{Overall}\quad NH_4^+ + 0.85O_2 \rightarrow 0.44N_2 + 0.11NO_3^- + 1.43H_2O + 0.14H^+ \qquad (3)$$

The remarkable advance in the molecular biological technique has disclosed a great variety of information on biodiversity of the Anammox bacteria [7]. The Anammox is mediated by a monophyletic group of bacteria that branches deeply in the *Planctomycetales*. Even though the ''Anammox'' are used exclusively for nitrogen removal by these *Planctomycetes*-like bacteria, the *Nitrosomonas* species can also oxidize ammonium anaerobically as well as aerobically [3,8–10]. Under favourable conditions, various autotrophic nitrogen removal bacteria involving these bacteria could be co-cultivated in the anoxic or oxygen limited bioreactor such as the Canon reactor, giving a promise of complete nitrogen removal by elimination of undesirable by-products (NO_3–N and N_2O, etc.). Moreover, reactor configuration with high biomass retention such as the immobilization process (biofilm or granular sludge bed, etc.) is required. In spite of its high potential for successful application, only a few researchers have studied the high rate nitrogen elimination process such as the Anammox and Canon process, particularly by using synthetic wastewater [4,6,11].

In this research, a new Canon-type nitrogen removal process adopting a granular sludge bed configuration and external aeration was investigated on its feasibility and process performance using synthetic wastewater and sludge digester liquids.

2. Materials and methods

2.1. Laboratory reactor setup

A 10 L upflow granular sludge bed type reactor (internal diameter 9 cm) with an external aeration chamber (0.4 L) was operated at mesophilic (30 °C) condition, as shown in Fig. 1, adopting similar configuration to that of the Canon process. During the early period of the first experiment (phase I for synthetic wastewater), the aeration was provided in an influent tank only, but there after, the position of air supply was changed to the separated external chamber with flow recirculation, to increase of oxygen supply. The hydraulic retention time (HRT) of the aeration chamber was decided based on a batch aeration test, so that the aeration could not affect the microbial nitrogen conversion. The reactor configuration allowed the stable sludge bed without disturbing the sludge bed zone or damaging the granule by upflowing air bubbles in the reactor. The flowrate of air was controlled by a flow meter. Dissolved oxygen (DO) concentration in the external aeration chamber was about 5.6–6.5 mg O_2 L^{-1}. 1. The reactor was operated using a semi-continuous feeding system and the substrate was fed four times daily in a fill-and-draw mode. During the experiments, nitrogen and DO concentrations in the external aeration chamber were occasionally examined by the batch aeration test (Fig. 2). The aeration chamber was operated for a short retention time with a constant HRT of 26 min, and little nitritation and nitrification were observed under the condition, indicating that the operating condition of the short HRT barely affected the microbial ammonium oxidation in the external chamber.

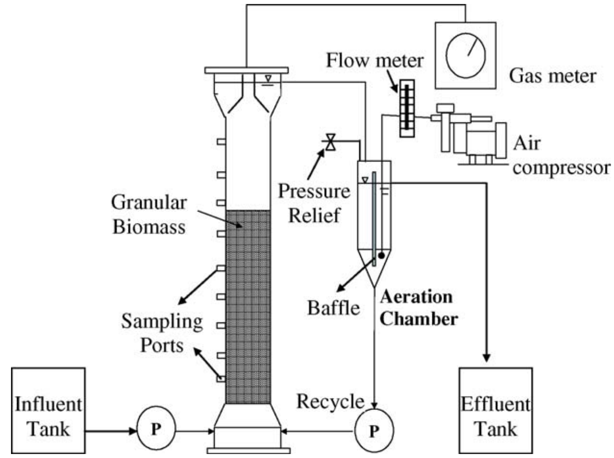

Fig. 1. Laboratory reactor setup.

The evaluation of the experiment consisted of two parts. In the first experiment, the reactor was operated with inorganic synthetic wastewater, which was prepared by adding ammonium (form of $(NH_4)_2SO_4$) to a mineral medium [12]. The ammonium concentration in the feed increased from 10 to 110 mg N L^{-1}, gradually, and the reactor was operated with a constant HRT for 5 days. The flow rates of air and recycle water in the experiment were about 100 mL min^{-1} and 20 L $days^{-1}$ ($R = Q_r/Q = 10$), respectively. In the second experiment, the reactor was operated with solely anaerobic sludge digester liquids (Table 1) without any addition of the mineral medium. In this period, the HRT decreased from 15 to 5 days, gradually, corresponding to the N loading of 0.03 g N L^{-1} $days^{-1}$ to about 0.1 g N L^{-1} $days^{-1}$. The flowrate of recycle water was about 20 L $days^{-1}$ but 50 L $days^{-1}$ ($R = 25$) for the case of 5 days of HRT. The air flowrate was 200 mL min^{-1} for phase I and 800 mL min^{-1} for phase II, respectively. The sludge digester liquids as the substrate, were prepared by dewatering the anaerobic digester supernatant which was collected from a municipal wastewater treatment plant (MWWTP), Gyungsan, Korea.

Five litres of sludge mixture with anaerobic granules and anoxic activated sludge (4:1 based on sludge volume) was inoculated as seed biomass. The granular sludge (18.6 g VSS L^{-1} and 76% VSS/TSS) and the anoxic activated sludge (2.3 g VSS L^{-1} and 75% VSS/TSS) were collected from a full-scale UASB reactor treating brewery wastewater and a biological nutrient removal reactor of the MWWTP, Gyungsan.

2.2. Analysis

The nitrogen (NH_4–N, NH_2–N and NO_3–N) concentration was measured colorimetrically according to Standard methods [13]. During the experiments, the pH (Orion 720, USA), bicarbonate alkalinity (BA) and gas production (Wet-

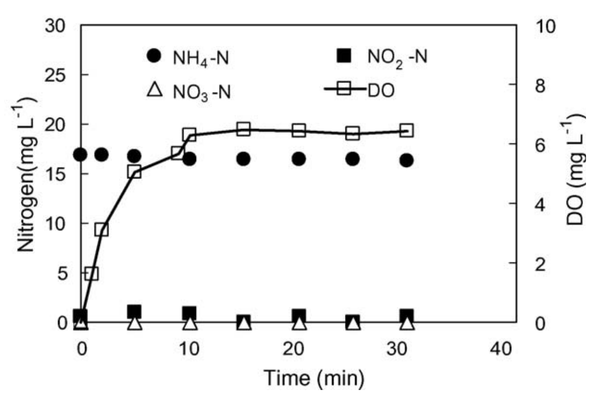

Fig. 2. Batch aeration test in aeration chamber.