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A study on submerged rotating MBR for wastewater treatment and membrane cleaning

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Abstract−A submerged rotating membrane bioreactor (SRMBR), with a rotatable, rounded, flat-sheet Poly(vinyldiene fluoride) (PVDF) membrane module fixed on hollow axes and moved by an electromotor, was used for wastewater reclamation. It was found that the effluent COD became stable and lower than 20 mg/L after one day running. The equilibrium permeate flux increased from 42.5 to 47.5 $L/m^2 \cdot h$ with the rotation speed increasing from 15 r/min to 25 r/min. Prolonging relaxation time could alleviate membrane fouling and enhance the flux. Finally, membrane cleaning was studied. The results showed that flushing the membrane surface with water, water/NaOH and water/NaOH/HCl recovered permeate flux to 48.4%, 83.5% and 90.2% of that of the initial operation, respectively.

Key words: Submerged Rotating MBR, Rotation Speed, Permeate Flux, Membrane Cleaning, PVDF Flat-sheet Composite Membrane

INTRODUCTION

The membrane bioreactor (MBR) provides a significant improvement in efficacy over conventional biological treatment technologies for wastewater treatment and reuse. This process consists of a suspended growth biological reactor combined with a membrane unit separating the biomass from the treated water. MBR systems have gained many advantages over the conventional processes with better effluent quality, higher organic loading, small footprint occupation and decreased sludge production [1,2]. However, the principal limitation of MBR process lies in membrane fouling which is mainly associated with the deposition of a filter cake or fouling layer onto the membrane surface, thus limiting the permeate flux. Membrane fouling leads to the frequent cleaning and/or the replacement of membranes, which then increases the operating costs [3,4]. Various methods including the development of new MBR types, the hydrophilic modification of membrane surface and the optimization of operation parameter have been adopted to control the membrane pollution and reduce the cost during the operational cycle of the MBR process [5-7]. However, relatively little attention has been paid to the reactor and membrane module configurations.

At present, some new membrane modules have been developed, such as Zeno Gem composite membrane module, Sterapor-L screen-type membrane module, Sterapor-HF set-mounted membrane module, Sterapor-G anti-washing cluster-style membrane module, HABER VRM frame-mounted fan sets flat membrane ultrafiltration module and polymer/ceramic tubular membrane module, and so on. Although these membrane modules revealed various advantages of antifouling or enhancing flux, they were immobile. In this work, a submerged rotating membrane bioreactor (SRMBR) using a flat-sheet Polyvinyldiene fluoride (PVDF) membrane module was used to treat synthetic sewage. Instead of the traditionally immobile membrane module, a new membrane module that is fixed on hollow axes and rotated by an electric motor was developed to enhance filtration capacity and fouling prevention ability. The objectives of this study were to investigate the possibility of enhancing the permeate flux through optimizing of system operations and the cleaning methods of fouled membrane.

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EXPERIMENTAL

1. Experimental Set-up

The membrane module is composed of a round flat-sheet PVDF membrane plate and a hollow pipe (Fig. 1(a)). There were many educing flumes linked to eight catchment grooves on the two surfaces of the round plate. Extending the catchment grooves to the hole wall of the middle of the round plate formed the effluent outlet. Then the PVDF/non-woven fabric membrane was assembled on the circumjacent surfaces of round plate by the adhesive. Ultimately, the round plate with PVDF composite membrane was fixed on the hollow pipe (effluent pipe) with some pores, and these pores were connected with the effluent outlets of the round plate (i.e., catchment grooves). The effective filtration area was 0.12 m^2. According to the actual treatment capacity, two round plates were installed on the hollow effluent pipe.

The wastewater treatment test system (Fig. 1(b)) consisted of a bioreactor in which the round flat-sheet membrane modules were directly immersed. During the process of SRMBR running, the membrane module was rotating by an electric motor. The bioreactor filled with activated sludge had a working volume of 80 L. Influent was allowed to flow into the bioreactor from a feed tank. The water level

