Desalination and Water Treatment
www.deswater.com

18 (2010) 239–244
June

doi: 10.5004/dwt.2010.1779

Coagulation-microfiltration for lake water purification using ceramic membranes

Weixing Li, Liyue Zhou, Weihong Xing*, Nanping Xu

State Key Laboratory of Materials-Oriented Chemical Engineering
Nanjing University of Technology, 5 Xinmofan Road, Nanjing 210009, People's Republic of China
Tel.: +86(25)83172286; Fax: +86(25)83172292; email: wxli98@sina.com

Received 3 June 2009; Accepted 18 December 2009

ABSTRACT

A microfiltration process coupled with online coagulation using honeycomb ceramic membranes was used to purify lake water. The turbidity of feed lake water was from 13 to 30 NTU and the suitable dose of the coagulant was 15–30 mg L^{-1} by the jar test. The turbidity of the treated lake water after coagulation was about 5 NTU, which was suitable for microfiltration at the optimised operating conditions of 0.2 MPa and 1 m × s^{-1}. The function of flux as membrane pore size showed that the optimal pore size was 500 nm in the tested four ceramic membranes for treating the lake water. The steady flux of microfiltration increased from 225 to 640 L × m^{-2} × h^{-1} by coupled with online coagulation, and the turbidity removal increased from 97.2% to 99.5%. The water quality analysis displayed that UV_{254}, the content of TOC and metal ions by microfiltration with online coagulation were lower than that without coagulation.

Keywords: Microfiltration; Coagulation; Lake water; Ceramic membrane

1. Introduction

Lake water is the important resource for drinking. However, with the improvement of the requirements on the quality of drinking water, lake water should be clarified first instead direct drinking. The conventional process for tap water purification was coagulation, sedimentation and filtration. The main limitations were the poor water quality and the large area covering caused by the low efficiency of the filtration and sedimentation processes. Nowadays, the new technologies for water purification became hot topics.

Membrane separation as a drinking water treatment process was the most important technological breakthrough in the last decades [1–3]. Membrane application in water treatment provides lots of advantages over conventional treatment, such as higher filtration efficiency, better water quality and simpler procedure. Usually, organic membranes have been applied in water treatment for drinking because of their lower economical cost compared with ceramic membranes. However, organic membranes had their innate limitations just like poor material stability in acid water, poor ageing resistance and poor antioxygenation. Therefore, some studies [4–7] reported that ceramic membranes were used to purify river water and the microfiltration of water with ceramic membranes obtained good filtration efficiency. Especially, the combination of ceramic membrane microfiltration and coagulation could improve the permeate flux and was a promising water technology for producing high quality drinking water.

Lake water, low polluted surface water, is easy to be treated as drinking water. Lake water was treated by microfiltration/ultrafiltration [8,9]. However, the

*Corresponding author.

membrane fouling caused by the impurities in the feed water led to low permeate flux. Therefore, coagulation was used as the pretreatment to intensify the micofiltration process for high permeate flux. Pikkarainen *et al.* [10] applied pre-coagulation for microfiltration of upland surface water. The coagulation-microfiltration process for treating river water was also studied [5]. Here, the coagulation-microfiltration process was used to purify lake water using ceramic membranes. The objective of this work was to optimize the coagulation-microfiltration process for treating the lake water by using the honeycomb ceramic membrane.

2. Experimental details

2.1. Ceramic membranes

In this study the honeycomb ceramic membranes (Jiusi High-Tech, China) with different pore sizes (50, 200, 500 and 800 nm) were used. Their thicknesses were 15, 20, 30 and 45 microns from the SEM images analysis, respectively. The porosity was 0.3–0.35. Each membrane provides 0.7 m^2 efficient filtration area.

2.2. Experimental apparatus

The test apparatus diagram (Fig. 1) showed a crossflow filtration unit using ceramic membranes. The coagulant was added into the feed water pipe and coagulation was carried out in the pipe and the feed tank.

2.3. Experimental procedure and analysis

The lake water was taken from the Xuanwu Lake of Nanjing at the southeast China. The experimental procedure went as follows.

