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Performance of a novel dynamic membrane bioreactor in treating synthetic domestic wastewater

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ABSTRACT

This article introduced an approach using cross-linked polyvinyl alcohol microspheres (PVA-MS) to form dynamic membrane on the surface of the industry filter cloth instead of the conventional MF/UF membrane to build a membrane bioreactor (MBR) for wastewater treatment. The performance of the dynamic MBR for treating synthetic domestic wastewater and membrane fouling were investigated. For treating synthetic domestic wastewater sequentially, the results of the batch tests showed that the effluent turbidity was less than 4 NTU and SS was zero at the most operation time. The average removal efficiency of COD_{Cr} and NH_4^+-N were 93.18 and 98.6%, respectively. Membrane fouling was mainly caused by sludge layer. The sludge cake and precoated dynamic membrane could be easily removed by brushing. The support membrane permeate flux was almost recovered fully and could be reused again. These results indicated that the precoated dynamic membrane could prevent pollutants and biomass intervening to the surface and interior of the support membrane which was helpful to alleviate support membrane fouling. The experimental results demonstrated that the novel dynamic membrane showed highly anti-fouling characteristics in the MBR and could be a potential technology for wastewater treatment.

Keywords: Industry filter cloth; Dynamic membrane; Membrane bioreactor; Synthetic domestic wastewater; Membrane fouling

1. Introduction

Membrane bioreactor (MBR) has attracted great attention in domestic and industrial wastewater treatment and reclamation in recent years [1,2]. MBR, which permits a very long sludge retention time (SRT), high mixed liquor suspended solids (MLSS) and low F/M ratio due to the interception of the membrane, has been found to be advantageous over the conventional activated sludge systems in terms of system stability and compactness [3]. The smaller footprint, higher quality effluent and better control over biological conditions provide the MBR with significant benefits over other biological wastewater treatment processes [4]. However, the popularization of MBR still encounters several problems such as high cost of the membrane module, unavoidance membrane fouling and high energy consumption [5]. Dynamic membrane technology would be one of the methods to settle the problems.

Dynamic membrane is also called secondary membrane or formed-in-place membrane [6]. The Oak Ridge National Laboratory first utilized the dynamic membrane for reverse osmosis in 1965. Dynamic membrane includes two types: a precoated dynamic membrane (PDM) and a self-forming dynamic membrane

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(SFDM). The PDM is produced by filtering a solution of one or more specific colloidal components or particle reagents over the surface of a porous medium [7]. The SFDM is formed by the substances which exist in the liquor to be filtered [8]. Dynamic membrane not only has almost all characteristics belonging to common membranes, but also has some distinct features, such as low expenditure, low energy consumption and high flux and so on [9]. Ye et al. [10] developed an approach using powder-active carbon to form dynamic membranes on the surface of the 56-μm terylene filter cloth. They found that the PDM could prevent pollutants from diffusing to the exterior and interior of the support membrane, thereby alleviating membrane fouling. Cai et al. [11] introduced the preparation of the MnO_2 dynamic membrane with a sintered porous PE tube as support and found that MnO_2 membranes could be easily cleaned off when the membrane modules were seriously polluted and new MnO_2 membranes could be dynamically formed *in situ* on these PE tubes once again. Li et al. [12] investigated the dynamic membrane prepared when an aqueous solution containing poly (vinyl alcohol), cross-linking agents and additives passed through porous substrate membranes. And the precoated dynamic membranes showed dramatically high anti-fouling characteristics.

This article introduces an approach using cross-linked polyvinyl alcohol microspheres (PVA-MS) to form dynamic membranes on the surface of the 56-μm industry filter cloth acting as the support membrane. This is a new PDM replacing conventional MF or UF membranes to build a MBR for wastewater treament. The novel precoating reagent cross-linked PVA-MS were prepared via an emulsion polymerization that PVA cross linked with glutaraldehyde which was extracted by anhydrous aether [13], which showed highly anti-fouling characteristics in dynamic membrane bioreactor [14]. Formation of the precoated dynamic membrane adopts the method which has been registered for a patent [15]. In this work, the performance of the dynamic MBR for treating synthetic domestic wastewater was investigated in order to evaluate its application potential for wastewater treatment. Moreover, the other major focus of this work related to membrane fouling.

