Municipal Sewage Treated by a Pilot-Scale Membrane Biological Reactor*

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Abstract: It is obviously advantageous for membrane biological reactor to treat municipal sewage over traditional active sludge process. Multi-species microbes in active sludge retained completely by submerged hollow fiber curtain-like micro-filtration membrane module with pore-size of 0.5 mm in an integrated pilot-scale membrane biological reactor self-designed. Meanwhile, the pilot plant comprised an anoxic zone to enable denitrification. In this experiment, two kinds of practical municipal sewage were continuously treated by using this membrane biological reactor in order to evaluate the properties of membrane module, such as the relationship between vacuum degree in membrane module and water flux of membrane, relationship between operational time and water flux of membrane and the way to prevent membrane pollution. Further, all sorts of water quality indexes for inlets and effluents, such as COD, turbidity, NH_3-N and apparent colourity were measured in time. And the experimental results showed that there were so excellent water qualities for outlet water as to meet the water-quality standards for urban miscellaneous consumption water. Moreover, the change of sludge concentrations (MLSS) was also monitored on every day. In conclusion, it is instructive for the designing and operational data to commercial applications in the future, which are obtained from this pilot-scale membrane biological reactor.

Key words: membrane biological reactor; micro-filtration; membrane module; municipal wastewater
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1 Introduction

Among traditional wastewater biological treating, the separation of sludge and water is carried out by gravity action in secondary settling basin, and its separating efficiency depends upon settling characters of sludge[1,2]. While the settling properties of active sludge are related with the running status of aeration tank, thus it is necessary to control the operation of aeration tank so as to improve settling properties. Meanwhile, due to the limitations of solid and liquid separating in secondary settling basin, the concentration of active sludge in aeration tank can not maintain higher level. In general, it is on the scale of 2 ~ 4 g/L, and this restricts the biochemical reaction rate and treating efficiency. Moreover, there is a large quantity of remainder sludge produced and the sludge bulking. As some suspending particles contain in outlet water, the water quality of effluents is not perfect. Thus, membrane biological reactors (MBR) were developed so as to avoid the disadvantages related with active sludge process[3].

As membrane technologies, such as micro-filtration and ultra-filtration, are introduced into the membrane biological reactor, the separating efficiency of sludge and water is greatly improved. At the same time, the concentration of active sludge in aeration tank increases and some highly-functional bacteria appear, so the treating efficiency obviously arises. Meanwhile, the amount of remainder sludge is reducing by means of F/M descending. Therefore, the prominent problems related with active sludge process can be satisfactorily overcome in the aid of membrane biological reactor[4]. In nature, membrane biological reactor is a type of combined wastewater treating technology, and this neotype process holds many merits, such as, excellent water quality in outlet, high removal rate to organics, little remainder sludge, higher sludge concentration and lower bulk organic load. Especially, membrane biological reactor completely replaces the secondary settling tank. And the water quality in outlet is advantageous over that in the effluents of traditional secondary settling tank.

The sludge concentration in MBR is usually sustained on higher level, that is, 8 ~ 12 g/L or so[5]. Thus, on

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condition that the air provided sufficiently, there is faster biodegradable rate of organics for multi-species microbes in system. Meanwhile, as the sludge age is longer and there is almost no remainder sludge producing, it is adaptive to the growth and propagation of long-generation microbes. If suitable operational conditions provided, it can realize the denitrification and dephosphorization.

In general, membrane biological reactor can divide into submerged MBR and recirculated MBR.

Here, an immersed micro—filtration membrane biological reactor was established to treat two kinds of practical municipal sewage in order to evaluate the purifying effects and the properties of membrane module according to our Peking Science and Technology Planning Project. And the emphases were to investigate the relationships between water flux of membrane and running time, between water flux of membrane and the vacuum degree in membrane module, between water quality indexes in effluents and operational time, the influence of vacuum degree in membrane module on water quality of outlet and the changes of sludge concentration in combined reactor along with operational time. The ultimate goal was to realize commercial application as soon as possible for this new type membrane biological reactor.

