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# Simultaneous nitrification denitrification in a Batch Granulation Membrane Airlift Bioreactor

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## ABSTRACT

This study investigates the performance of a batch aerobic granulation system coupled with membrane airlift bioreactor (MABR). Performance of the system was examined in terms of organic carbon and nitrogen removals, and membrane fouling. It was observed that the removal of organic carbon and nitrogen were 99% and 61% respectively with 35% of denitrification when the system was operated at organic and nitrogen loadings of 1.5 kg TOC/m$^3$.d and 0.4 kg $NH_4^+$–N/m$^3$.d respectively. The retention of soluble EPS produced due to deflocculation and cell lysis phenomena was the main cause for membrane fouling. Besides, it was noted that the denitrification and fouling control could be directly linked to the stability of aerobic granules as high soluble EPS production was observed during the granule breakage which resulted in rapid fouling in the membrane. In addition, the external electron donor supply can augment the denitrification process in MABR where both aerobic and anoxic zones exist.

## 1. Introduction

During the last decade, aerobic granular sludge systems were studied extensively, especially for operating at high organic loading. These aerobic granules have spherical compact structure with the size ranging from 0.5 to 9.0 mm with the aerobic and anaerobic conditions within the granules due to the oxygen diffusivity limitation. Thus, the simultaneous nitrification and denitrification could be achieved inside the granules (Li et al., 2005; Wang et al., 2008). In addition, the aerobic granular sludge has a number of advantages over the conventional sludge such as excellent settling ability leading to good solid–liquid separation, high biomass retention, and ability to withstand high organic and nitrogen loadings (Beun et al., 2002; Tay et al., 2002; Thanh et al., 2013). Nevertheless, aerobic granulation reactor alone can not fulfil the effluent standards as the granulation process produces high suspended solids in the effluent in the range of 50–1200 mg/L (Beun et al., 2002; Arrojo et al., 2004; Thanh et al., 2008). Consequently, there is always a need for a post–treatment process to remove the fine colloidal fraction from the effluent. In this regard, using an MBR system might be more attractive when compared with the conventional secondary sedimentation unit. Besides, the MBR system can not only filter the remaining colloidal fraction but also biodegrade them within the reactor.

The MBR technologies have evolved drastically in the recent period, and the membrane systems could considerably reduce the space requirement to treat a given flow, increase the volumetric loading rate, augment the effluent quality and trim down the chemical requirements for disinfection. On the other hand, membrane fouling impedes the widespread application of MBR as it reduces productivity, and increases operation and maintenance costs. To evade the said drawbacks of MBR, it could be coupled with aerobic granulation process to minimize the suspended solids concentration in the granulation effluent and membrane fouling. When compared with the conventional MBR, aerobic granular sludge MBR provides low permeability loss, less frequent fouling and improved effluent quality based on high simultaneous nitrification and denitrification (Li et al., 2005; Tay et al., 2007).

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However, in this study, the membrane airlift bioreactor (MABR), where both aerobic and anoxic zones exist, was coupled with sequencing batch airlift reactor (SBAR) where aerobic granular sludge was cultivated to promote the removal of nitrogenous compounds through simultaneous nitrification and denitrification. Further, it was reported that the MABR showed less direct contact with substrate supply, lower biomass concentration in the reactor, lower aeration requirement to achieve the required aeration shear stress, and presence of aerobic and anoxic zones within the reactor when compared with that of the conventional MBR (Kimura et al., 2008). Accordingly, this study was designed to investigate the simultaneous nitrification and denitrification potential along with membrane fouling issues at high organic and nitrogen loading conditions of the Batch Granulation Membrane Airlift Bioreactor (BG-MABR).

## 2. Materials and methods

### 2.1. Synthetic wastewater characteristics

Synthetic wastewater was prepared with 1260 mg/L of commercial grade glucose, 470 mg/L of $NH_4Cl$, and some other constituents such as (concentrations are given in parentheses as mg/L) $NaHCO_3$ (1800), $KH_2PO_4$ (40), $CaCl_2 \cdot 2H_2O$ (30), $MgSO_4 \cdot 7H_2O$ (12) and $FeCl_3 \cdot 6H_2O$ (4) dissolved in the tap water. In addition, 1 mL solution of trace element mixture was added per litre of wastewater as described by Thanh et al. (2008). The above described constituents were designed for organic loading rate (OLR) of 1.5 kg TOC/m$^3$.d (4 kg COD/m$^3$.d) and nitrogen loading rate (NLR) of 0.4 kg $NH_4^+{-}N$/m$^3$.d. The concentration of $NaHCO_3$ was varied in order to maintain the pH of the feed within the range of 7.6 ± 0.2.

Bivalve shell carrier was used as the support media for cultivation of aerobic granules. This media was produced with bivalve shell of white rose cockle which enhanced the microbial adhesion and granulation. The size of the media used was 0.15–0.30 mm (density of 1.45 g/cm$^3$ and settling velocity of 55–300 m/h). At the initial stage of granule formation 20 g/L of support media was used, and subsequently 2 g/L was added on a weekly basis to substitute the washed out carriers to MABR at each cycle of operation.