2. Materials and methods

2.1. Experimental set-up

Fig. 1 presents the schematic diagram of the experimental set-up of a dynamic MBR, in which a flat-sheet type filter module is submerged. The working volume of the reactor is 12 L and the effective area of the membrane module is 870 cm^2. The filter module is made of 56-μm industry filter cloth packing an organic frame to prevent the surface becoming concave when pumping out the effluent. A self-made aerator using the principle of tee joint is shown in Fig. 2. The aerator could serve both for aeration and cleaning the membrane surface. The aeration unit was installed under the filter module so that air bubbles coming from bilateral perforated tubes could scour the membrane surface effectively, which was helpful to lessen membrane pollution.

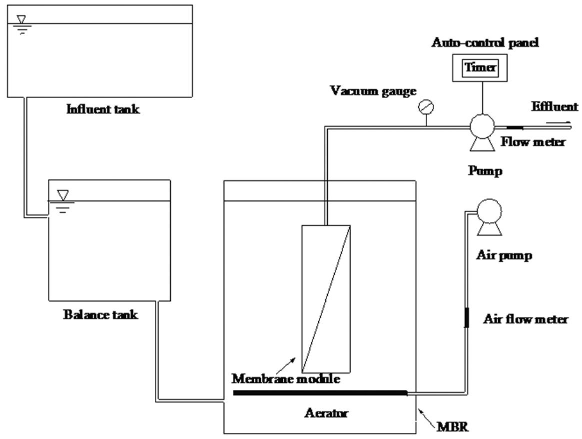

Fig. 1. Schematic diagram of the experimental set-up.

2.2. Wastewater and seeds

Sucrose-based synthetic domestic wastewater was used in the experiment by adding NH_4Cl, K_2HPO_4, $NaHCO_3$ and nutrients to tap water. The typical composition of the wastewater is listed in Table 1.

The bioreactor was inoculated with activated sludge taken from the local municipal wastewater treatment plant (Dalian, China). The ratio of MLVSS to MLSS and the sludge SVI were 0.75 and 55 mL g^{-1}, respectively.

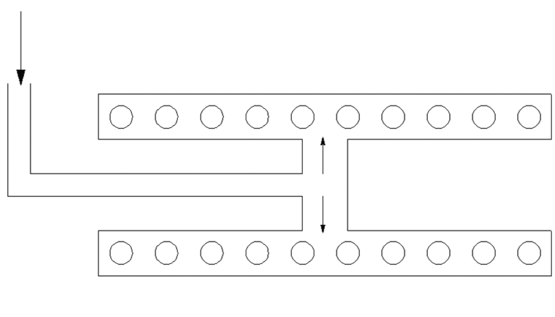

Fig. 2. Schematic diagram of the aerator.

Table 1
Characteristics of the domestic wastewater

Items	Concentration		
	Low	High	Average
pH	5.63	7.57	6.87
COD (mg L^{-1})	137.92	542.98	329.53
NH_4^+-N (mg L^{-1})	16.02	33.75	26.44
SS (mg L^{-1})	7.73	55.57	42.34

2.3. Analysis

The SS, COD, NH_4^+-N, MLSS and MLVSS contents were determined according to the Chinese NEPA Standard Methods [16]. COD was analyzed using the $K_2Cr_2O_7$ oxidation method and NH_4^+-N was measured using the Nessler reagent method. Turbidity was evaluated using a WGZ-200 Photoelectric Turbidity Instrument. DO and pH were measured by DO (YSI55/12FT, USA) and pH (Sartorius PB-10, Germany) meters, respectively. Morphologies of the PVA-MS and membranes were observed by using a scanning electron microscope (KYKY-2800B, Zhongke, China).

