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Osmotic stress on nitrification in an airlift bioreactor

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Abstract

The effect of osmotic pressure on nitrification was studied in a lab-scale internal-loop airlift-nitrifying reactor. The reactor slowly adapted to the escalating osmotic pressure during 270 days operation. The conditions were reversed to the initial stage upon full inhibition of the process. Keeping influent ammonium concentration constant at 420 mg N L^{-1} and hydraulic retention time at 20.7 h, with gradual increase in osmotic pressure from 4.3 to 18.8 × 10^5 Pa by adding sodium sulphate, the ammonium removal efficiencies of the nitrifying bioreactor were maintained at 93–100%. Further increase in osmotic pressure up to 19.2 × 10^5 Pa resulted in drop of the ammonium conversion to 69.2%. The osmotic pressure caused abrupt inhibition of nitrification without any alarm and the critical osmotic pressure value causing inhibition remained between 18.8 and 19.2 × 10^5 Pa. Nitrite oxidizers were found more sensitive to osmotic stress as compared with ammonia oxidizers, leading to nitrite accumulation up to 61.7% in the reactor. The performance of bioreactor recovered gradually upon lowering the osmotic pressure. Scanning and transmission electron microscopy indicated that osmotic stress resulted in simplification of the nitrifying bacterial populations in the activated sludge as the cellular size reduced; the inner membrane became thinner and some unknown inclusions appeared within the cells. The microbial morphology and cellular structure restored upon relieving the osmotic pressure. Addition of potassium relieved the effect of osmotic pressure upon nitrification. Results demonstrate that the nitrifying reactor possesses the potential to treat ammonium-rich brines after acclimatization.

Keywords: Osmotic stress; Nitrification; Airlift bioreactor; Nitrogen removal; Wastewater treatment

1. Introduction

Nitrogenous compounds like ammonium are prevalent in many wastewaters and need to be removed to prevent oxygen depletion and eutrophication of surface waters. Biological nitrogen removal from wastewater using nitrification-denitrification is a well-known and cost-effective treatment process. The first part of this process (nitrification) consists of the oxidation of ammonium to nitrite and finally to nitrate, being carried out by autotrophic ammonia and nitrite oxidizers, respectively. The nitrite and nitrate are then reduced to nitrogen gas by heterotrophic denitrifying bacteria using a carbon source (normally present in the raw wastewater) as the electron donor [1].

Nitrification is commonly the rate-limiting step of the process and nitrifying bacteria are sensitive to environmental factors such as temperature, dissolved oxygen concentration, pH, available substrate, product inhibition, and inhibitory compounds [2–4], and may be sensitive to the osmotic conditions of aquatic environment where this process occurs.

Water is a basic requirement for all living organisms to carry out normal metabolism and water availability is an important factor affecting microbial growth in nature. Water availability depends on the concentration of solutes such as salts, sugars, or other substances that are dissolved in water. This is because dissolved substances have an affinity for water, which makes the water associated with solutes unavailable to organisms. Water availability is generally expressed in physical terms such as water activity and osmosis [5].

High nitrogen-concentrated streams can also contain large amounts of other ions like chloride (fish canning industry, wet lime-gypsum desulphurization process), sulphate (tannery wastes, antibiotic process, monosodium glutamate process), etc. [6,7] These ions tend to exert high osmotic pressure (OP) on nitrifying microorganisms. Most of the microbial populations are unable to cope with environments of very high osmotic pressure and either die or become plasmolyzed and dormant under such conditions [5]. It is imperative to study the effect of osmotic stress resulting from ionic-strength on the nitrification,

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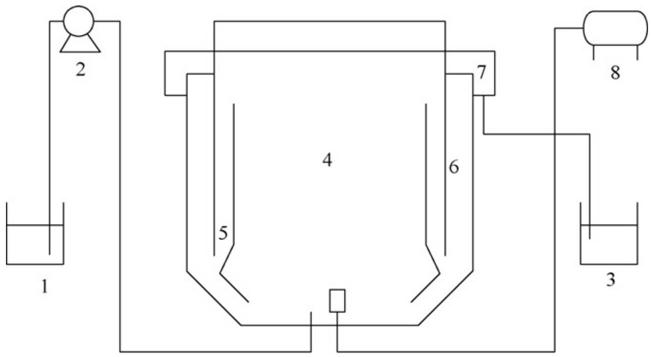

Fig. 1. Scheme of the experimental system. (1) Influent tank, (2) peristaltic pump, (3) effluent tank, (4) riser, (5) downcomer, (6) settler, (7) overflow weir, (8) air pump.

not only from microbiological standpoint but also for the wastewater treatment industry.

The effect of salts in wastewater on nitrification has been investigated extensively [7–11]. However, presently no report concerning the effect of osmotic pressure on the biological wastewater treatment is available. The objective of this study was to investigate the performance of an airlift reactor for treating nitrogen-concentrated wastewater under high osmotic pressure. Reactor performance, microbial morphology, and cellular structure of the activated sludge prior to and following osmotic stress were compared.

