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Study of the influence of the electric field on membrane flux of a new type of membrane bioreactor

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Abstract

The effect of appending direct electric field on the membrane flux of an antifouling membrane bioreactor (MBR) designed and built in our laboratory was investigated. The results showed that appending electric field had significant influence on the membrane flux. At an operation pressure of $\Delta P = 0.1$ MPa, membrane flux increased with electric field strength from $E = 15$ V/cm to 20 V/cm, then kept almost constant after E arrived 20 V/cm. This might result from the fact that charged coarse particle and colloid accounted for 80% of COD_{Cr} and BOD_5 in urban domestic sewage. Those particles and colloid moved away from the membrane surface in the electric field and their speed increased with the increase of electric field strength. When the electric field strength was strong enough to make the deposited layer on the membrane surface no longer a limiting factor in the membrane flux, no much effect was observed after the electric field strength exceeded the critical point.

Keywords: Electric field; Membrane flux; Membrane bioreactor; Anti-fouling

1. Introduction

Submerged membrane bioreactor has a lot of advantages over traditional sewage treatment techniques, such as taking less space, higher impurities removing efficiency, lower energy consumption and sludge yield, and higher quality of effluent water, and easier handling [1,2]. It is getting more attention and applications. Nevertheless, submerged membrane reactor also has some shortcomings, such as unstable membrane flux, and membrane fouling.

Main pollutants leading to membrane fouling includes activated sludge floc, soluble polymer, superfine colloidal particle, and viable bacterium inside the membrane pores. It has been found that the sediment of sludge on membrane surface had the most influence on membrane fouling, maybe more than 50% under general conditions [3]. In order to solve membrane fouling, lots of researchers have put membrane filtration and appending electric field together recently [4–6]. Tarleton studied the influence of appending electric field on cross-flow membrane filtration in 1992 [7], Wakeman et al. studied the process of cross-flow membrane filtration under electric–ultrasonic complex field strength [8], Jurado used the method of vortex mixing and appending electric field to reclaim hemalbumen in 1994 [9–12], Zhao and his co-workers studied a series of electro-membrane filtration process for low concentration suspension under direct current electric field [13–16]. All the studies show that the appending electric field with the role of intensifying colloidal particle mass transfer can restrict membrane fouling, enhance membrane flux obviously.

Up to now, however, there is no report on appending electric field using in membrane bioreactor (MBR). In order to stabilize membrane flux and slow up membrane fouling, a new type of MBR with ability in controlling membrane fouling was built in our lab investigate the influence of electric field on membrane flux in the presence of appending direct-current field.

2. Experimental and analysis

2.1. Experimental

The reactor was made of plastic with a dimension of 40 cm × 30 cm × 42 cm. The effective volume was 40.5 L. The

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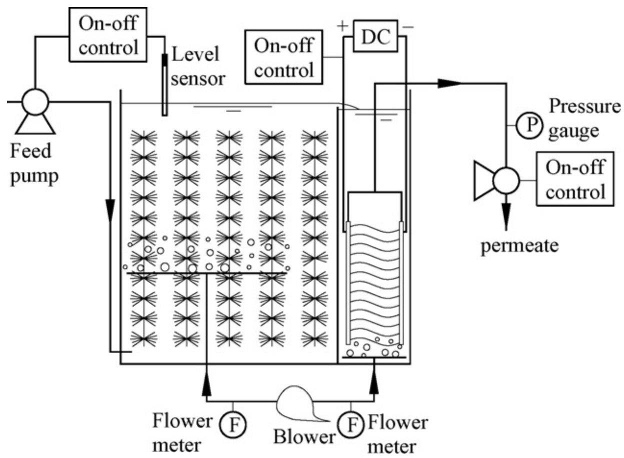

Fig. 1. Schematic of the new style membrane bioreactor after appending direct current field.

reactor was partitioned into two compartments with clapboard. The bigger one was three times of the small one in size. A tubular aerator was furnished to the height of the pool so that aerobic and anoxic biofilm could be formed in the upper and lower part, respectively. The hollow fiber membrane assembly was furnished in the other pool, a little perforated pipe aerator was furnished under the membrane assembly. The clapboard height was lower than the waterline to ensure water efflux into the small pool from the bigger so that the membrane fouling could be alleviated. The scheme of bioreactor is shown in Fig. 1.