2.4. Experimental procedure

In the wastewater treatment experiments, dosage of PVA-MS coating on the industry filter cloth was just the amount of PVA-MS covering the whole membrane to form a thin layer. The dosage of PVA-MS coating on the membrane module which was calculated by weighing the uncoated and coated filter in dry state was 23.9 g m^{-2}; the effective separation pore size of the dynamic membrane which was measured by the technique of extrusion flow porometry was 0.75 μm. SEM pictures of the PVA-MS, uncoated and coated filter are presented in Fig. 3.

The effluent of MBR was driven by a peristaltic pump like the conventional MBR, 3 min on and 1 min off, controlled by the relay. A temperature control system was not installed and temperature fluctuated between 20 and 26 °C according to ambient conditions. The aeration rate was controlled at less than 75 L h^{-1}. The permeation flux was kept constant and the trans-membrane pressure was recorded daily. When the trans-membrane pressure in the MBR increased over the maximum allowable level (45 kPa), the polluted membrane module was washed with tap water and could be reused. In this study, the MBR was continuously operated for 52 days. The operating conditions are listed in Table 2.

3. Results and discussion

3.1. Performance for wastewater treatment

3.1.1. Comparison of turbidity in the influent and effluent

As described earlier, the precoated dynamic membrane on the industry filter-cloth was considered to act as the conventional micro-filtration membrane. So the interception capacity was one of the most important factors to evaluate the dynamic membrane bioreactor properties. Fig. 4 shows the influent and effluent turbidity over the running time. In the most of operation period, the effluent turbidity was less than 4 NTU although the influent turbidity fluctuated from 28 to 55 NTU. The effluent SS concentrations were nearly zero in most cases. Therefore, the effluent quality of the dynamic membrane is satisfactory in retaining sludge.

3.1.2. COD removal

The COD concentrations in the influent, supernatant liquor and effluent during the whole operation period are presented in Fig. 5. During the operation, the fluctuations of influent COD concentration ranging from 137.92 mg L^{-1} to 542.98 mg L^{-1}, the average COD

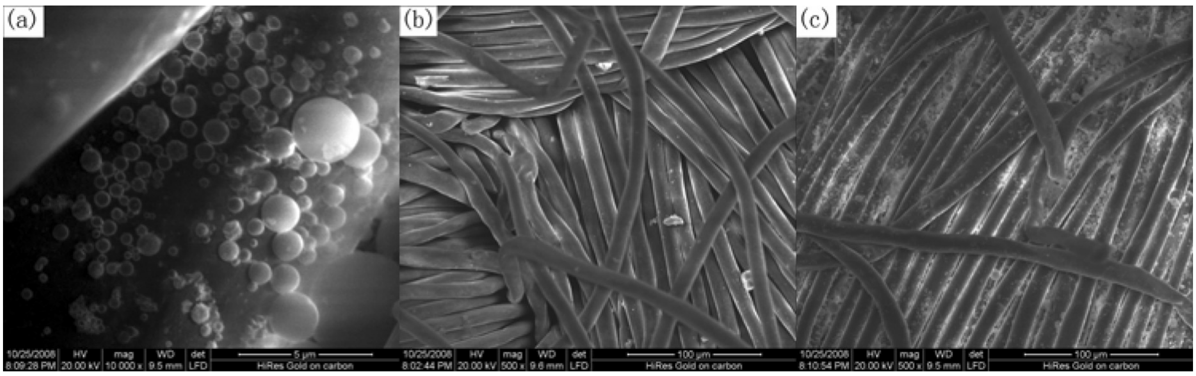

Fig. 3. SEM pictures of (a) PVA-MS; (b) uncoated filter; (c) PVA-MS coated filter.

Table 2
Operating conditions of precoated dynamic membrane bioreactor

Items	Value
Temperature (°C)	20–26
SRT (d)	52
Effective flux (L m^{-2} h^{-1})	15
Maximum transmembrane pressure (kPa)	45
MLSS (mg L^{-1})	4,500–6,800
MLVSS (mg L^{-1})	3,500–5,600
Sludge viscidity (MPa s)	1.8–2.7
Dissolved oxygen (mg L^{-1})	3.5–6.4
pH	6.44–8.08

concentrations in the influent were 329.53 mg L^{-1}. The average COD concentrations in the supernatant liquor and effluent were 43.51 mg L^{-1} and 21.07 mg L^{-1}, respectively. Variations of COD removal efficiency are shown in Fig. 6. The average COD removal efficiency of this system was 93.18%, which biological degradation and membrane interception accounted for 87.31% and 5.87%, respectively. It was noticeable that most of the COD was removed by biological degradation. However, membrane interception could ensure a stable effluent quality, especially when removal efficiency of microorganism declined obviously. The results indicated that the system could provide a consistent high efficiency of COD removal.