The first stage was optimisation of the coagulation. The influence of dose of the coagulant (Ferric chloride) on the coagulation efficiency and the coagulation dynamic were investigated.

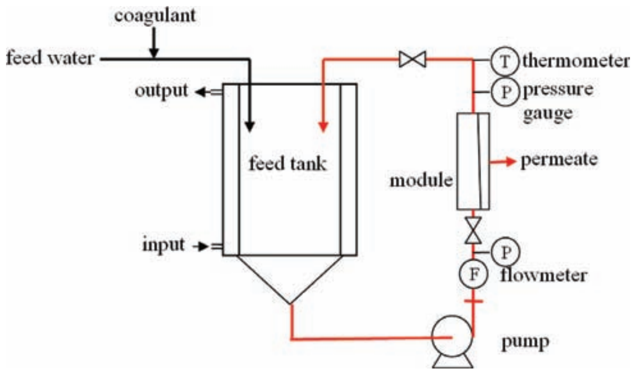

Fig. 1. Microfiltration apparatus.

The second stage was to optimize the operating parameters for microfiltration. The feed lake water was treated by coagulation and then used as the feed of microfiltration. An orthogonal experiment of three factors (crossflow velocity, trans-membrane pressure, dose of coagulant) with three levels was designed for the optimization.

The third stage was the coagulation–microfiltration using the ceramic membrane. Two processes of microfiltration without coagulation and with online coagulation were compared. The microfiltration of lake water using four ceramic membranes was carried out at 0.2 MPa, 1.0 m × s^{-1}, 20°C.

The efficiency of coagulation, microfiltration and the hybrid process was assessed based on the physicochemical analysis of feed water, water after the coagulation and on the permeates. The analysis involved the determination of the following: turbidity, total organic carbon (TOC), absorbance at 254 nm (UV_{254}) and metal ions (Ca, Mg, Fe, Cu, Cr and Pb) content.

3. Results and discussion

3.1. Optimization of the coagulation

The jar test for selecting the coagulation parameters was carried out. In this test the dose of the coagulant and the coagulation time were investigated.

Because the quality of the feed lake water fluctuates according to the weather, the feed lake waters with different turbidity (13, 15, 20 and 30 NTU) were used to investigate the efficiency of the coagulation. The results shown in Fig. 2 (a)–(d) depicted the function of turbidity variation as time. The turbidity of the lake water after coagulation decreased with increasing dose of the coagulant in the range of 5–30 mg L^{-1} and dropped rapidly in the first 20 min but varied slightly after 40 min. The final coagulation efficiency for the four feed lake waters was shown in Fig. 3. As shown, for the feed lake waters of 13, 15 and 20 NTU, the turbidity variation of the coagulated water with the dose of the coagulant showed the same tendency. When the dose of the coagulant was 15 mg L^{-1}, the turbidity of the treated water arrived at about 5 NTU. However, when treating the feed water of 30 NTU using 15 mg L^{-1} coagulant, the turbidity was 7.5 NTU and reached 5.2 NTU using 30 mg L^{-1} coagulant. The lake water of higher turbidity contained more impurities, which resulted in the lower coagulation efficiency. From Fig. 3, the doses of coagulant that made the effluent turbidity of 5 NTU for the different turbidities feed lake waters (13, 15, 20 and 30 NTU) were 11.8, 13.4, 15.6 and 30.0 mg L^{-1}, respectively. The doses of coagulation showed linearity with the feed turbidity.

