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Self-adaptive dynamic membrane module with a high flux and stable operation for the municipal wastewater treatment

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ABSTRACT

A gradual decline of membrane flux or gradual rise of filtration resistance appeared during the dynamic membrane running processes in previous studies, limiting the acceptance of dynamic membrane bioreactor in a wastewater treatment. In this study, we designed a special tubular membrane module, which can be self-adaptive according to the dynamic membrane filtration process, to gain a sustainable stable flux and enhance the backwashing effect. The comparison among different membrane modules in submerged bioreactor and the performance of the self-adaptive module in recirculated bioreactor were investigated. A pilot scale test lasting for 12 months was conducted to evaluate the long-term applicability of the self-adaptive membrane module. The results demonstrate that the self-adaptive structure had a beneficial effect on the formation and backwashing of the dynamic membrane. The formation time of dynamic membrane was much shorter than the flat module and the average turbidity of effluent was excellent. The self-adaptive membrane module had the longest stable operation time, up to 72.3 h when operated in submerged bioreactor, much larger than other membrane modules. When operated in 60 L/m^2 h in recirculated dynamic membrane bioreactor, the stable operation time reached up to 480.3 h, due to the uniform flow field and effective impulse backwashing. The effluent concentrations of COD, TP, NH_3-N and SS as well the turbidity in the pilot scale test were similar to or even below the values achieved in the wastewater treatment plants.

1. Introduction

The self-forming dynamic membrane bioreactor (SF-DMBR) is a promising new sewage treatment technology, which is made up of active sludge system and dynamic membrane modules [1–3]. When the active sludge is rejected by the support material with relative bigger pores, the dynamic membrane (DM) forms gradually and then supplies a high quality effluent. Compared with the membrane bioreactor (MBR), the SF-DMBR has the following advantages: low cost filter material, high flux, low energy requirement and high anti-pollution capacity [4–6].

The DM, which plays an essential role in the rejection of particulate matter in DMBRs, could be divided into two layers, a cake layer and a gel layer. The cake layer was mainly composed of sludge flocs that are attached loosely and could be easily removed. The cake layer comprised of most of the filtration resistance of the DM and improved the effluent quality by rejecting most of the coarse flocs [7]. The gel layer was mainly composed of extracellular polymeric substance (EPS) and considered to be the major part of the irreversible pollution of the DM [8].

The DM can be formed on different support materials, such as non-woven fabrics and meshes. The DMs used non-woven fabrics with a spatial structure [9–11], form in 0.3–24 h, with a flux between 5 L/m^2 h and 40 L/m^2 h. While the DMs used meshes with a single layer structure [12–13], form in 0.5 –24 h, with a flux between 20 L/m^2 h and 150 L/m^2 h. Obviously, the latter have a higher flux and greater potential applications. However, a gradual decline of membrane flux or gradual rise of filtration resistance was observed during both running processes [14–18].

Different membrane module configurations and reactor configurations also had a great effect on the performance of dynamic membrane, especially for the formation and the backwashing of the DM. Generally flat sheet membrane modules are used, due to the operational simplicity and easiness of construction [19–21]. Although having better hydraulic conditions, tubular modules are used rarely [22–24], probably due to the difficulty of construction. But both of them were relatively simple and cannot meet the special requirements of the formation and backwashing of the DM, such as a low velocity space which helps to form the DM rapidly

Abbreviations: AAO, Anaerobic–Anoxic–Oxic system; CFD, Computational fluid dynamics; COD, Chemical oxygen demand; DM, Dynamic membrane; DO, Dissolved oxygen; EPS, Extracellular polymeric substance; HRT, Hydraulic retention time; MBR, Membrane bioreactor; MLSS, Suspended solids; NH_3-N, Ammonia; PET, Polyethylene terephthalate; PVC, Polyvinyl Chloride; SF-DMBR, Self-forming dynamic membrane bioreactor; SRT, Sludge retention time; TMP, Trans-membrane pressure; TP, Total phosphorus; WWTP, Wastewater treatment plant

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and a deformation during the backwash, which is conducive to break up and clean up the DM. All of the self-forming membrane modules have been tested at submerged SF-DMBRs [7,25–27]. As the operation period of SF-DMBR can be divided into three stages, such as DM layer formation, filtration and backwashing, there are some defects in submerged SF-DMBR. The aeration system is often placed under or aside the membrane modules, causing a strong cross flow which has adverse effect on the formation of DM. The shear force caused by aeration is random, leading a difficulty on effective control of DM [2]. The high concentration activated sludge in bioreactors also has a seriously unfavorable effect on the backwashing.

To sum up, there are still some shortcomings which limit the acceptance of SF-DMBR in the wastewater treatment, including unstable flux and incomplete membrane backwashing. Hence, we designed a special tubular membrane module, which can be self-adaptive according to the dynamic membrane operation process, to gain a sustainable stable flux and enhance the backwashing effect. The primary objectives of this study are: (1) to compare the performance of self-adaptive membrane module and other membrane modules in submerged bioreactor; (2) to investigate the performance of self-adaptive membrane module in recirculated bioreactor and optimize the backwashing method; (3) to evaluate the long-term applicability of the self-adaptive membrane module in a pilot scale test.