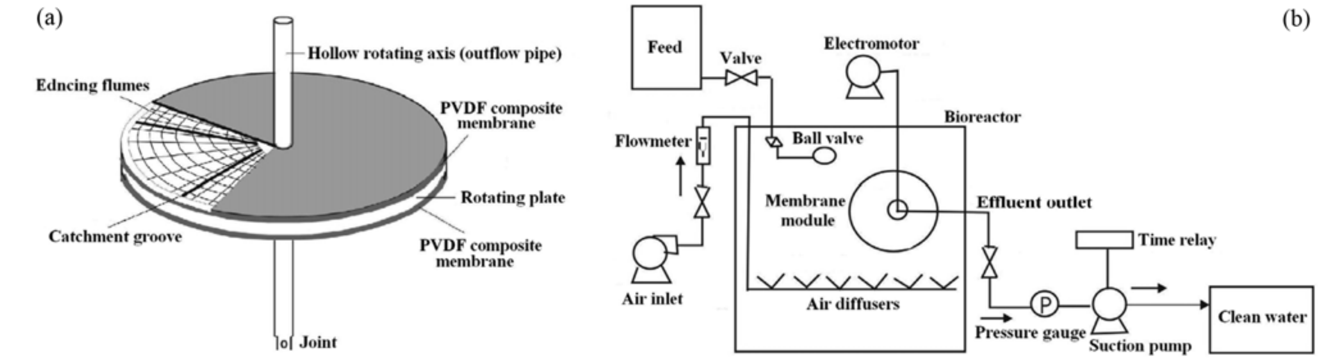

Fig. 1. Schematic diagram of rotating membrane module (a) and flow chart of SRMBR (b).

Table 1. Membrane module characteristics and operating parameters of the SRMBR

Membrane module characteristics		Operating parameters of SRMBR	
Membrane material	PVDF, TiO_2, PVP	Transmembrane pressure, kPa	25
Membrane type	Flat-sheet, composite	Hydraulic retention time, h	6-8
Membrane pore size, μm	0.2	Sludge retention time, d	30
Membrane flux, $L\cdot m^{-2}\cdot h^{-1}$	1294	pH	6-8
Membrane thickness, μm	175	Temperature in tank, °C	25-28
Module shape	Round plate	Dissolve oxygen, mg/L	0.4-2.5
Total surface area, m^2	0.12	MLSS, g/L	7-10

Note: PVDF composite membranes were supplied by Institute of Polymer Science, Zhejiang University

of the bioreactor was kept a constant by a ball valve. Air diffusers were placed under the membrane module to provide oxygen for microorganisms and to create the shear force to alleviate membrane fouling. The effluent was drawn through PVDF membrane to the hollow pipe of the membrane module by a suction pump in the mode of intermittent permeation. The ratios of suction time to relaxation time were chosen to be 10 min/0 min, 9 min/30 s, 9 min/1 min and 8 min/2 min.

The SRMBR was operated to treat synthetic sewage consisting of glucose, NH_4Cl and Na_2HPO_4 etc., which yielded the chemical oxygen demand (COD) of 180 mg/L to 368 mg/L. The properties of membrane module used in this study and the operating parameters of SRMBR system are given in Table 1.

2. Experimental Method

SRMBR started to run after the seeding sludge was cultured for one week under aeration. The COD of feed and permeate was tested with standard methods of the potassium dichromate method. The permeate flux was measured by the volume method. After drying, the fouled and cleaning membranes were fractured in liquid nitrogen, and the surface morphologies were recorded on a scanning electronic microscope (SIRion FESEM, Netherlands) after coating with gold under vacuum.

RESULTS AND DISCUSSION

1. Treatment Efficacy of SRMBR

When the transmembrane pressure (TMP) was 25 kPa, the ratio of suction time to relaxation time was 9 min/1 min, aeration intensity was 0.4 m^3/h, and the rotation speed of membrane module was 25 rpm, the COD removal percent of the wastewater reached 90%

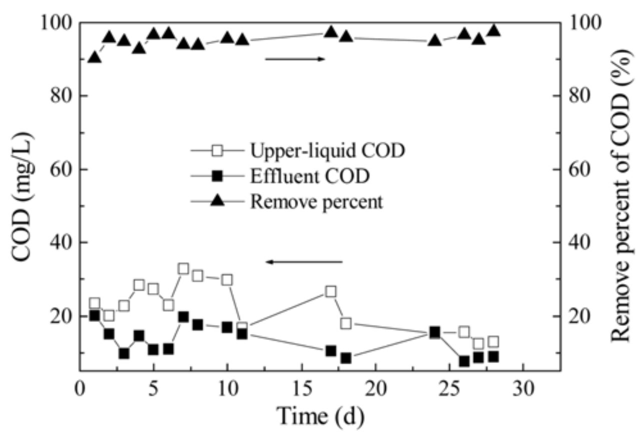

Fig. 2. COD of effluent and upper-liquid and remove percent of the effluent during operation process.

above after SRMBR running one day. It can be seen from Fig. 2, when the influent COD fluctuated between 180 mg/L to 368 mg/L, after the SRMBR running of 28 days, the effluent COD became stable and lower than 20 mg/L, and the COD removal percent remained above 93%, and the permeate flux kept in the range of 42.5 to 50.5 $L/m^2\cdot h$. Compared with 30 mg/L COD of the supernatant, the effluent COD was lower, which indicated that sludge activity was not destructed for a long running time. The permeate water was colorless and insipid without suspended solid.