2. Materials and methods

2.1. Airlift bioreactor

The laboratory-scale internal-loop airlift bioreactor is shown in Fig. 1. It was made of Perspex with a working volume of 10.4 L and height/diameter ratio of 1, and it consisted of four sections: riser, downcomer, gas separator, and settling section. The cross sectional area of riser, downcomer, and settling section were 153.9, 97.4, and 346.4 cm^2, respectively. The reactor was operated at 30 ± 1 °C in a room equipped with thermostat.

2.2. Inoculum

Nitrifying sludge from a lab-scale reactor was used as inoculum for the present study. The mixed liquor volatile suspended solids (MLVSS) of inoculum were 4.5 $g\,L^{-1}$. The operational parameters of 'mother' bioreactor were kept at influent NH_4-N of 420 $mg\,L^{-1}$, hydraulic retention time (HRT) 20.7 h, and nitrogen loading rate (NLR) of 486 $mg\,L^{-1}\,day^{-1}$. The NLR was in the range of common nitrifying activated sludge system.

2.3. Synthetic wastewater

The composition of synthetic wastewater is listed in Table 1. For alkalinity and carbon source supplement, the theoretical $NaHCO_3$ requirement for nitrification (7.1 g as $CaCO_3\,g^{-1}$ NH_4-N) was added to the wastewater. In phase III described later, $NaHCO_3$ was partly or thoroughly replaced by $KHCO_3$ with equimolar ratio.

Table 1
Composition of synthetic ammonium-containing wastewater, in $g\,L^{-1}$

Compound	Concentration
KH_2PO_4	0.027
$MgSO_4 \cdot 7H_2O$	0.300
$CaCl_2$	0.136
Na_2SO_4	0–30.7
$NaHCO_3$	1.68–7.78
$(NH_4)_2SO_4$	0.66–3.06
Trace elements I[a]	1.25 $mL\,L^{-1}$
Trace elements II[b]	1.25 $mL\,L^{-1}$

[a] Composition of trace elements I ($g\,L^{-1}$): EDTA 5.00, $FeSO_4$ 5.00.
[b] Composition of trace elements II ($g\,L^{-1}$): EDTA 15, $ZnSO_4 \cdot 7H_2O$ 0.43, $CoCl_2 \cdot 6H_2O$ 0.24, $MnCl_2 \cdot 4H_2O$ 0.99, $CuSO_4 \cdot 5H_2O$ 0.25, $Na_2MoO_4 \cdot 2H_2O$ 0.22, $NiCl_2 \cdot 6H_2O$ 0.19, $Na_2SeO_4 \cdot 10H_2O$ 0.21, $H_3BO_4 \cdot 7H_2O$ 0.014.

2.4. Experimental set-up

The reactor was operated in three phases described as follows:

Phase I-Osmotic stress experiment: In this phase, the operational parameters were fixed at influent NH_4-N of 420 $mg\,L^{-1}$, HRT 20.7 h, sludge retention time (SRT) about 24 days, NLR 486 $mg\,L^{-1}\,day^{-1}$, pH 7.5–8.5, airflow rate 0.65 $L\,min^{-1}$ and dissolved oxygen (DO) of 1.5–5.0 $mg\,L^{-1}$. At the same time, the influent sodium sulfate concentration was increased stepwise, with a 710 $mg\,L^{-1}$ (equal to OP of 0.4×10^5 Pa) increment per step to raise the OP, until the deterioration of the performance of bioreactor. An adaptation period of four days was allowed at each step before increasing the sodium sulfate to the next higher level.

Phase II-Relieving osmotic stress experiment: After phase I, the influent sodium sulfate concentration was decreased stepwise that is 1420 $mg\,L^{-1}$ (equal to OP of 0.8×10^5 Pa) per step initially. When the OP was lower than 12×10^5 Pa, the concentration was changed to 2840 $mg\,L^{-1}$ (equal to OP of 1.6×10^5 Pa) per step. Like phase I, an adaptation period of four days was provided. Other operational parameters were the same as phase I.

Phase III-Osmotic stress adjustment experiment: During this period, $NaHCO_3$ was partly or fully replaced with $KHCO_3$ (with the same molar amount) as a buffer and inorganic carbon source to study the potential adjustment function of potassium in environment of high osmotic stress. HRT was set at 6.2 h with OP of 19.2×10^5 Pa. Other operational conditions were the same as phase I.

2.5. Analytical methods

Ammonium, nitrite, and nitrate were determined using the standard methods [12]. The mixed liquor volatile suspended solids determination was performed after filtration of a 50 mL sample of mixed liquor on a glass microfibre filter. Dry weight was determined after the filter was dried for 24 h at 105 °C and weighted on a microbalance. The ash content was calculated after incinerating the dried filter in an oven for 1 h at 550 °C. The DO was measured by JPB-607 dissolved oxygen meter. The OP was calculated by Donnan equilibrium ion distribution and OP equations [13].