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Effects of bio-carriers on membrane fouling mitigation in moving bed membrane bioreactor

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ABSTRACT

Two moving bed membrane bioreactors (MBMBR) were compared with a conventional membrane bioreactor (MBR) to investigate the effects of bio-carriers on membrane fouling treating real domestic wastewater. Under the experimental conditions, membrane filtration operating time of the MBMBR (without the scouring of bio-carriers) was nearly 1.5 times extended when compared to the MBR. Furthermore, with the scouring of membrane by bio-carriers in the MBMBR (denoted as $MBMBR_{SC}$), the membrane filtration operating time was 8 times further extended. From the characterization of the mixed liquor suspensions and the membrane foulants of the three bioreactors, the results showed that the MBMBR could reduce membrane fouling due to the 58.8% lower concentration of biopolymers especially lower concentration of carbohydrates, and 15.6% lower concentration of low molecular weight (LMW) compounds than the MBR. Scouring of the membrane surface by bio-carriers was sufficiently effective in controlling membrane fouling, and the effects of bio-carriers on mitigation of membrane fouling depended more on mechanical effects of bio-carriers scouring than physio-chemical effects of mixed liquor suspension. The fouling resistance distribution showed that the dominant fouling mechanism in the MBR and the MBMBR was cake layer fouling which contributed to 84.8% and 79.4% of the total fouling resistance, respectively, while the resistance of cake layer was significantly reduced by 40.5% via the scouring of bio-carriers in the $MBMBR_{SC}$. It suggested that scouring of bio-carriers could enhance the shear force on the membrane surface. As a result, the selective enrichment of *Nitrospirae* in the cake layer of the $MBMBR_{SC}$ was observed. Also, total suspended solids (TSS), organic matters and the inorganic matters in the fouling cake layer of the $MBMBR_{SC}$ could be largely reduced by the scouring of bio-carriers and resulted lower membrane fouling rate. The effective mitigation of the cake layer fouling contributed to the remarkable enhancement of the membrane filtration performance in the $MBMBR_{SC}$, while the slowly accumulation of the dissolved organic matters and the inorganic matters in the pore blocking and constriction (PBC) as well as their combined bridging effects resulted in the final membrane fouling.

1. Introduction

Moving bed biofilm reactor (MBBR) has been widely adopted in wastewater treatment, with the advantages of smaller footprint requirements, higher specific biomass activities and better treatment performances than conventional activated sludge (CAS) process [1]. The principle of MBBR is to employ bio-carriers with attached-growth biomass that are able to move freely in the reactor with the agitation provided by aeration (in aerobic reactors) or mechanical mixing (in anaerobic and anoxic reactors). With the aid of bio-carriers, washout of the biomasses could be reduced, allowing development of specific slow-growing microorganisms such as nitrifying bacteria [2]. Furthermore, comparing with other biofilm processes such as fixed bed biofilm reactor, MBBR could avoid bed clogging by having a good mixing condition. As a result, high loading capacity of particulate matter is enabled due to efficient mass transfer [3]. However, biomass in the MBBR is reported to have difficulty with settling as compared to CAS [4]. Therefore, membrane bioreactor (MBR), with property of perfect solid-liquid separation that makes it capable of producing excellent effluent quality, could overcome the disadvantages of MBBR. Nevertheless, membrane fouling is always the major drawback of MBR application although a number of studies have been conducted to control and reduce membrane fouling [5–7].

Recently, moving bed membrane bioreactor (MBMBR) with membrane coupling into MBBR has been reported to enhance organics and nutrients removal for both low-strength and high-strength wastewater treatment by having a more diverse and

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populated microbial community [8–10]. However, contradictory results on the membrane fouling behavior were also reported. In general, the effect of bio-carriers on membrane fouling propensity can be classified into (1) physio-chemical effects that exert on the characteristics of mixed liquor suspension; and (2) mechanical effect that exerts on membrane surfaces [11,12]. It is noticed in literature that most of the studies that employed bio-carriers focused on the physio-chemical effects – bio-carriers were not dosed into membrane tanks. In those studies, bio-carriers were dosed into a fully-mixed tank and the mixed liquor in this tank was then pumped into a separate permeate tank. For instance, Leiknes and Ødegaard [13] reported that bio-carriers reduced the concentration of mixed liquor suspended solids (MLSS) in the system, which potentially reduced membrane fouling rates. However, Yang et al. [14] found that the MBMBR suffered from more severe membrane fouling primarily due to the proliferation of filamentous bacteria. In another study, Yang et al. [15] reported that shear stress induced by the bio-carriers led to breakup of bioflocs and reduced the filterability of the biomass suspension. On the other hand, bio-carriers will exert both the physio-chemical effects and mechanical effect in those studies where bio-carriers are dosed into the same tank with the membrane module. Lee et al. [16] found that the addition of bio-carriers could mitigate membrane fouling not only by decreasing MLSS concentration, but also by creating collisions with membrane surface. In contrast, Hu et al. [17] found that the physio-chemical effects of bio-carriers on biomass characteristics were the main contributor to the membrane fouling reduction, whereas the mechanical effect was negligible. Nevertheless, only with the aid of an iron net or a baffle to prevent the interaction of bio-carriers with membrane surface in earlier reported studies, the individual contribution of the mechanical effect of bio-carriers on membrane fouling propensity was not thoroughly investigated. In addition, due to the complicated underlying mechanisms, the effects of bio-carriers on membrane fouling have not been completely understood.