2. Effect of the Rotation Speed on Membrane Permeate Flux

The effects of rotation on flux were evaluated at rotational frequencies of 15, 25, 40 and 55 rpm. Initial conditions for each test

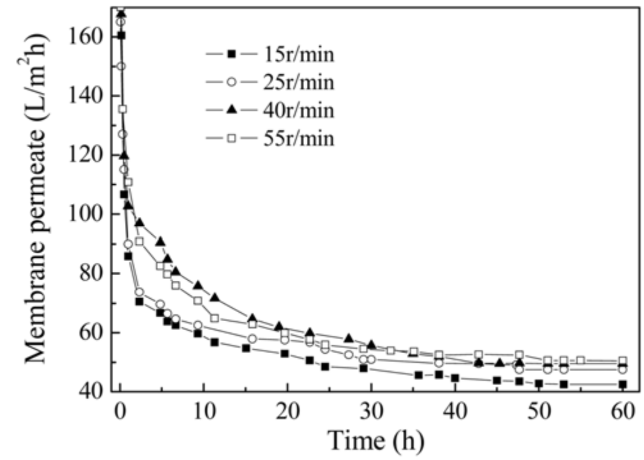

Fig. 3. Effect of rotation speed on membrane permeate.

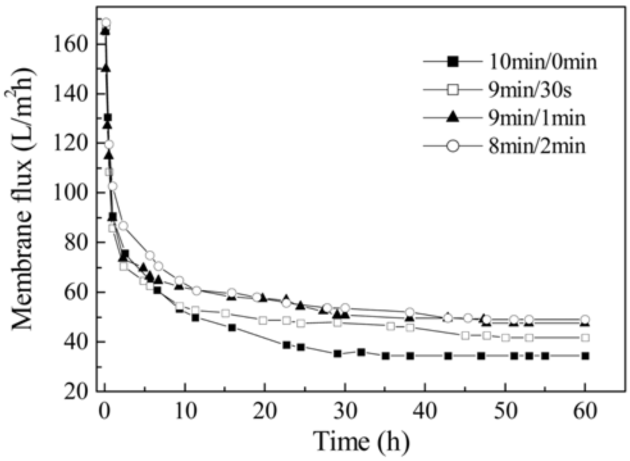

Fig. 4. Effect of suction/intermittent time ratio on the membrane flux during processing.

point consisted of 25 kPA TMP, a suction ratio of 9/1 and an aeration density of 0.4 m^3/L. For different rotation speed, the plots of permeate flux versus operation time are presented in Fig. 3. Under different rotation speed, permeate flux declined with operation time prolonging, eventually attaining the plateau levels.

At the initial stage for about 1 h, the permeate flux decreased abruptly in spite of rotation speed. This was probably because the rapid decline of permeate flux was induced by macromolecule adsorption and pore plugging, which cannot be alleviated by increasing the cross-flow velocity. Thus increasing rotation speed cannot control this irreversible fouling. At the second stage, lasting for approximate 20 h, the higher the rotation speed, the slower the permeate flux decline. In this period, the cake layer fouling, which can be controlled by the shear cross-flow produced by rotating membrane module, began to form. The shear velocities of the cross-flow increased with rotating speed increasing. In the third stage, the permeate flux approached the plateau levels, i.e., the equilibrium permeate flux. The negative pressure produced by the permeate pump transported particles to the membrane surface, whereas the shear force prevented particles from approaching membrane surface. When these two forces were balanced, a constant permeate flux was maintained. This condition was reached after SRMBR running for 20 h.

With the rotation speed increasing from 15 to 25 rpm, the equilibrium permeate flux was enhanced from 42.5 L/m^2·h to 47.5 L/m^2·h. However, when the rotation speeds kept on increasing to 40 and 55 rpm, the increasing amount of the equilibrium permeates was small. The result indicated that there was a critical rotation speed beyond which a further increment in the rotation speed could not further enhance the equilibrium flux. What's more, the higher rotation speed required higher consuming-energy and easily damaged the rotation axis. Consequently, in this case, 25 rpm was a critical rotation speed.

