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Coupling sequencing batch airlift reactor (SBAR) and membrane filtration: Influence of nitrate removal on sludge characteristics, effluent quality and filterability ☆

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A B S T R A C T

This study investigates the sludge and effluent characteristics of a new process of coupling an aerobic granular sludge bioreactor with a membrane filtration. The effluent and mixed liquor of sequencing batch airlift reactor (SBAR) were analyzed at various aeration shear stresses when fed with high nitrate containing wastewater. The presence of nitrate nitrogen and aerobic/anoxic condition was able to improve the sludge characteristics in terms of biomass retention, density and settling ability in SBAR. MLSS and SVI could reach 9 g/L and 44 mL/g respectively at the aeration rate of 0.6 cm/s. The presence of nitrate and the denitrification process could minimize the fouling potential. The membrane fouling can be better correlated to SBAR sludge characteristics than biomass concentration. The high aeration rate in the reactor increased the fouling resistance due to production of large MW soluble microbial products (30–50 kDa). The soluble fraction of SBAR effluent contained mainly hydrophilic substances when nitrate is present in the wastewater.

1. Introduction

Membrane bioreactors have become attractive treatment systems in wastewater treatment works around the world due to its advantages such as compactness, high treated effluent quality and less sludge production. However, several operational factors such as type of wastewater, sludge loading rate, sludge age, MLSS concentration and mechanical stress tend to influence the fouling propensity of the membrane. There is poor understanding on fouling tendency and sludge characteristics in the case of high nitrate containing wastewater. Nitrate is a common pollutant in domestic and industrial wastewaters. Its presence in wastewater could be natural and/or resulting from chemical reactions (nitrification from ammonia and/or nitrogenous compounds). Nitrate was found to enhance the elimination of soluble microbial products (SMP) in membrane bioreactor [1]. The anoxic/aerobic stage can improve the nitrogen removal through denitrification process and form a compact and stable aerobic aggregate in the reactor [2]. Currently, the literature on the effect of nitrate on quality of the sludge and membrane filterability is limited.

This research aims to evaluate a new process based on coupling an aerobic granular sludge bioreactor with a membrane filtration. Hence, the fouling capacity of effluent of the sequencing batch airlift reactor (SBAR) treating nitrate-containing wastewater at various air shear rates was investigated. In addition, the fouling behaviour, the SBAR effluent characteristics at different aeration rates which simulate the operating conditions of the conventional and granulation SBAR have been compared.

2. Materials and methods

Synthetic wastewater was prepared from glucose, sodium propionate, sodium acetate and ethanol, each component contributing for 25% of total COD (850 ± 150 mg/L). Ammonium chloride was added to achieve the COD/N ratio of 20 while the nitrate nitrogen ($NaNO_3$) concentration was about 100 mgN/L during the experiment. pH of the feed was maintained in the range 7.4–7.8, by adjusting the amount of $NaHCO_3$ solution. The other nutrient and trace element of feed wastewater was similar to [3].

The SBAR has a working volume of 17 L and exchange volume of 47%. A plate is positioned vertically in the middle of the reactor for dividing the column into two zones namely raiser and down comer. The SBAR operation includes 4 batches per day with each batch consists of: filling without aeration during 30 min, aeration during 4 h 30 min, settling without aeration during 30 min and finally effluent withdrawal without aeration during 30 min. The reactor was operated at aeration rates of 0.8 cm/s (days 1–37), 2.2 cm/s (days 38–79) and

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0.6 cm/s (days 80–174). During the last run from days 121 to 174, the cycle was modified by adding an anoxic mixing stage just after filling the reactor. Here, nitrogen gas instead of air was supplied for 30 min at the same gas flowrate of 0.6 cm/s. This step was aimed to enhance denitrification process by anoxic/aerobic condition.

Fouling characteristics of biomass fractions, namely suspended solids (SS), colloids (CL) and solutes (SL), were characterized by filtration tests, calculation of the total resistance (R) and its increase with the filtrate volume (dR/dV), specific cake resistance (α), reversible and irreversible resistance (R_{rev}, R_{ir}). The fouling rate (dR/dV) was measured in an AMICON filtration cell (model 8200, 250 rpm) at various trans-membrane pressures (TMPs) (0.25, 0.50, 0.75, 1.00 and 1.25 bar). Each step of TMP lasted for 10 min. The resistance-in-series model (Darcy's law) was then used to evaluate the fouling characteristics of each sample. Membrane resistance (R_m) was measured for clean membrane while total resistance (R_t) was measured after membrane had been filtered at the last operating TMP with distilled water ($R_f = R_t - R_m = R_{rev} + R_{ir}$). The R_{ir} was measured after cleaning the fouled membrane with distilled water (200 mL). The polyether sulfone membrane with pore size of 0.1 μm and surface area of 28.7 cm^2 was used. The colloidal fraction and soluble fraction of the sludge sample were prepared by centrifuging sludge sample at 4000 g and 10,000 g during 15 min respectively [4].