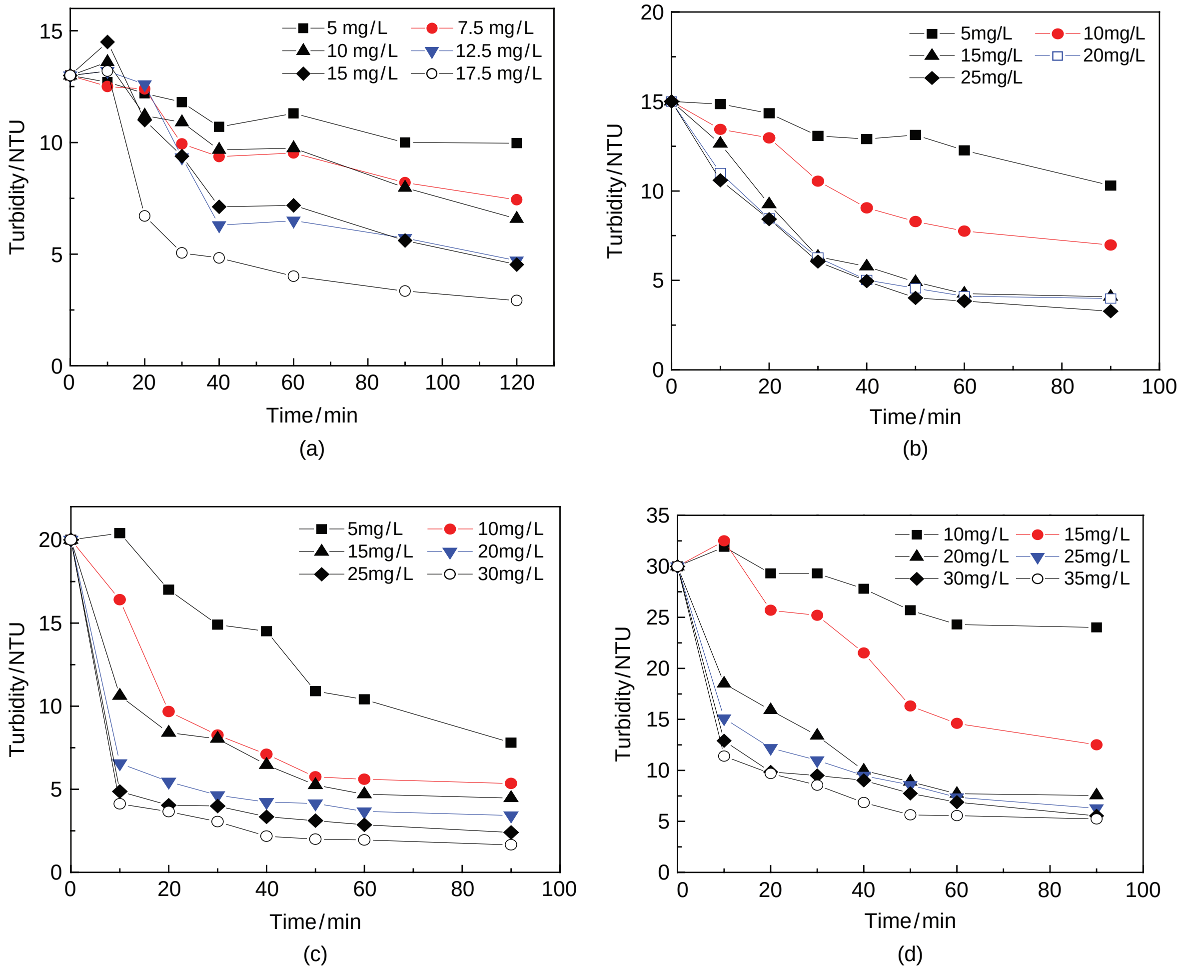

Fig. 2. Coagulation for feed lake waters with different turbidities: (a) 13 NTU, (b) 15 NTU, (c) 20 NTU and (d) 30 NTU.

3.2. Optimization of operating parameters for microfiltration of treated lake water by coagulation

The operating parameters for microfiltration of treated lake water by coagulation using ceramic membranes were optimized by the orthogonal experiments of three factors with three levels (listed in Table 1). The objective of the orthogonal experiments is to pick out some typical factors of experiments and obtain the best factor combinations by designing the factor levels properly. The optimization result by the orthogonal experiments was listed in Table 2.

In Table 2 the influence of three operating parameters on coagulation–microfiltration using ceramic membranes were analysed. From the error of the fluxes, the importance order of the factors was C > B > A. And the velocity had the least influence because error(A) was

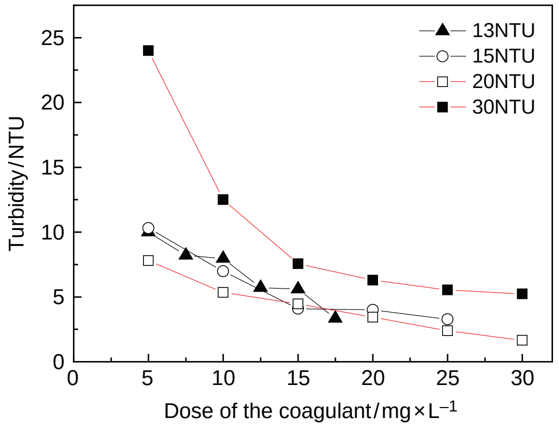

Fig. 3. Coagulation efficiency for treating feed lake waters with different turbidity values.