The polypropylene hollow fibrous membrane assembly was purchased from Zheda Kaihua Technical Co. Ltd. The inner and outer diameters of the membrane are 0.32 and 0.47 mm, respectively. The area of the membrane assembly is 4 m^2. The length and height of the membrane are 24 cm and 22.5 cm, respectively.

Activated sludge was taken from Wuhan Shahu Sewage Treatment Plant. The initial incubation concentration was 4.5 g/L. The MBR began to operate formally after the active sludge was cultured for 7 days. No sludge was discharged during the experiment operation normally.

Hydraulic retention time was set to 8 h. The effluent was pumped under operating pressure $\Delta P = 0.1$ MPa. The initial effluent flow was 36.7 L/m^2 h.

The electrode was made of stainless steel with a lot of evenly distributed tiny holes. The distance between the electrode plates was 5 cm. The membrane assembly and the electrode plates were bounded together. The adjustable power regulator ST-DRPS1000F was purchased from Hangzhou supertech electronic technology Corp. Ltd. (Hangzhou, China).

2.2. Sewage properties

Sewage water was taken from a septic tank at No. 2 residential building situated at the northern part of a university in Wuhan, China. The quality of water is shown in Table 1.

Table 1
Water quality in the experiments

COD_{cr} (mg/L)	310–740
pH	5–8
Turbidity (NTU)	100–500
SS (mg/L)	400–800
ζ-potential (mV)	−18.4 to −22.6
Water temperature (°C)	15–25

3. Results and discussion

3.1. The influence of electric field strength on membrane flux in the MBR

The membrane flux under different electric field strength is shown in Fig. 2. $E = 0$ V/cm means that there is no appending electric field. It is obvious that the membrane flux dropped with the operation time. This may be owing to the absorption and clogging of the pores of the membrane, the concentration drop across the membrane, and the sedimentation layer was also formed on the membrane. After the electric field was applied, the membrane flux increased with the electric field strength. It can be seen that the membrane fluxes under all testing conditions dropped fast at the early stage of operation. The membrane flux stabilized in 2–4 h of operation. It appears that the extent of drop of membrane flux for operations at $E = 15$ V/cm and $E = 0$ V/cm was much less than the counterparts under other conditions.

A lot of minute colloidal particles carry residual charges and the most likely, negative charge. The electric properties of particle differ from one material to another material. All of them can be determined by experiment [17]. There are several forces acting on the charged particle when appending electric field is applied in the MBR. One is the electric field force, which drives the electriferous colloidal particle away from the membrane surface. The other one is hydraulic kinetic force, which drives all particles onto the membrane surface due to movement of liquid out of the membrane. The third one is the diffusion effect, moving the particle from higher concentration side to the lower one. The forth is the electro-osmosis effect of electriferous particle. The electric force always counteracts the sedimentation process while diffusion acts in the same direction when sedimentation dominates in the filtration process but in the opposite direction when electrophoresis dominates the filtration process.

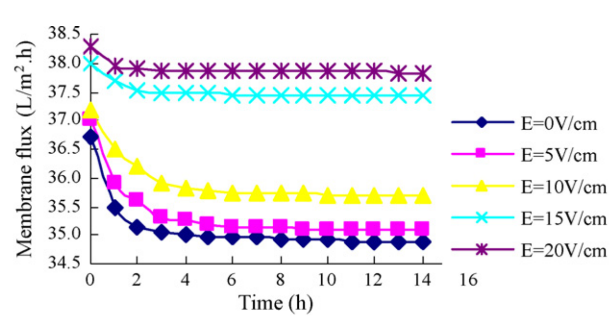

Fig. 2. Attenuation curves of membrane filtration flux varying with time.