### 2.2. Experimental setup

The experimental setup consisted of two reactors: SBAR to cultivate the aerobic granules and MABR to further treat the effluent from SBAR by membrane filtration (Fig. 1). The SBAR had a working volume of 9.7 L, with 115 mm diameter and 1300 mm height while the riser inside was with 70 mm diameter and 900 mm height. The operation of SBAR had five stages in each 4 h cycles which comprised of feeding of synthetic wastewater (6 min), high aeration (180 min), low aeration ("denitrification" stage) (48 min), settling of granules (3 min) and discharge of 5.3 L supernatant (3 min). High and low aeration rates of a cycle were 10.2 L/min (59 m$^3$/m$^2$/h) and 0.5 L/min (2.9 m$^3$/m$^2$/h) respectively. Dissolved oxygen (DO) in bulk liquid was ranging from 6.3 to 7.8 mg/L during the high aeration stage. Then, it was reduced to 4.0–5.0 mg/L for the low aeration stage. Low aeration was applied to ameliorate the denitrification process due to oxygen diffusion limitation into the core of the aerobic granules, and to cut down the energy requirement. The sludge retention time (SRT) of SBAR was calculated based on the volume of sludge washout from the reactor and sludge retained in the reactor. The calculated SRT of SBAR was approximately of 24 days during the operation. The MABR had a working volume of 13 L with 145 mm diameter and 620 mm height while the riser inside was with 105 mm diameter and 520 mm height. The SBAR effluent was pumped into the MABR which was operated for 7 min on and 3 min off filtration cycle and with a fixed SRT of 40 days. After two hours of MABR operation the biomass level in the reactor went below the upper edge of the inner tube. This caused no circulation of biomass in the outer part of the reactor and initiated the anoxic conditions locally. The net permeate rate through the membrane was maintained at 4.14 L/m$^2$.h (29 mL/min) throughout the experiment. A hollow fibre membrane unit made up of polyethylene material with pore size of 0.1 μm and surface area of 0.42 m$^2$ (STRERAPORE, Mitsubishi Rayon, Japan) was used for the experimental runs.

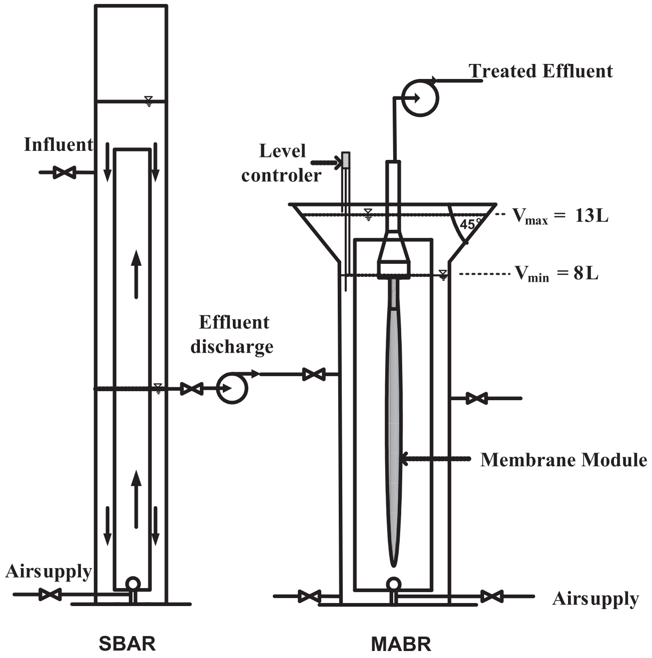

**Fig. 1.** Design set-up of the Batch Granulation Membrane Airlift Bioreactor (BG-MABR).

### 2.3. Analytical methods

Standard methods (APHA et al., 1998) were followed to measure the $NH_4{-}N$, $NO_2{-}N$, $NO_3{-}N$, SVI and MLSS/MLVSS. The Sludge Volume Index (SVI) for granular sludge and MABR sludge were measured after allowing the sludge to settle for 15 min and 30 min respectively in samples of 100 mL. The soluble total organic carbon (TOC) was measured using a Total Organic Carbon Analyzer (TOC 5000A, Shimadzu, Japan). Further, the TN was measured with a Total Nitrogen Measurement Unit (SHIMADZU, model TNM-1) equipped with the above mentioned TOC analyzer for the samples of cell lysis test. The bound extracellular polymeric substances (EPS), which mainly includes polysaccharides (PS) and protein (PN), were extracted using cation exchange resin method by Frølund et al. (1996). The soluble PS and PN, and extracted PS and PN, were measured using the method developed by Dubois et al. (1956) and Lowry et al. (1951) respectively.

## 3. Results and discussion

### 3.1. Characteristics of granular and MABR sludge

The average MLSS and SVI during the experiment of granular and MABR sludge (flocculent sludge) at OLR 1.5 kgTOC/m$^3$.d and NLR 0.4 kg $NH_4^+{-}N$/m$^3$.d are tabulated in Table 1. In this research, the $SVI_{15}$ of the granular sludge was 22 mL/g which proved the good settling ability of the granular sludge. Furthermore, this result