Table 1
The factors and their levels for the orthogonal experiments.

Factors	Levels		
	1	2	3
A. Crossflow velocity ($m \times s^{-1}$)	1	2	3
B. Trans-membrane pressure (MPa)	0.10	0.15	0.20
C. Dose of coagulant ($mg \times L^{-1}$)	10	20	30

Table 2
The orthogonal array to optimize operating parameters for coagulation–microfiltration.

Experiment no	Factors			Flux ($L \times m^{-2} \times h^{-1}$)
	A	B	C	
1	1	0.10	10	426
2	1	0.15	20	847
3	1	0.20	30	1232
4	2	0.10	20	586
5	2	0.15	30	1173
6	2	0.20	10	540
7	3	0.10	30	777
8	3	0.15	10	495
9	3	0.20	20	1060
Mean k1	835.12	596.89	487.40	
Mean k2	766.81	838.63	831.68	
Mean k3	778.12	944.53	1060.97	
Error	68.30	347.64	573.57	
Optimized	A1	B3	C3	

far lower than the others. The best factor combination was A1B3C3 (the crossflow velocity of $1 m \times s^{-1}$, transmembrane pressure of 0.2 MPa and dose of coagulant of $30 mg \times L^{-1}$) from the mean values at three levels. As listed in Table 2 the optimized operating conditions happened to be investigated and the permeate flux was $1232 L \times m^{-2} \times h^{-1}$. Due to the varied turbidity (13–30 NTU) of the feed lake water, the optimization of the dose of the coagulant could not be taken as the optimized operating condition. The dose of coagulant should be adjusted by the turbidity of the feed lake water.

3.3. *Coagulation–microfiltration using the ceramic membrane*

In order to reduce the tank volume for coagulation, the online coagulation was taken into account. The processes of microfiltration without coagulation and with online coagulation were compared. The microfiltration of lake water using four ceramic membranes (50, 200, 500 and 800 nm) was carried out at 0.2 MPa, $1.0 m \times s^{-1}$, 20°C. The quality of the feed lake waters was listed in Table 3. Fig. 4 showed the effects of pore size on the permeate flux by microfiltration without coagulation (a) and with online coagulation (b). The experiment results displayed that the microfiltration permeate flux with online coagulation was higher than that without coagulation, which implied that the coagulation had the positive influence on microfiltration permeate flux.

The differences between microfiltration with online coagulation and without coagulation are shown in Fig. 5 and Table 3. The function of flux as ceramic membrane pore size presented in Fig. 5 showed that the flux increased with pore size for the ceramic membrane from 50–500 nm and decreased after 500 nm. The reason for the function of flux as pore size might be that 800 nm was so large that a few particles in the lake water entered into membrane pores, which resulted in the serious membrane fouling and the large filtration resistance. And the membrane fouling developed very fast and the flux dropped dramatically (Fig. 4). Therefore, the flux by the ceramic membrane with a pore size of 800 nm was the lowest, which had nothing to do with coagulation. The experimental data listed in Table 3 also showed that turbidity removal by the ceramic membrane with a pore size of 800 nm was the least because a few ultra-fine particles in the lake water could pass through the membrane into the permeates. The ceramic membrane with a pore size of 500 nm had the good turbidity removal of 97.2% and 99.5% by without coagulation and with online coagulation, respectively. The steady flux of microfiltration increased when coupled with online coagulation. When using the ceramic membrane with a pore size of 500 nm, the steady flux increased from $225–640 L \times m^{-2} \times h^{-1}$ (Fig. 5). The experimental results implied that the optimal pore size was 500 nm in the tested ceramic membranes for treating the lake water.