3.1.3. Nitrogen removal

The NH_4^+-N concentrations in the influent, supernatant liquor and effluent during the whole operation period are shown in Fig. 7. During the operation, the fluctuations of influent NH_4^+-N concentration ranging from 16.02 mg L^{-1} to 33.75 mg L^{-1}, the average NH_4^+-N concentrations in the influent were 26.44 mg L^{-1}. The average NH_4^+-N concentrations in the supernatant liquor and effluent were 0.421 mg L^{-1} and 0.362 mg L^{-1}, respectively. Variations of NH_4^+-N removal efficiency are presented in Fig. 8. The average NH_4^+-N removal efficiency of this system was 98.6%, which biological degradation and membrane interception accounted for 98.36% and 0.24%, respectively. The results demonstrated that NH_4^+-N was mainly removed by nitrification of activated sludge. It was obvious that the dynamic membrane had few

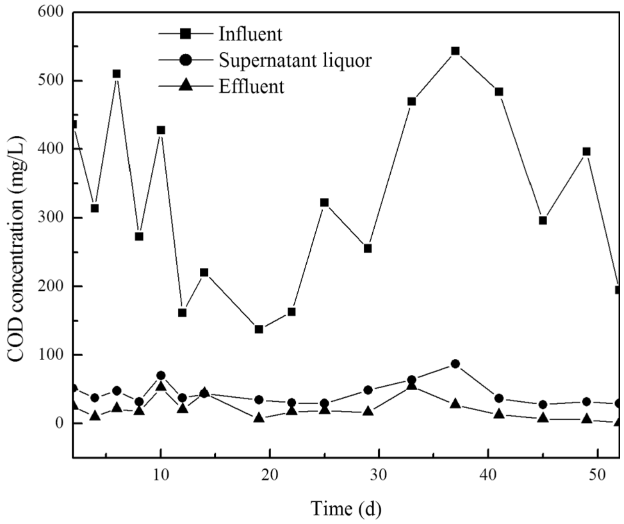

Fig. 5. Variations of COD concentration in the influent, supernatant liquor and effluent.

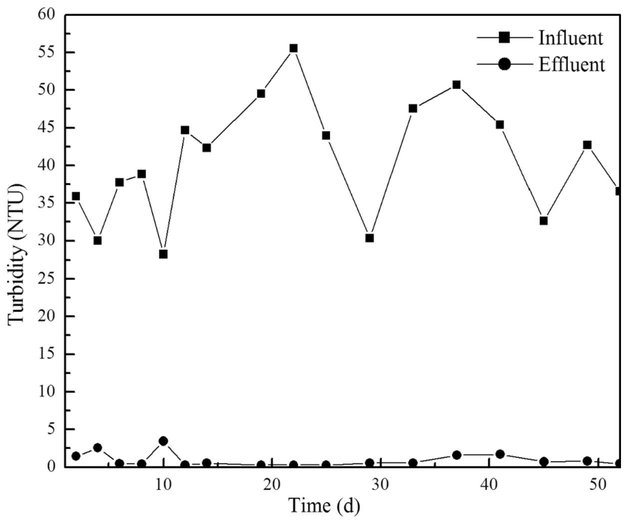

Fig. 4. Variations of turbidity in the influent and effluent.