2. Materials and methods

2.1. Bench-scale test of submerged DMBR

A bench-scale submerged DMBR consisted of a sequence of two tanks: an aeration tank and a membrane tank. Fig. 1 is a schematic diagram of submerged DMBR for bench-scale test. A baffle was set between the aeration tank and the membrane tank, which can help to produce the circulation flow. The effective volume of the aeration tank and the membrane tank was 22.2 L and 54.1 L, respectively. Five aerators were placed at the bottom of the aeration tank and the aeration rate reached up to 3.7 L/min. Four membrane modules were placed in the middle of the membrane tank. The effective area of membrane No.1 was 0.051 m^2 and all the effective area of membranes No.2–No.4 was 0.048 m^2.

The detailed parameters of membranes are shown in Table 1. For the membrane module No.1, the polyethylene terephthalate (PET) mesh was fixed on the Polyvinyl Chloride (PVC) frame by glue. The other membrane tubes were welded spirally by ultrasonic, using narrow strips with a width of 14 mm. The width of support material of membrane module No.3 was 2 mm, made of PET film.

The membrane module No.3 was made up of PET mesh and hard support materials, as shown in Fig. 2. As the PET mesh was elastic, it would concave inward when subjected to external pressure during the DM formation. The biggest relative depth reached up to 0.20 mm, helping to form the DM rapidly. It would bulge outward when subjected to internal pressure during the backwash. The biggest relative height reached up to 0.16 mm, which was beneficial in the effective cleaning of the DM. Hence, it could be named as ‘self-adaptive membrane tube’.

Raw municipal wastewater was collected from a local septic tank in Wuxi city, China, which was fed into the bioreactor continuously with a peristaltic pump. The characteristics of the influent are shown in Table 2. The sludge concentration in the bioreactor was 3800 mg/L and the turbidity of supernatant liquor was 13.7NTU. The sludge retention time (SRT) and the hydraulic retention time (HRT) were 40 d and 8 h, respectively. During the experiment, the sludge loading rate kept between 0.2 and 0.25 kg COD/kg VSS · d and the dissolved oxygen (DO) concentration in the aerobic tank was maintained at 2–3 mg/L.

The performance of dynamic membrane in different head losses was investigated in a single period test, including 30 mm, 70 mm and 120 mm H_2O. The membrane flux, effluent turbidity, formation time of the DM and the stable time were recorded and analyzed, in order to evaluate the operation characteristics of each membrane.

A multi-period experiment was conducted in 70 mm H_2O head loss to investigate the possibility of keeping stable operation with high membrane flux for dynamic membrane. The operating conditions were consistent with the single period test. When all the membrane fluxes declined by 25%, the membrane modules were cleaned up by bottom aeration at the same time. The aeration rate was 8 L/min, lasting for 5 min per side. The experiment was ended when the flux of all membranes declined rapidly and the aeration cannot remove the membrane pollutions. Five to seven pieces of the dynamic membrane and the supporting material were cut

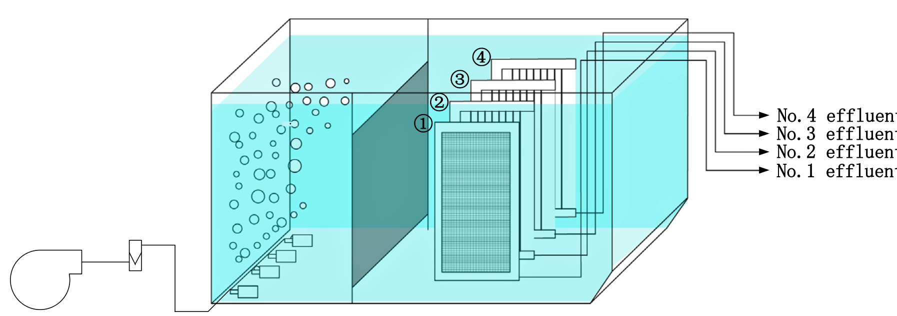

Fig. 1. Schematic diagram of submerged DMBR for bench-scale test.

Table 1
Detailed parameter of membranes.

No.	Configurations	Support material	Size	Pore size	Number of layers
No.1	Flat sheet	PET mesh	270 mm × 95 mm, double -sided	300 mesh	Single
No.2	Tubular	PET non-woven fabric	ϕ6 mm × 290 mm, 11 tubes	75 μm	Single
No.3	Tubular	PET mesh	ϕ6 mm × 290 mm, 11 tubes	300 mesh	Single
No.4	Tubular	PET mesh	ϕ6 mm × 290 mm, 11 tubes	300 mesh	Double, with a supporting material