Table 3
The permeability of various ceramic membranes at 0.2 MPa, $1.0 m \times s^{-1}$, 20°C.

Microfiltration	Pore size (nm)	Turbidity (NTU)		Turbidity removal (%)	Flux ($L \times m^{-2} \times h^{-1}$)
		Feed lake	Permeate		
Without coagulation	50	11.1	0.230	97.9	155
	200	15.2	0.427	97.2	196
	500	23.4	0.663	97.2	225
	800	17.9	0.961	94.6	148
With online coagulation	50	16.7	0.078	99.5	316
	200	16.9	0.081	99.5	512
	500	30.1	0.147	99.5	640
	800	30.1	0.800	97.3	190

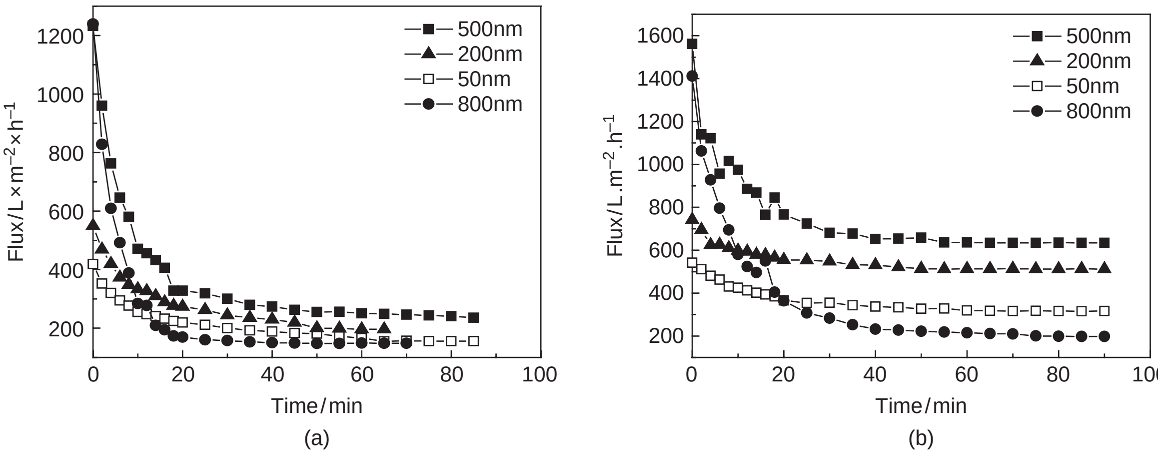

Fig. 4. Effect of pore size on the permeate flux at 0.2 MPa, 1.0 m × s^{-1}, 20°C with different treatment process: (a) without coagulation and (b) with online coagulation.

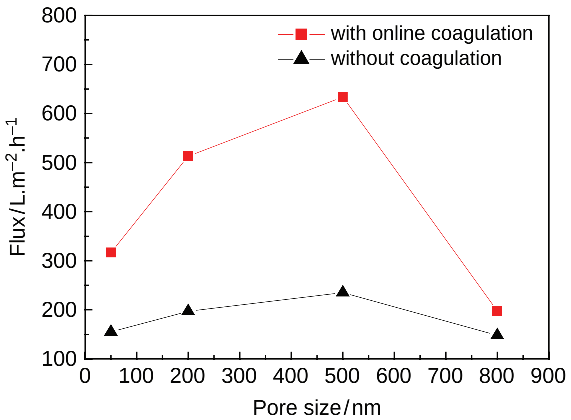

Fig. 5. The function of the steady permeate flux as pore size at 0.2 MPa, 1.0 m × s^{-1}, 20°C.

Table 4
Water quality analysis for the permeate.

