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Influence of static mixer on the formation and performance of dynamic membrane in a dynamic membrane bioreactor

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ABSTRACT

Homogeneous formation of a dynamic membrane (DM) on macroporous materials (such as mesh filter) in a dynamic membrane bioreactor (DMBR) is very important. In this research, an economical and efficient method was introduced for homogeneous formation of DM using a static mixer. To investigate the effectiveness of the static mixer in formation and filtration of DM, in comparison with the state without a static mixer, the size of the static mixer was examined at different aeration rates. The filtration characteristics of DMBR including formation time, stability time and fouling propensity were obtained. Further, the properties of DM including the mean particle size (M_{ps}), soluble microbial product (SMP), average thickness and porosity of DM were measured to analyze the formed DMs in the bioreactor. The results indicated that the static mixer size ($r_p = -0.892$) has the maximum effect on the formation time. With the crossflow velocity control, the static mixer contributed to homogeneous formation of cake layer and increased share of large particles on the mesh filter surface at the very beginning, such that the minimum formation time was achieved. Moreover, to achieve suitable conditions for the site of static mixer in the bioreactor, the effects of the place of the static mixer were examined in the best DM formation state (formation time < 5 min). It had a great impact on the stability time ($r_p = -0.941$) and fouling propensity ($r_p = 0.926$). Based on the obtained results, application of static mixer can contribute to saving energy and promoting the DMBR technology in wastewater treatment through shortening DM formation time and decreasing membrane fouling.

1. Introduction

In recent years, many attempts have been made to develop and modify membrane bioreactors (MBRs). A dynamic membrane bioreactor (DMBR) is one of these creatively modified MBRs which has a high operational flux in biological wastewater treatment application. The main idea in this system, which has been able to significantly reduce capital and operational costs, is usage of macro porous materials in sludge separation including mesh filter, mesh nylon, woven and nonwoven fabric filter, and stainless steel mesh instead of conventional MF/UF membranes [1–5]. A macro porous filter (e.g. mesh filter) in a bioreactor alone has a low-quality effluent, and is not comparable to a conventional MBR system. Therefore, by formation of a sludge layer on the mesh filter surface called dynamic membrane (DM), one can improve the quality of wastewater. However, over-aggregation of activated sludge particles on the mesh filter surface causes early fouling. Therefore, the role of a cake layer in DMBR system is very effective and pivotal [6,7].

The extent of improvement in the effluent quality in DMBR system is largely dependent on homogeneous formation of DM on the mesh filter surface, so that DMBR process can have a suitable efficiency and strength for treating wastewater [8–10]. In spite of different research on DMBR system, no extensive information has been presented about the manner of homogeneous and uniform formation of DM to enhance the effluent quality and stability time with controlling fouling. Further, the effect of parameters including hydrodynamic and operational conditions of a MBR and the effect of biological parameters of DMBR on formation and filtration of DM in detail have been seldom reported.

DMBR process is largely dependent on primary sedimentation of particles on the mesh filter surface. Unlike conventional systems in wastewater treatment, DMBR has two main stages of formation of DM and filtration stability. For homogeneous formation of DM and controlling its fouling, optimization of hydraulic conditions in the bioreactor should be taken into account [11–14].

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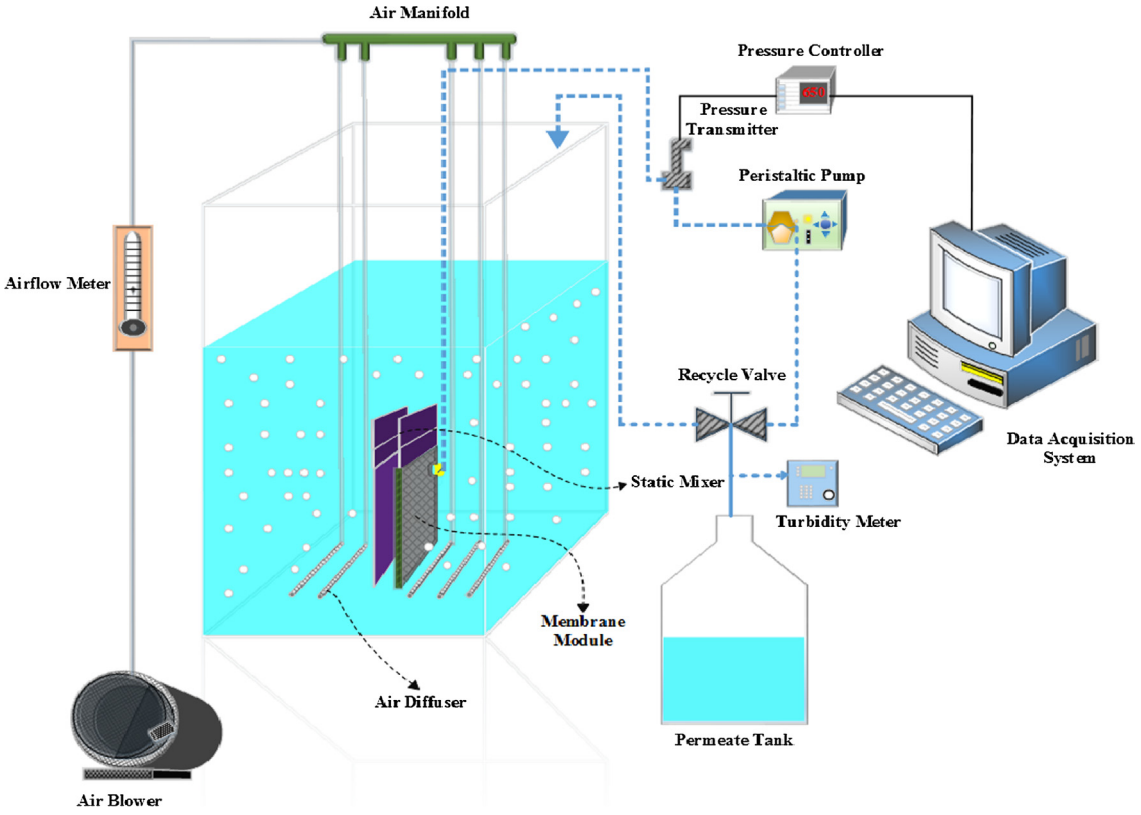

