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Simultaneous organics and nutrients removal in side-stream aerobic granular sludge membrane bioreactor (AGMBR)

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ABSTRACT

Membrane fouling mitigation has been variously reported in aerobic granular sludge membrane bioreactor (AGMBR). AGMBR has also achieved, to varying degrees, the removal of organics and nitrogen-based compounds from wastewater. However, scanty information is available in the literature on phosphorus removal in AGMBR. Thus, the present study focused on simultaneous removal of organics and both nutrients (nitrogen and phosphorus) in AGMBR at semi-pilot-scale. Aerobic granules were cultivated in a cylindrical reactor with a working volume of 19 L, diameter of 15 cm, and height-to-diameter (H/D) ratio of 8. The effluent from the granular reactor was discharged into a side-stream membrane module. At steady state, the granule mean size, 5-min sludge volume index (SVI_5), SVI_{30}, and MLSS were 576 µm, 40 mL/g, 37 mL/g, and 9200 mg/L, respectively. Results show that the system achieved 98% chemical oxygen demand (COD) degradation, 96–99% total nitrogen (TN) removal, and ≥95% removal of PO4-P. The outstanding removal of both organics and nutrients in the AGMBR is attributed to the coexistence of aerobic and anaerobic layers within the granule as well as the anaerobic feeding adopted. These findings demonstrate the potential of AGMBR to simultaneously remove organics and nutrients (nitrogen and phosphate)

1. Introduction

Membrane bioreactor (MBR) technology is becoming widely used for wastewater treatment and reclamation due to its compact nature, production of high-quality effluent, capability of withstanding high organic loading, low sludge generation, and production of largely disinfected effluent [1,2]. However, membrane fouling is its major drawback [3–6]. Bacteria and their by-products (extracellular polymeric substances – EPS) have been identified as major contributors to membrane fouling [3,7,8].

The development of aerobic granular sludge membrane bioreactor (AGMBR) has been proposed to mitigate membrane fouling [9–13]. In AGMBR, the activated sludge is modified into aerobic granules which are essentially bacteria bound together by EPS, hence less membrane fouling. The large size and rigid structure of aerobic granules expectedly reduces pore blocking and cake layer formation in AGMBR [14], hence enhanced membrane filtration. In addition, aerobic granules exhibit a layered structure with an oxic zone near the granule surface, an anoxic zone in the middle layer, and an anaerobic zone at the granule centre [15,16]. This stratified structure provides suitable conditions for the removal of organics and nutrients (nitrogen and phosphorus) even when the system is operated entirely aerobically.

Previous studies have reported increased membrane permeability [17,9], enhanced membrane filtration [18,10], extension of filtration period by 78 days without physical cleaning [19], and eight-fold lower membrane fouling in AGMBR compared to MBR during long-term (220 days) municipal wastewater treatment [20]. In terms of organics degradation, while some studies found similar treatment efficiency for both AGMBR and conventional MBR [9], others reported higher removal efficiency in AGMBR [18,10,21]. The capability of AGMBR to remove nitrogen-based compounds has also been explored. Some of these studies reported removal efficiencies at steady state as follows: 90% NH_4-N (influent concentration ~40 mg/L) [22], 85.4–99.7% NH_3-N (influent = 28.1–38.4 mg/L) and 41.7–78.4% total nitrogen (TN) removal [15], 95.7% NH_4-N removal at influent NH_4-N concentration of 14.4 ± 1.7 mg/L [23], and 61% TN removal at nitrogen loading rate of 0.4 kg NH_4^+-N/m^3.day [21].

Thus, the aim of the present study was to determine the simultaneous removal of organics and both nutrients (nitrogen and phosphorus) in a side-stream AGMBR.