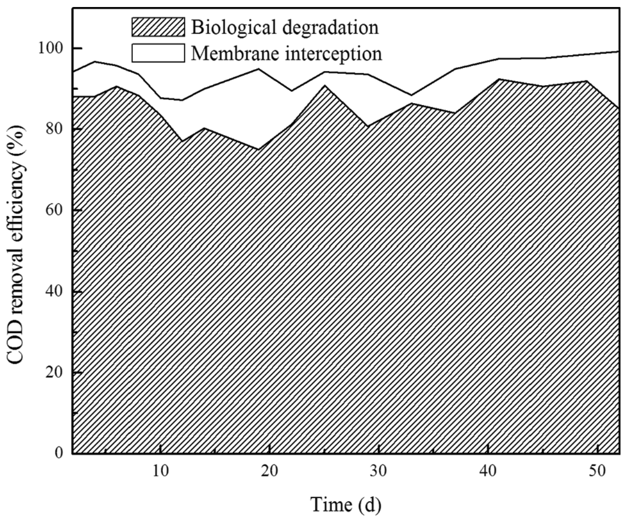

Fig. 6. Variations of COD removal efficiency.

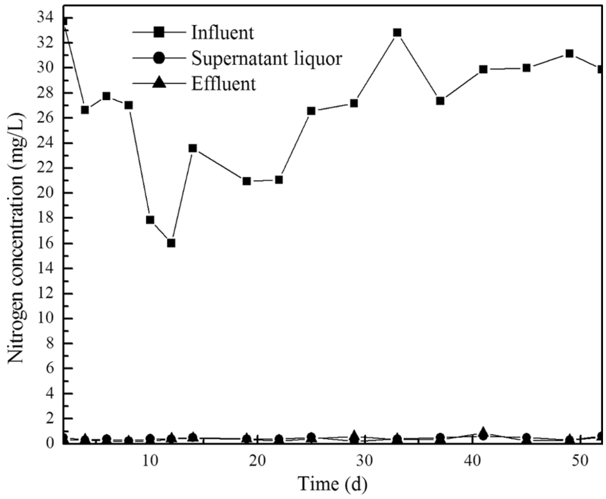

Fig. 7. Variations of nitrogen concentration in the influent, supernatant liquor and effluent.

contribution to intercepting small molecular substances such as NH_4^+-N.

3.2. Membrane fouling in long-term runs

3.2.1. Variations of TMP

The membrane fouling of the MBR was demonstrated by the increase of the trans-membrane pressure (TMP). Fig. 9 shows variations of the TMP with time. The permeation flux was kept constant and the TMP was recorded daily. The TMP increased from 1.5 kPa to 45 kPa during more than 50 days of operation. During the early days of experiments, the TMP gradually increased and the predominant pollutants on membrane were undegraded organism and particulate pollutants, which were so-called reversible pollutants. So

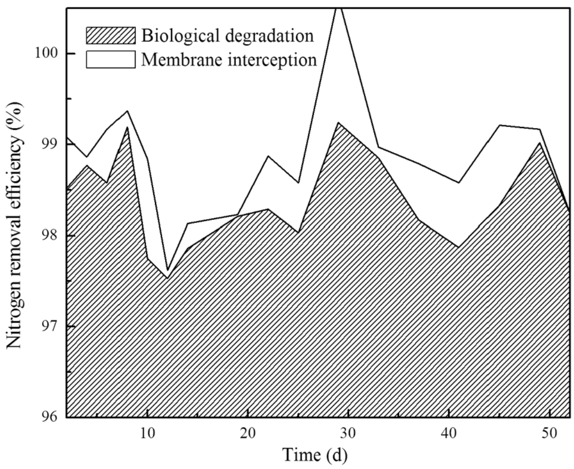

Fig. 8. Variations of nitrogen removal efficiency.