Sludge volume index (SVI), Suspended solids (SS), nitrite, nitrate, and ammonia were measured in accordance to standard methods [5]. Particle size distribution was obtained by laser diffraction technique (Mastersizer 2000, Malvern, UK, size detecting range of 0–2 mm). Molecular weight (MW) of soluble fraction (10000 g) was obtained by size exclusion chromatography (HPLC-SEC) equipped with fluorescence detector (excitation emission matrix — EEM). The wavelength of excitation was 280 nm and emission was 350 nm which effectively detects the protein-like substances. In addition, hydrophobic character of soluble matters was determined by hydrophobic interaction chromatography (HIC) by HPLC-EEM system. The HIC is an important technique for protein purification, which exploits the separation of proteins based on hydrophobic interactions between the stationary phase ligands and hydrophobic regions on the protein surface. The HiTrap Octyl separation column (1 mL, Amersham, Sweden) with the flowrate of 1 mL/min was used for the test. Phosphate buffer and ammonium sulfate 2 M were used as eluent solutions for the HIC measurement. The concept of dimensionless retention time (DRT) of protein-like material was used to estimate the degree of hydrophobicity (DRT = 0: less hydrophobic, DRT = 1: extreme hydrophobic). The detailed method is described by Lienqueo et al. [6].

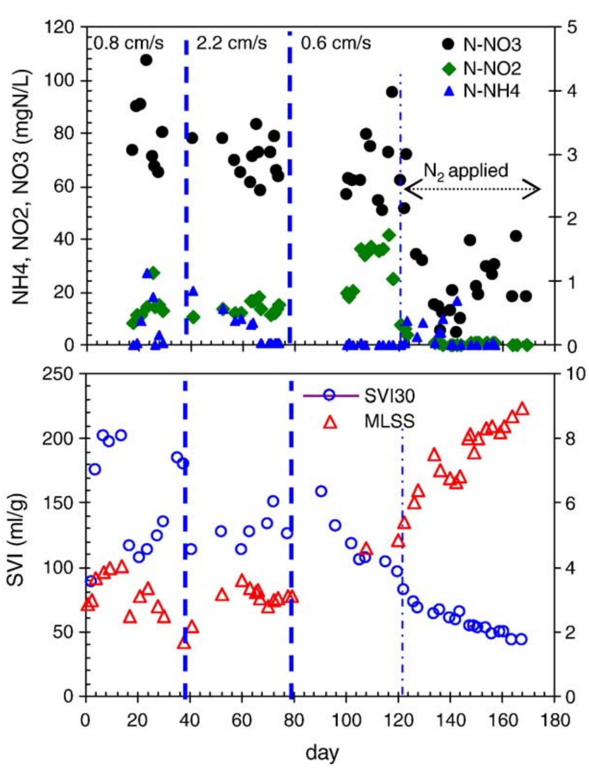

Fig. 1. Nitrogen removal and sludge characteristics of SBAR.

3. Results and discussion

3.1. SBAR performance

The treatment performance of SBAR is summarized in Fig. 1. During the first two runs (0.8 and 2.2 cm/s) no significant nitrate removal was observed. The sludge characteristics in terms of SVI and MLSS were almost similar with the conventional SBR. In contrast, at the stage of aeration of 0.6 cm/s and after anoxic mixing stage was introduced (day 121 onward) the treatment performance and sludge quality improved significantly. During this period, the denitrification of nitrate was improved. In parallel, the biomass concentration considerably increased and settling ability in reactor impressively improved (SVI decrease). The anoxic/aerobic condition enhanced sludge retention or biomass density obviously compared to the previous runs. Similarly it was observed that existence of anoxic stage in a SBAR could enhance structure of aggregate [2]. This shows the positive effect of nitrate reduction and anoxic/aerobic condition on the reactor performance of SBAR.

3.2. Effect of aeration rate and anoxic mixing stage on resistance rate

Fig. 2 represents the fouling rates of the three sludge fractions (SS, CL and SL) of the SBAR effluent at the different aeration rates. At the

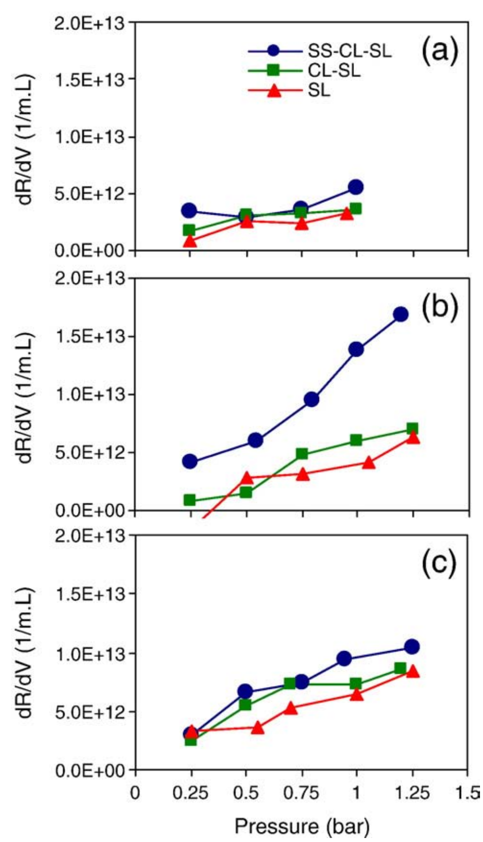

Fig. 2. Resistance rates at aeration rates (a) 0.8 cm/s (day 28), (b) 2.2 cm/s (day 65) and (c) 0.6 cm/s with anoxic/aerobic operation (day 145).