2 Experimental

In this paper, two kinds of municipal wastewater were chosen for treating, one was from the drain at 1st student dormitory in Tsinghua University; the other was from the effluents of initial settling tank at Beixiaoqiao municipal sewage treating plant in Peking. According to the measuring results for these two kinds of sanitary waste, it indicated that they were almost identical. See table 1 and table 2.

Tab 1　Indexes of sewage from the drain of 1st dormitory in Tsinghua University

COD ($mg \cdot L^{-1}$)	NH_3—N ($mg \cdot L^{-1}$)	Turbidity FTU	Apparent colority	pH
200～400	20～40	20～60	300～500	6.5～7.0

Tab. 2　Indexes of sanitary waste from the outlet of initial settling basin in Beixiaoqiao

COD ($mg \cdot L^{-1}$)	NH_3—N ($mg \cdot L^{-1}$)	Turbidity FTU	Apparent colority	pH
300～400	20～40	20～60	300～500	6.8～7.2

Multi-species microbes, from active sludge in the lagoon of wastewater treating plant at Jizhuangzi in Tianjin, China, were aerobically cultured for two months so as to obtain sufficient amount and adapt to the environment of practical municipal sewage.

Fig. 1 shows the schematic diagram of self-designed pilot-scale membrane biological reactor.

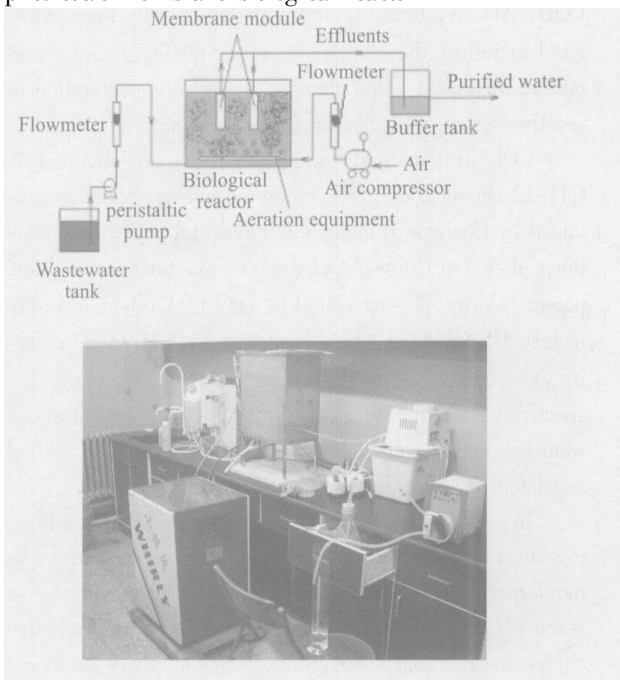

Fig 1　Schematic diagram of membrane biological reactor

The immersed membrane biological reactor is mainly composed of a biological reactive apparatus and two pieces of micro-membrane module. These two pieces of micro-filtration membrane module were submerged into active sludge system. Biological reactor is made of steel plates, and its sizes are 400 mm in length, 250 mm in width and 450 mm in height, respectively.

Fig. 2 provides the schematic diagram of fiber hollow membrane module.

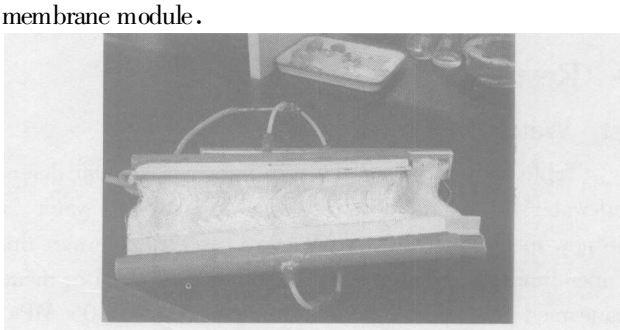

Fig 2　Fiber hollow membrane module

Micro-membrane module was provided by Blue-cross Membrane Technology Co. Ltd., in Tianjin, and it was made from hydrophilic polymer propylene hollow fiber with micro pores' diameter of 0.01～0.1 μm. For each piece of membrane module, the hollow fiber pipe bundles were arranged to three layers, there were 100 bundles in each layer and there were 25 fibers in each bundle. The length of each hollow fiber pipe was 155 mm, and its pipe diameter was 0.5 mm. In each time, two pieces of membrane module were equipped, and its effective water flowing area

was 3.8 m^2.