Fig. 1. Schematic diagram of the DMBR for evaluation of DM formation process.

In DM formation, various techniques have been used. Among these techniques in the DM formation stage is alteration of operational conditions including elevation of the initial flux up to 1000 LMH, where the formation time is obtained as 0.3–24 h, given the properties of the mesh filter. However, considering the compression developed in the cake layer, due to exertion of a very large flux, reduction of the stability of the separation operations occurs [15,16]. Further, use of microporous materials in activated sludge separation causes reduction of the effluent turbidity to its minimum value. However, in comparison with macro porous materials, it has the minimum output flux [15,17].

In some studies, a stirrer has been used to develop homogeneous DM with a high effluent quality [18]. However, given its high energy consumption and operational cost, this method has been used less. On the other hand, in other studies, aeration method alone has been used for formation of DM, and different results have been reported for the effect of shear stress resulting from aeration on the formation and performance of DM [14,19,20].

The developed shear stress affects the mesh filter surface and the sludge flocs, causing reduction of size distribution of the particles and porosity of the cake layer, enhanced emission of soluble microbial product (SMP), extracellular polymeric substances (EPS), and shortened stable filtration time [21,22]. In this regard, Liang et al. [23] observed that with elevation of the larger particles of the sludge on the mesh filter surface and EPS dispersion, DM formation time will be significantly shorter. As a result, energy consumption also decreases.

In some studies, with elevation of the shear stress, greater effluent turbidity was obtained in the output of the mesh filter [2]. On the other hand, in other studies, the effluent turbidity has not been influenced significantly [24,25].

Attempts have been made to optimize the hydraulic conditions in MBRs to prolong stable filtration duration using baffles. Baffles have been used to develop a crossflow on the surface of polymer membranes in airlift MBRs, causing diminished precipitation of sludge particles and membrane fouling by developing shear stress on the membrane surface [22]. Therefore, this perspective of applying baffles cannot be effective and practical in DMBRs considering removal of cake layer on the mesh filter surface. However, it is expected that the place and size of baffles be very influential in hydraulic conditions in DMBRs.

In spite of the significance of hydrodynamic conditions in the membrane tank, there is no sufficient information for suitable design of crossflow in DMBRs for homogeneous formation of DM and prolongation of stability duration. Experimental studies in this regard have been seldom reported, which might be due to the problem of hydrodynamic measurement and not deeply understanding the minor effects of hydrodynamic conditions in DMBR [26]. Thus, it is essential that development of an optimal crossflow for DM formation be taken into account using a combination of baffles called static mixer.

The aim of this study has been improving DM formation on the surface of a mesh filter using static mixer and finding a suitable configuration for reducing fouling and prolonging the stability time of DMBR during filtration, without any significant change in the effluent turbidity. This operation includes three scenarios: without static mixer (scenario i), variable size of the static mixer (scenario ii), and variable place of the static mixer (scenario iii). At the beginning, to investigate the effectiveness of the static mixer in the formation and filtration of DM in comparison with the state without static mixer, the static mixer size was altered at predetermined aeration rates. Changes in TMP, effluent turbidity, and average crossflow velocity in the region between the static mixer and mesh filter were also recorded. Further, to examine the role of the site of static mixer in formation and stability of filtration, the best DM formation state by static mixer was chosen in scenario ii and only the distance between the static mixer and the membrane module in that state was changed. In each scenario, the properties of the formed DM including the mean particle size (M_{ps}), SMP of the cake layer, average thickness and porosity of DM were investigated.