3. Effect of the Ratio of Suction Time to Relaxation Time on Permeate Flux

Intermittent permeation is a membrane cleaning technique where operation is suspended periodically through controlling the suction pump. Particles deposited on the membrane surface will be removed by the shear cross-flow when the pressure that is acting on particles is relaxed during non-suction periods [8]. In this work, in the case of 25 kPa TMP, 25 rpm rotation speed of membrane module, and 0.4 m^3/L aeration intensity, the permeate flux was examined for different ratios of suction time to relaxation time with 10 min/0 min, 9 min/30 s, 9 min/1 min and 8 min/2 min. The change in permeate flux was plotted in terms of operation time, as shown in Fig. 4. In initial running 1 h, the attenuation trends of permeate flux were almost same for different ratios of suction time to intermittent time. This suggested that different ratios of suction time to relaxation time could not eliminate membrane irreversible fouling that originated from the blockage of membrane pores at the initial 1 h. With running time extending to 20 h, the flux attenuation rates became slow. Whereas, the decrease rate of permeate flux was slower in terms of the longer relaxation time. The reason was as follows. The main membrane fouling was the formation of a cake layer in this operation period. The pressure acting on contaminant was removed abruptly in the absence of transmembrane suction pressure, and then contaminants departed from the membrane surface under the shear flow of the mixture. Consequently, in the case of the lower ratio of suction time to relaxation time, such as 9 min on /1 min off and 8 min on / 2 min off, the longer the relaxation time, the longer the time of the pressure relaxation for the contaminants, and the more the contaminants removed from the membrane surface, then the more sluggish the flux decline rate. In the last running period, a stable cake layer formed, and then the permeate flux remained at plateau levels for various ratios of suction time to relaxation time.

From Fig. 4, it was inferred that the equilibrium permeate flux increased with the relaxation time prolonging. As the relaxation time increased from 0 min, 30 s to 1 min, and the equilibrium flux was enhanced from 34.5 L/m^2·h, 41.8 L/m^2·h to 47.5 L/m^2·h. These results showed that prolonging relaxation time favored the contaminant separation from membrane surface.

4. Membrane Fouling and Cleaning

After SRMBR was running for 60 days, the membranes were fouled badly. Adopting high-intensity air bubbling cleaned the membrane surface for 1 h in SRMBR, which could make permeate flux recover to 28.5% of the initial flux. Thereby, the membrane module was taken out from the bioreactor, and physical and chemical methods were used to rinse the membrane. In this work, fouled ma-