During the running of membrane biological reactor, COD, NH_3-N, turbidity and apparent colority were monitored to reflect the changes of water quality in inlet and outlet. Meanwhile, the changes of sludge concentration in reactive system were also monitored in time.

COD in municipal sewage and outlet was obtained by CTL-12 chemical oxygen demand measuring apparatus produced by Chengde Huatong environmental protection apparatus plant, in China. And the NH_3-N, turbidity and apparent colority were measured by H5-HI93703-11 turbidity meter, H5-HI93733 NH_3-N meter and H5-HI93727 colority meter produced by Hanna Instruments Co. Ltd, respectively. At the same time, the sludge concentrations were monitored every day in accordance with the method regulated by the criterion of national water quality.

In general, the experiments are carried out as following steps. Firstly, open 1st peristaltic pump and make municipal sewage flow into membrane biological reactor to reach a certain height. Secondly, input air to let active sludge suspend and make multi-species microbes lie in excellent aerobic surroundings. Thirdly, open vacuum pump to form a certain vacuum degree in membrane module. Finally, open 2nd peristaltic pump to get purified water flow out from the buffer tank, and adjust inflow according to outflow so as to sustain a certain water height in reactive system. In addition, it is necessary to form and maintain some anaerobic and anoxic bacteria in somewhere of membrane biological reactor in order to realize denitrification and dephosphorization. While the operation of system reaches the stable status, the experimental data can be obtained periodically.

3 Results and discussion

3.1 Water flux of membrane

Table 3 lists the relationship between vacuum degree and water flux of membrane measured with tap water for the new membrane module. It can be seen that water flux of membrane increases along with vacuum degree in membrane module improving on the scale of 0 ~ 0.05 MPa. And the experiment indicates that when vacuum degree in membrane module exceeds 0.05 MPa, peristaltic pump is hard to suck purified water out from the buffer tank.

Tab 3 Relationship between vacuum degree and water flux of membrane for new membrane module

Vacuum degree (Gauge pressure)/MPa	0	0.015	0.025	0.035	0.05
Water flux of membrane/($L \cdot h^{-1} \cdot m^{-2}$)	0.0657	0.432	0.681	0.895	1.02

During municipal sewage treating, adjust vacuum degree in membrane module to 0.025 MPa, and let the performance of membrane biological reactor reach stable status. Fig. 3 indicates the relationship between water flux and operational time for the hollow fiber membrane module to treat municipal sewage on condition that vacuum degree is 0.025 MPa. It can be seen that water flux of membrane decreases fast along with the increase of operational time at the initial stage. Subsequently, water flux of membrane reaches stable. And the value of water flux maintains on the scale of 0.105 ~ 0.118 $L \cdot h^{-1} \cdot m^{-2}$. This shows that when membrane module is immersed into biological reactor, some impurities in wastewater and active sludge adhere to the surface of membrane so as to produce the membrane pollution and micro pores in membrane are blocked or diminished.

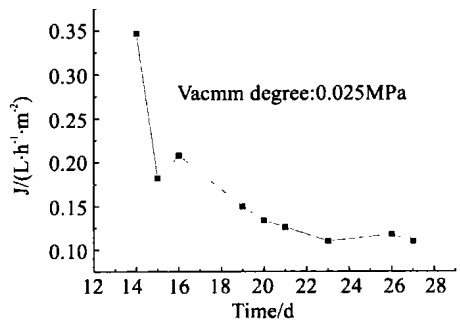

Fig 3 Relationship between water flux of membrane and operation time

After continuously operated for 27 days, adjust vacuum degree in membrane module to 0.05 MPa till up to stabilization for the operation of membrane biological reactor, water flux of membrane is 0.276 $L \cdot h^{-1} \cdot m^{-2}$; then have vacuum degree in membrane module return to 0.025 MPa again and restore stabilization, we obtain new relationship between water flux of membrane and operating time as shown in Table 4.