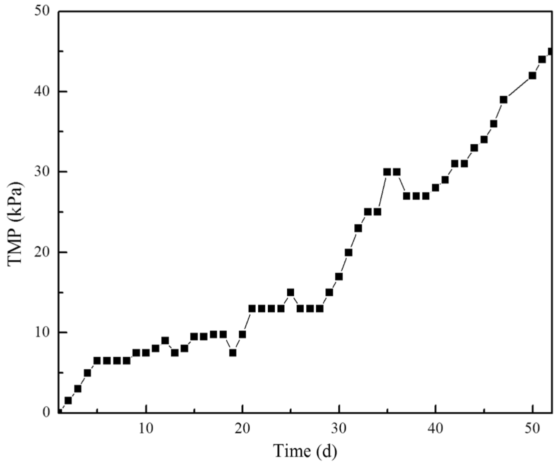

Fig. 9. Variations of TMP with time.

after 30th day, the TMP gradually reached 17 kPa. With the experiment continuing, especially after the 40th day, the TMP increased to 28 kPa. From 30th to the 52nd day, extracellular polymeric substances (EPS) had gradually become the predominant component of membrane fouling. At the end of the whole operation period, the fouling membrane module was removed for its characterization and analysis.

3.2.2. Wash of the precoated dynamic membrane

The appearance of the fouling membrane module is displayed in Fig. 10a. It was found that a sludge layer deposited on the membrane surface. Fig. 11a is the SEM picture of the fouling membrane. The sludge layer on the dynamic membrane surface was bound loosely. Then, the membrane module was brushed by removing the sludge cake and the precoated dynamic membrane. After physical cleaning, the support membrane module was shown in Fig. 10b. The industry filter-cloth as support membrane was applied to study its permeability recovery. Fig. 12 showed that the membrane permeate flux was almost recovered fully and the support membrane could be reused again. Fig. 11b is the SEM picture of the industry filter after cleaning. The results indicated that the precoated dynamic membrane could prevent pollutants and biomass intervening to the surface and interior of the support membrane which was helpful to alleviate support membrane fouling.

4. Conclusions

In this study, the performance of the dynamic MBR for treating synthetic domestic wastewater and

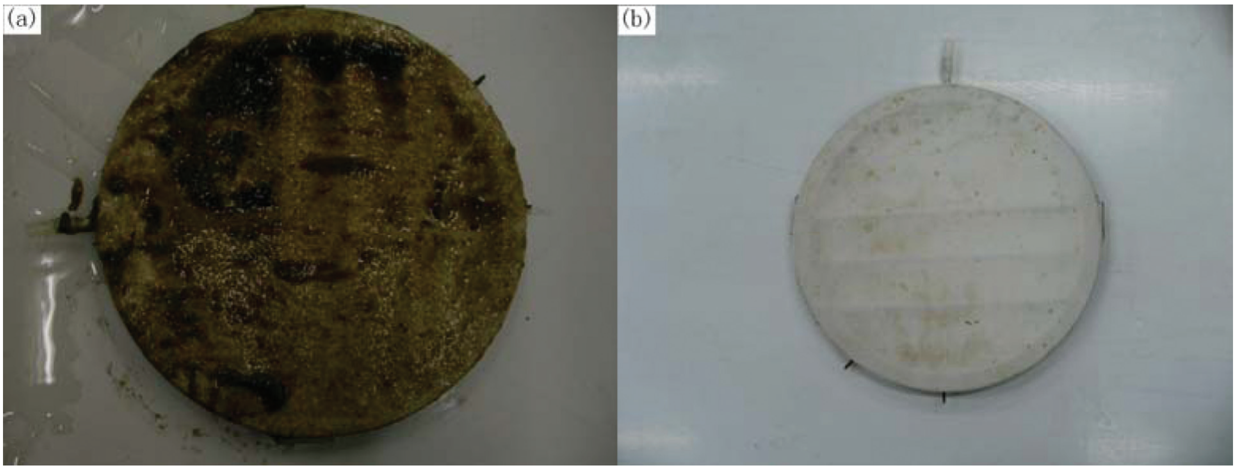

Fig. 10. Appearance of (a) the fouling membrane module and (b) the membrane module after cleaning.

membrane fouling were investigated. Synthetic domestic wastewater was treated by the dynamic MBR for more than 50 days. Conclusions resulting from the novel dynamic MBR can be drawn:

(1) For treating the wastewater sequentially using the dynamic MBR, the effluent turbidity was less than 4 NTU although the influent turbidity fluctuated from 28 to 55 NTU. The effluent SS concentrations were nearly zero in most cases. The average removal efficiency of COD_{Cr} and NH_4^+-N were 93.18 and 98.6% respectively. It was feasible to treat the synthetic domestic wastewater using the dynamic MBR and the effluent quality consistently met the requirement for discharge.
(2) The observation of the fouling membrane module confirmed that a sludge layer deposited on the membrane surface which resulted in the fouling of the membrane. However, the sludge layer could be easily removed by physical cleaning. Then the membrane permeate flux was almost recovered fully and could be reused again. And the precoated dynamic membrane could prevent pollutants and biomass intervening to the surface and interior of the support membrane which was helpful to alleviate support membrane fouling.
(3) The industry filter cloth as support membrane is much more cheaper than the hollow fiber membrane which has a universal application in MBR. Based on the observed results, the novel dynamic membrane showed highly anti-fouling

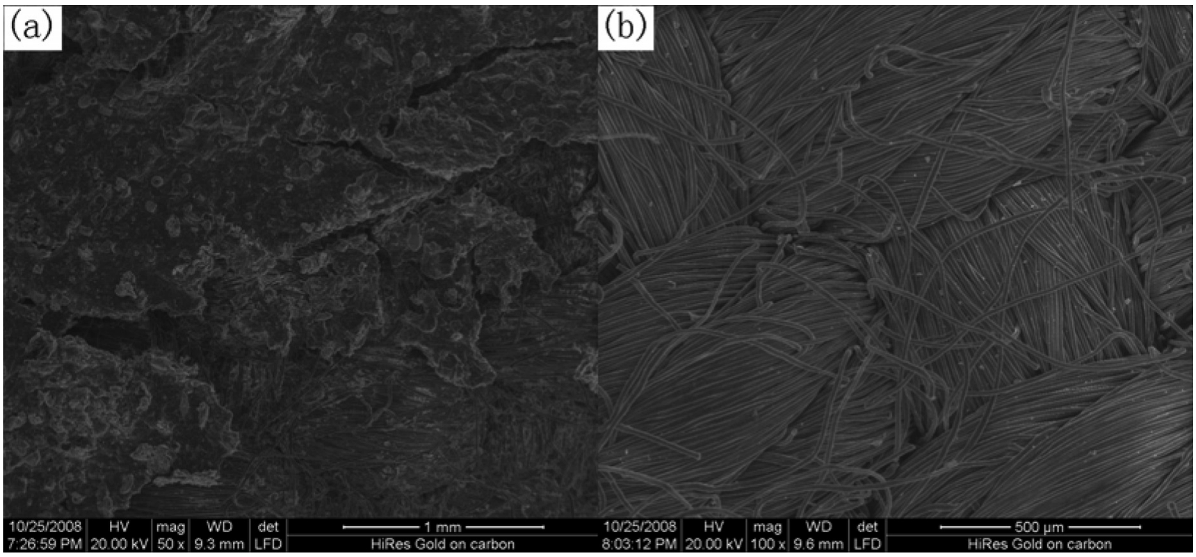

Fig. 11. SEM pictures of (a) the fouling membrane and (b) the membrane after cleaning.

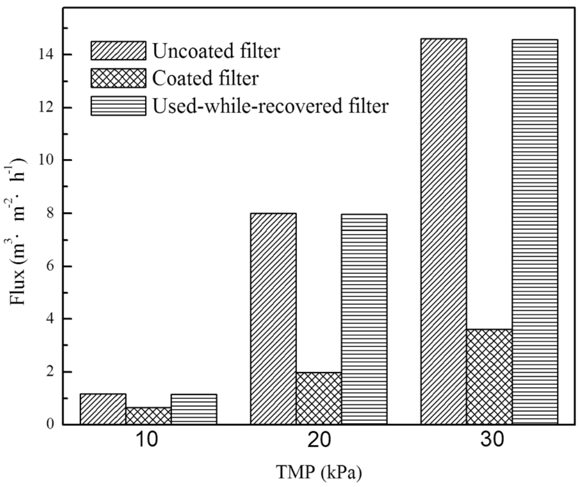

Fig. 12. Variations of pure water flux with TMP.

characteristics in the MBR which could be a potential technology for wastewater treatment.

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