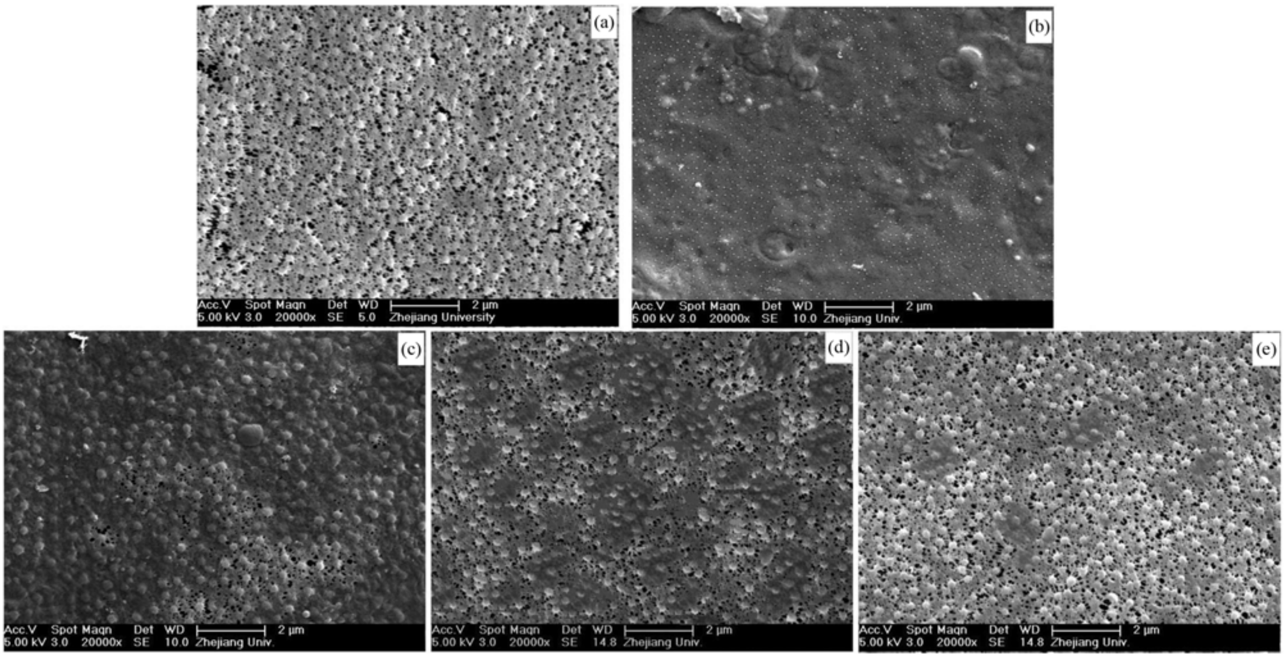

Fig. 5. SEM photos of PVDF composite membranes before and after cleaning. (a) Pristine membrane, (b) Fouled membrane, (c) Membrane washed with water, (d) Membrane washed with water/NaOH, (e) Membrane washed with water/NaOH/HCl.

terials were removed efficiently through washing with water, water/NaOH and water/HC1/NaOH. Washing with water was to flushing the membrane surface by an amount of tap water until the fouled materials were invisible by the naked eye. The cleaning with water/NaOH was water scouring firstly, 1 wt% NaOH aqueous solution scouring for 5 h subsequently, and water scouring lastly. Water/NaOH/HC1 cleaning was executed by scouring firstly with water, secondly with 1 wt% NaOH aqueous solution for 5 h, thirdly with 0.5 wt% HCl aqueous solution for 5 h, and lastly with water scouring again.

The surface SEM photos of the pristine membrane, fouled membrane and cleaned membranes are shown in the Fig. 5. For the fouled membrane, there was a layer of contaminants on the surface as seen in Fig. 5(b). After water washing, the great mass of contaminants and gel layer were eliminated, and the membrane pores became visible (Fig. 5(c)). After water/NaOH cleaning of the fouled membrane, the membrane pores were more distinct, while a small amount of gel existed on membrane surface, as shown in the SEM photo in Fig. 5(d). This was because NaOH solution could eliminate organic contaminants of protein, and microorganisms nourished on surface and inside of membrane were removed effectively [9]. After the fouled membrane was handled via water/NaOH/HC1 cleaning, the pores were very distinct and there was a thimbleful of gel on the membrane surface. As observed from Fig. 5(e), the surface morphology of the membrane was similar to that of the pristine membrane (Fig. 5(a)). Through HCl washing, the cleaned membrane was further rinsed by elimination of inorganic mineral materials and salts on membrane surface because of concentration polarization during SRMBR running.

The cleaned membrane was mounted again in the SRMBR. The equilibrium permeate flux was measured for membranes treated by three different cleaning ways. It was found that cleaning the fouled membrane by water washing, water/NaOH washing and water/NaOH/HC1 washing can recover the permeate flux to 48.4%, 83.5% and 90.2% of that of the pristine membrane, respectively. From the above results on, effective cleaning can remove fouling materials on the membrane surface and in membrane pores, which recovered effectively the permeate flux, and prolonged membrane life span and maintained normal operation.

CONCLUSIONS

(1) Wastewater treatment in SRMBR can be operated stably with high efficiency for an extended duration. The effluent COD reached a steady value lower than 20 mg/L with COD remove percent up to 93%.
(2) Increasing the rotation speed can improve the equilibrium permeate flux. As the rotation speed increased from 15 rpm to 25 rpm, the equilibrium permeate flux was enhanced from 42.5 $L/m^2 \cdot h$ to 47.5 $L/m^2 \cdot h$. However, with a further increment of rotation speed, permeate enhancement was not obvious.
(3) Prolonging the relaxation time was propitious to remove contaminants from the membrane surface and alleviated membrane fouling. With the relaxation time increasing from 0 min to 1 min, the equilibrium flux increased from 34.5 $L/m^2 \cdot h$ to 47.5 $L/m^2 \cdot h$.
(4) The fouled membrane after running 60 days was cleaned through three methods of water washing, water/NaOH washing and water/NaOH/HCl washing with recovering the membrane permeate flux to 48.4%, 83.5% and 90.2% of that of the pristine membrane, respectively.

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