Tab. 4 Relationship between water flux and the operating time

Operational time/d	1	2	3	6	7	8	9
Water flux /($L \cdot h^{-1} \cdot m^{-2}$)	0.171	0.169	0.161	0.158	0.158	0.155	0.157

After membrane biological reactor has been operated for a certain time, water flux of membrane is capable of increasing if consciously to improve the vacuum degree in membrane module to a higher level and return back to the original. Thus, it can be realized for membrane washing on line by this way. In addition, it has been discovered that during membrane module replacing, there is some of active sludge adhering to the surface of membrane indeed, especially on the surface of medium layer of three-layer membrane module. The reason is that it is hard to swash the middle layer of membrane module for turbulent fluid aerated by air. Therefore, it is necessary to consider the influences of active sludge adhesion on water flux of membrane during the membrane module design in the future.

For example, it can be designed only one layer of hollow fiber membrane bundles for a membrane module. In addition, it is very effective for improving water flux of membrane as flow rate of liquid on membrane surface increases during the operation of membrane biological reactor.

3.2 Water quality indexes

Fig. 4 describes the changes of COD in effluents along with operational time during municipal sewage treating by micro-filtration membrane biological reactor.

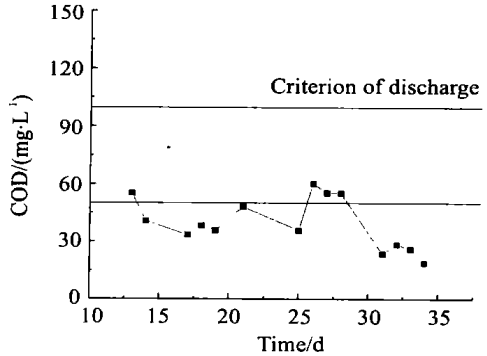

Fig 4　Changes of COD in outlet along with operational time

When vacuum degree in membrane module is 0.025 MPa and water flux of membrane is 0.118 $L \cdot h^{-1} \cdot m^{-2}$, there is excellent treating results on municipal sewage for membrane biological reactor. COD in outlet are very lower than that of national water quality criterion for discharge. And COD of 20 $mg \cdot L^{-1}$ in outlet water is approaching to the criterion of urban miscellaneous consumption water during the last stage of operation.

In addition, as vacuum degree in membrane module is adjusted up to 0.05 MPa and subsequently back to 0.025 MPa in order to carry out membrane washing on line during wastewater treating, COD in outlet increases to 60 $mg \cdot L^{-1}$ for some time, however, it is capable of returning back to 20 $mg \cdot L^{-1}$ after the stable operation of membrane biological reactor is restored.

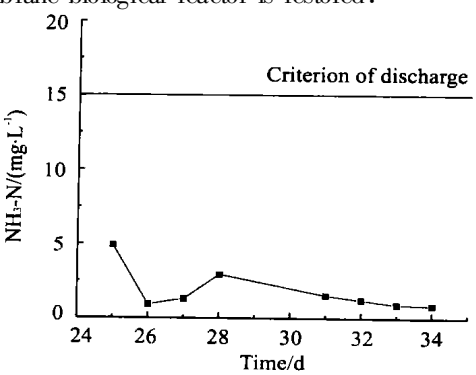

Fig 5　Curve of NH_3-N concentrations in outlet

Fig. 5 shows the changes of NH_3—N concentration in outlet water along with the performing time for membrane biological reactor with a vacuum degree of 0.025 MPa. It can be seen that the concentrations of NH_3—N in outlet are also rather low, and it is lower than that of national discharge criterion. This shows that there are long-generation anaerobic and aerobic microbes living in somewhere of membrane biological reactor to carry out nitrification and denitrification.

Fig. 6 illustrates the changes of apparent colority in outlet along with operational time for membrane biological reactor to treat municipal sewage.