Water quality		Feed lake water	Microfiltration	
			Without coagulation	With online coagulation
Turbidity (NTU)		23.4	0.663	0.147
UV254 (cm^{-1})		0.198	0.105	0.043
TOC (mg × L^{-1})		2.102	1.982	1.265
Metal ion (mg × L^{-1})	Ca	26.64	25.12	24.01
	Mg	7.49	7.30	6.59
	Fe	0.100	0.017	0.004
	Cu	0.017	0.009	0.005
	Cr	0.0020	0.0012	0.0003
	Pb	0.0018	0.0017	0.0005

Table 4 listed the water quality of lake water before and after microfiltration. The analyzed items on water quality were turbidity, UV_{254}, TOC and metal ions (Ca, Mg, Fe, Cu, Cr and Pb). Due to coupling with online coagulation, the microfiltration had the better impurities removal and the turbidity, UV_{254}, the content of TOC and metal ions were lower than that without coagulation. These values were all lower than that in the national standard and met the national drinking water requirements. The water quality by the coagulation–microfiltration for treating the Xuanwu Lake water was good enough for tap water.

4. Conclusion

The lake water treatment by the coagulation–microfiltration process was investigated. The coagulation experimental results showed that the dose of coagulant (Ferric chloride) increased with increasing turbidity of the feed lake water. As for the turbidity from 13 to 30 NTU, the suitable dose of the coagulant was 15–30 mg L^{-1} and the turbidity of the treated lake water was about 5 NTU. The suitable operating parameters for microfiltration of the treated lake water by coagulation were the crossflow velocity of 1 m × s^{-1} and transmembrane pressure of 0.2 MPa. The optimal pore size was 500 nm in the tested ceramic membranes for treating the lake water. The coagulation–microfiltration experiment result displayed that the permeate flux and turbidity removal with online coagulation were higher than that without coagulation. The steady flux of microfiltration increased from 225 to 640 L × m^{-2} × h^{-1} using the ceramic membrane with a pore size of 500 nm when coupled with online coagulation, and the turbidity removal increased from 97.2% to 99.5%. The water quality analysis showed that the coagulation–microfiltration produced high quality water. The coagulation–microfiltration using ceramic membranes was an optional method for tap water produce.

Acknowledgements

The authors thank the supports from National hi-tech research and development plan of China (No. 2007AA03Z437), National Natural Science Foundation of China (No. 20806039) and Program for Tackling Key Problems of Science and Technology of Jiangsu Province (No. BS2007119).

References

[1] J.G. Jacangelo, R. Rhodes Trussell, M. Watson, Role of membrane technology in drinking water treatment in the United States, Desalination, 113 (1997) 119–127.
[2] S. Bouguecha, M. Dhahbi, The role of membrane technologies in supplying drinking and industrial water in Tunisia: Conventional process and new trends, Desalination, 151 (2003)75–86.
[3] A.W. Zularisam, A.F. Ismail, R. Salim, Behaviours of natural organic matter in membrane filtration for surface water treatment—a review, Desalination, 194 (2006) 211–231.
[4] A. Bottino, C. Capannelli, A. Del Borghi, M. Colombino, O. Conio, Water treatment for drinking purpose: Ceramic microfiltration application, Desalination, 141 (2001) 75–79.
[5] A. Lerch, S. Panglisch, P. Buchta, Direct river water treatment using coagulation ceramic membrane microfiltration, Desalination, 175 (2005) 41–50.
[6] K. Konieczny, M. Bodzek, M. Rajca, A coagulation-MF system for water treatment using ceramic membranes, Desalination, 198 (2006) 92–101.
[7] A. Loi-Brügger, S. Panglisch, P. Buchta, K. Hattori, H. Yonekawa, Y. Tomita, R. Gimbel, Ceramic membranes for direct river water treatment applying coagulation and microfiltration, Wat. Sci. Technol.: Wat. Supply, 6 (2006) 196–205.
[8] K. Khatib, J. Rose, O. Barres, W. Stone, J.Y. Bottero, C. Anselme, Physico-chemical study of fouling mechanisms of ultrafiltration membrane on Biwa lake (Japan), J. Membr. Sci., 130 (1997) 53–62.
[9] L. Coccagna, B. Amaroli, O. Conio, M. Colombino, A. Carbone, E. Borelli, G. Ziglio, Microfiltration pilot plant performance investigations into lake water treatment, J. Wat. Supply: Res. Technol., 50(2001)377–386.
[10] A.T. Pikkarainen, S.J. Judd, J. Jokela, L. Gillberg, Pre-coagulation for microfiltration of an upland surface water, Wat. Res., 38 (2003) 455–465.