In addition, ceramic membranes have been attracting increasing attention due to its mechanical strength and tolerances for adverse conditions such as extreme pH, temperature and pressures [18]. Due to their hydrophilicity, cake layers on the ceramic membranes were much easier to be detached from the membrane surfaces than polymeric membranes [19]. Hence, using ceramic membranes in MBMBRs might improve the scouring efficiencies. Jin et al. [11] found that the bio-carriers could decrease the cake layer fouling and hence could delay the eventual fouling when using ceramic membrane. However, their study did not decouple the physio-chemical and mechanical effects, and elucidate their relative dominance. In order to fundamentally understand the effects of bio-carriers on membrane fouling in MBRs employing ceramic membrane, there is a need to decouple the two effects with a comprehensive analysis of their respective mixed liquor characteristics as well as the membrane foulant compositions.

In view of the above, the objective of this study was to evaluate the contribution of the physio-chemical versus the mechanical effects of bio-carriers on membrane fouling. In order to do so, two MBMBRs with the same dosages of bio-carriers but in different compartmental arrangement were used. Their performances were also compared with a conventional ceramic MBR.

2. Materials and methods

2.1. Experimental set-up and operating conditions

Fig. 1 shows the schematic diagram of the three lab-scale MBRs – an MBR, an MBMBR and an MBMBR with bio-carriers scouring in the membrane compartment ($MBMBR_{SC}$). Each of the reactors had a total effective volume of 12.8 L, and was consisted of two compartments – the MBBR compartment and the membrane compartment, with effective volumes of 7.68 and 5.12 L, respectively. Aeration rate in each compartment was maintained at 2 L/min. As a result, the shear intensity linked to air-scouring of the membrane was 99.1 s^{-1} based on the equation deduced by Delgado et al. [20]. A flat-sheet ceramic ultrafiltration (UF) membrane module (ItN, German) with a nominal pore size of 0.1 μm and a total surface area of 0.08 m^2 was immerged into the membrane compartment. For the MBMBR, 3200 pieces of bio-carriers were dosed into the MBBR compartment; while for the $MBMBR_{SC}$, 640 pieces of bio-carriers were dosed into the membrane compartment and of the rest of 2560 pieces were dosed into the MBBR compartment. As a result, the filling ratios were 20% for both the MBMBR and $MBMBR_{SC}$. As such, the bio-carriers had scouring effects on the membrane in the $MBMBR_{SC}$ but not on the membrane

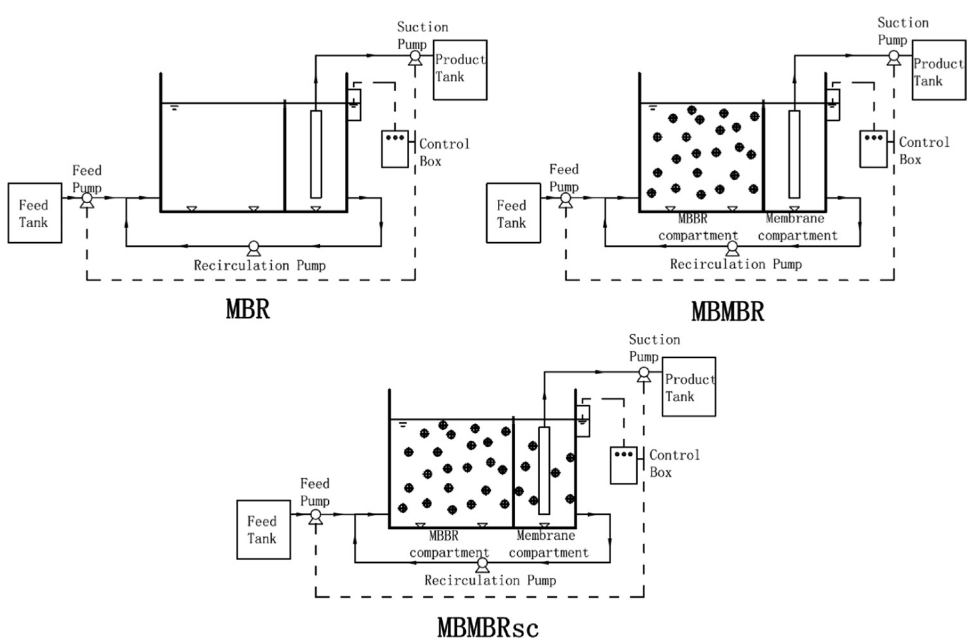

Fig. 1. Schematic diagram of the three bioreactors used in the study: (a) the MBR, (b) the MBMBR, and (c) the $MBMBR_{SC}$.