It is shown that the apparent colority in outlet water is fluctuating on the basis of wastewater reuse criterion, and sometimes can not meet the national standard. The reason of this is that it is difficult to interrupt some soluble organics and inorganic ions in municipal sewage for micro-filtration membrane. In addition, vacuum degree in membrane module, constitutions of wastewater and properties of membrane are the main factors to affect apparent colority in outlet. Therefore, it is restricted for improving vacuum degree in membrane module. And it is necessary to make correct choice between apparent colority and water flux of membrane.

Fig. 7 illustrates the relationship between turbidity in outlet and operational time for membrane biological reactor to treat municipal sewage. It can be seen that turbidity in effluents is rather low and meet the criterion of reclaimed water. There is good interrupting ability for big molecular organics and insoluble granule materials.

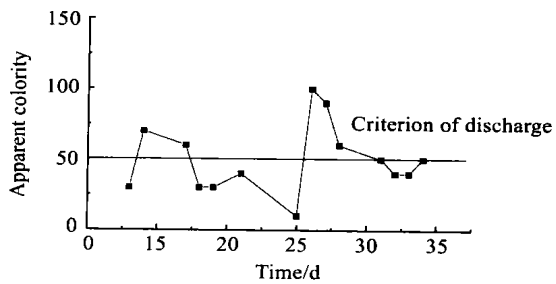

Fig 6　Relationship between apparent colority and operational time

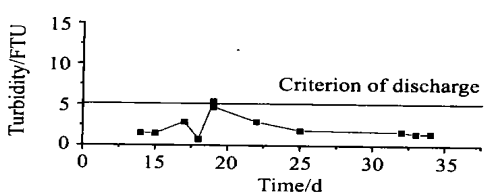

Fig 7　Relationship between turbidity in outlet water and operational time

3.3 Concentrations of sludge

Fig. 8 provides the relationship between concentrations of sludge in reactor and operational time as membrane biological reactor is continuously operating. The concentrations of sludge in reactor are stable all over the treatments of municipal sewage and maintains on the sale

of 8 ~ 10 $g \cdot L^{-1}$. In order to maintain the concentration of sludge, COD in inlet water (organic load) should keep in a certain range. Otherwise, multi-species microbes will trap in endogenous metabolism and decrease the concentrations of sludge in reactor. In addition, it is necessary to provide the excellent aerobic conditions for multi-species microbes.

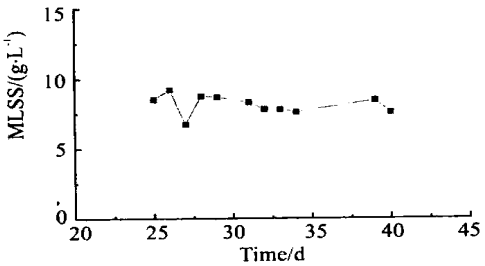

Fig 8 Changes of sludge concentrations in reactor along with operational time

4 Conclusion

In summary, it is advantageous for membrane biological reactor to treat municipal sewage. When micro-filtration hollow fiber membrane is adopted as membrane module to form membrane biological reactor in conjunction with active sludge process, it will treat municipal sewage efficiently so as to meet the standards of recycling (non-drinking water) or discharging. Compared with ultra-filtration membrane module, it can greatly save the power consumption.

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膜生物反应器处理市政污水中试研究

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摘 要：相对于传统活性污泥法，膜生物反应器处理生活污水具有显著的优势。通过在自行设计、加工的浸没式中空纤维微滤膜生物反应器中试装置上连续处理两种生活污水，旨在研究中空纤维微滤膜组件的性能及其影响因素，膜水通量随膜组件内真空度的变化，膜水通量随运行时间的变化和膜污染产生的原因及防治措施。了解膜生物反应器对生活污水的净化效果，出水 COD、NH_3-N、表色色度和浊度随运行时间的变化，膜生物反应器内污泥浓度随运行时间的变化情况等。为下一步中空纤维微滤膜生物反应器商业化应用提供基础设计数据和运行参数。

关键词：膜生物反应器；微滤；膜组件；市政污水

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