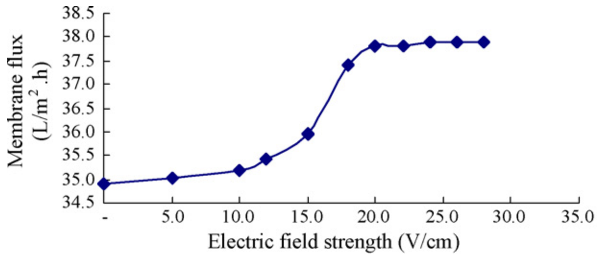

Fig. 3. A curve of membrane flux varying with electric field strength.

3.2. *The influence of electric field strength on fouling membrane flux in the new style MBR*

The electric field strength increases after operating the bioreactor for 10 h. The relationship between the electric field strength and membrane flux is shown in Fig. 3.

From Fig. 3, it can be seen that the increase of membrane flux was relatively slow when the electric field strength was from 0 to 10 V/cm. It was reported that coarse particle and colloid accounted for 80% of COD_{Cr} and BOD_5 in urban domestic sewage [17]. The effect of anti-sedimentation of low electric field strength was not high enough to counteract the sedimentation of particle.

At the electric field strength of 10–15 V/cm, the membrane flux increases at a high rate with the electric field strength. This should be due to high electrophoresis rate from high electric field strength.

When the electric field strength was set at 15–20 V/cm, the membrane flux increased linearly with electric field strength. The electrophoresis of particle and the sedimentation of particle onto the membrane surface equilibrated as the electric field strength increased further. The thickness of gel layer on the membrane got thinner when the increase of electric field strength occurred and then stabilized. The increase of electro-osmosis with electric field strength also contributed to the dramatic drop in filtration resistance of membrane. When E was greater than 20 V/cm, the membrane flux's increase had little to do with the electric field strength. It can be concluded that at $E \geq 20$ V/cm, the increasing speed of electrophoresis was much higher than that of sedimentation, fouling was no longer a limiting factor in membrane flux. 20 V/cm was the optimal electric field strength under the investigated condition.

3.3. *The effect of operation pressure on optimal electric field strength*

To find the relationship between operation pressure and optimal electric field, the optimal electric field strengths under different operation pressure was determined and the result shown in Fig. 4.

Fig. 4 shows that the optimal pressure increases linearly with the operation pressure. High pressure results in increasing the velocity of sedimentation of particle on the membrane, and higher electric field strength was needed to counteract the rate of electrophoresis of charged particle to alleviate the sedimentation of particle.

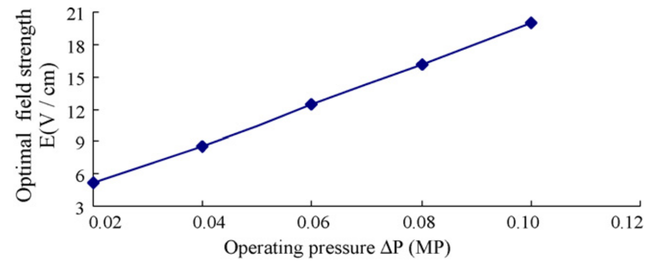

Fig. 4. The relation between optimal field strength and its operation pressure.

4. Conclusion

(1) Appending electric field has significant affects on the membrane flux of new MBR: the electrophoresis of particle will increase, the sedimentation layer will become thinner, and the resistance of filtration drop with the electric field strength.
(2) There is an optimal electric field strength for the operation of MBR. The membrane flux is smaller at electric field strength higher or lower than that point.
(3) High operation pressure leads to high membrane flux. However, pressure has obvious influence on the optimal electric field strength. The optimal electric field strength's increase goes with the operation pressure's increase.

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