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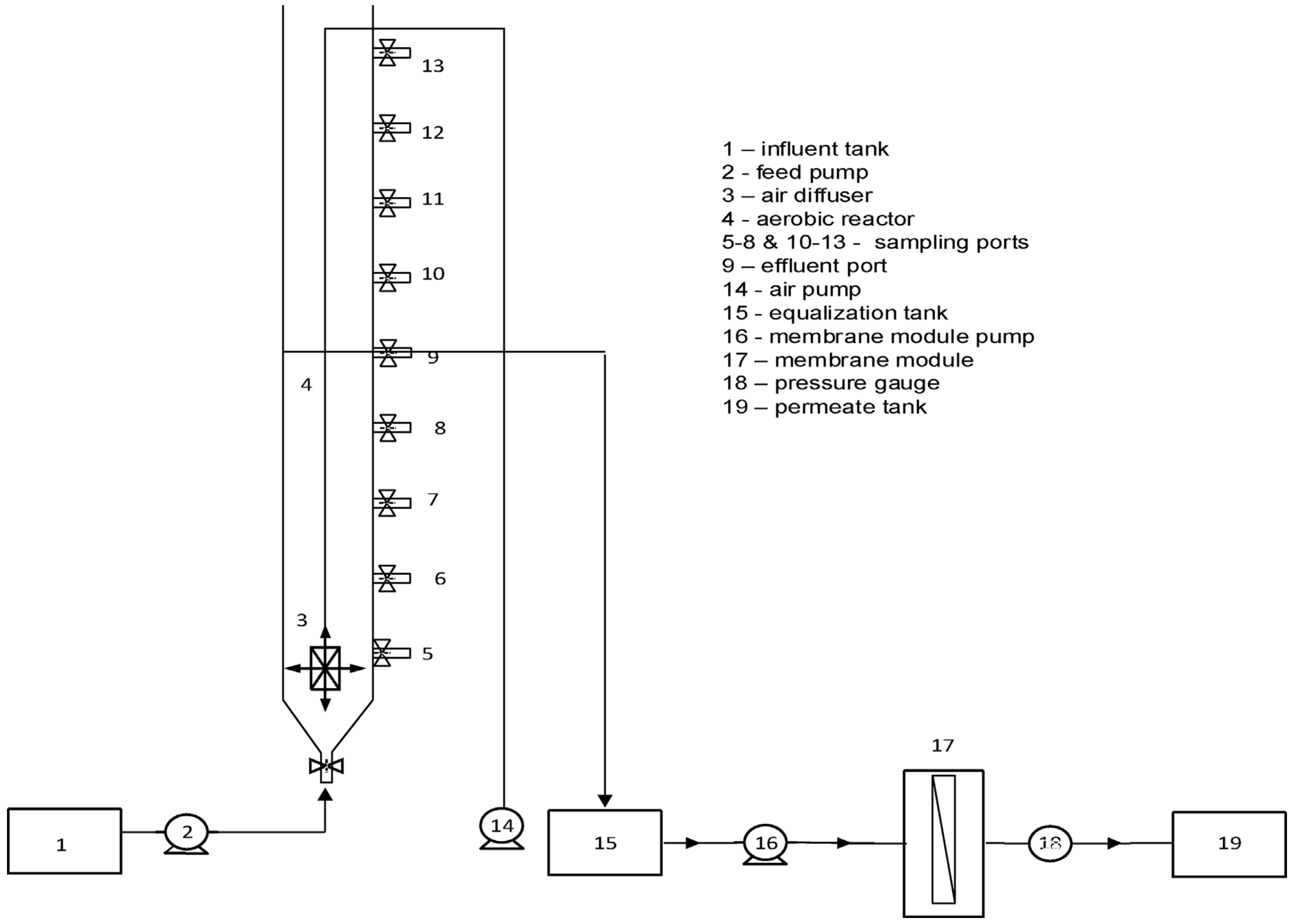

Fig. 1. Schematic of AGMBR set-up.

2. Materials and methods

2.1. Experimental set-up

A cylindrical aerobic granular reactor with height-to-diameter (H/D) ratio of 8 was used for the experiment. The reactor had a working volume of 19 L and a diameter of 15 cm. The system was operated in sequencing batch reactor (SBR) mode with 60 min of anaerobic filling, 170 min of aeration, 5 min of settling and 5 min of decanting. Fine air bubbles were supplied at the bottom of the reactor using Paintair diffusers (AS40) at a superficial upflow air velocity of 3 cm/s. Effluents were discharged from the middle port of the reactor corresponding to a volumetric exchange ratio (VER) of 50%. The effluents were discharged into the side-stream membrane module (Sterlitech Sepa CF Cell) containing microfiltration membrane module. The membrane module contained a flat-sheet membrane made of polyvinylidene fluoride (PVDF), and had a pore size of 0.1 μm and membrane active area of 140 cm^2. The membrane was operated in continuous flow (in cross-flow filtration mode). The schematic diagram of the AGMBR set-up is shown in Fig. 1.

The system was seeded with settled activated sludge obtained from a wastewater treatment plant in Calgary. The settled sludge had an initial mean particle size of 115 μm, sludge volume index (SVI_{30}) of 119.5 mL/g, SVI_5 (after 5 min of settling) of 122 mL/g and a mixed liquor suspended solids (MLSS) concentration of 8.2 g/L. The return activated sludge (RAS) was acclimated for five days in a batch mode prior to starting the system. At the beginning of the experiment, the SVI_{30} and SVI_5 of the reactor mixed liquor were 161 mL/g and 187 mL/g, respectively. The experiment was conducted at room temperature (21 ± 2 °C).

2.2. Media

Synthetic wastewater was prepared from the following compounds: sodium acetate (carbon source), NH_4Cl, KH_2PO_4, K_2HPO_4, $CaCl_2 \cdot 2H_2O$, $MgSO_4 \cdot 7H_2O$, and $FeSO_4 \cdot 7H_2O$. Micronutrients were prepared from: H_3BO_3, $ZnCl_2$, $CuCl_2$, $MnSO_4 \cdot H_2O$, $(NH_4)_6 \cdot Mo_7O_{24} \cdot 4H_2O$, $AlCl_3$, $CoCl_2 \cdot 6H_2O$, and $NiCl_2$. The influent chemical oxygen demand (COD) was 2902 ± 129.5 mg/L, the organic loading rate (OLR) was 8.71 ± 0.39 kg COD/m^3.day. The influent TN and PO_4 concentrations were 74.53 ± 4.12 mg/L and 34.5 ± 4.39 mg/L, respectively.

2.3. Analytical methods

Biomass characteristics (MLSS, SVI_{30}) were determined according to standard methods [24]. SVI_5 was measured in a similar way to SVI_{30} but with the settling time modified from 30 min to 5 min. COD was determined using Hach kits. The total nitrogen (TN) was analyzed using Shimadzu Total Nitrogen Measuring Unit (TNM-L). PO_4-P was analyzed using Metrohm Compact IC Flex. The average particle size was determined by a laser particle size analysis system (Malvern MasterSizer Series 2000).

3. Results and discussion

3.1. Granule development

Granules appeared in the reactor on day 3 of operation, attaining steady state within three weeks. At steady state, the mean size of the granules was 576 μm (from the initial value of 115 μm). Mature granules were obtained in the system by day 25 of operation. With stable