ELSEVIER

Desalination 204 (2007) 351–358

DESALINATION

www.elsevier.com/locate/desal

Ultrafiltration of surface water with coagulation pretreatment by streaming current control

Shengji Xia[a]*, Xing Li[b], Qiaoli Zhang[a], Bin Xu[a], Guibai Li[c]

[a]*State Key Laboratory of Pollution Control and Resources Reuse, Tongji University, Shanghai, 20092 China*
Tel. +86 (21) 27080062; Fax +86 (21) 6598631; email: shengjixia@yahoo.com.cn
[b]*School of Architecture and Civil Engineering, Beijing University of Technology, China*
[c]*School of Municipal and Environmental Engineering, Harbin Institute of Technology, China*

Received 30 November 2005; accepted 15 March 2006

Abstract

Due to unfit soil and water conservancy in some regions of China, conventional water treatment has showed some defects for the poor quality of water resource. Ultrafiltration (UF) by hollow-fiber membranes is in increasing development in the fields of drinking water purification. Coagulation/UF process can be used to treat poor quality surface water: the permeate quality is increased and membrane fouling is reduced. In this research, a streaming current detector (SCD) method was introduced to asses how coagulation affects membrane performance. Results showed that membrane performance was improved with the coagulant added to get the positive streaming current (SC) value, since with the positive SC coagulation removed more organic matters. In the coagulation/UF process, coagulation unit does not need to be controlled to get complete charge neutralization, the point of zero charge, because the ultrafiltration membrane has an excellent ability to remove particles and colloids.

Keywords: Surface water; Drinking water; Ultrafiltration; Coagulation; Streaming current

1. Introduction

Very high contamination of surface waters and increasingly stringent regulations related to treated water quality require new methods that allow the efficient removal of pollutants from water streams. Application of the membrane technology to drinking water treatment offers many advantages such as strict solid–liquid separation, ease of operation

*Corresponding author.

Presented at EuroMed 2006 conference on Desalination Strategies in South Mediterranean Countries: Cooperation between Mediterranean Countries of Europe and the Southern Rim of the Mediterranean. Sponsored by the European Desalination Society and the University of Montpellier II, Montpellier, France, 21–25 May 2006.

and small footprint [1,2]. Ultrafiltration (UF) systems are becoming an attractive alternative for groundwater and surface water clarification, particularly concerning the removal of particles, colloidal species and microorganisms. Specific hollow-fiber membranes and modules have been designed for this application, a crossflow filtration process has been proposed, and many plants are now in operation.

However, in most of the applications of membrane filtration, the natural organic matter (NOM) found in the liquid leads to membrane fouling, flux reduction and inferior effluent quality [3]. To overcome such problems caused by NOM in UF applications, conjunctive use of coagulation and membranes is thus becoming more attractive for water treatment because the coagulation is an opportunity to join NOM with other particles present in water before NOM reaches the membrane surface [4]. As a result, the addition of a coagulant as a pretreatment prior to membrane filtration has been proposed for the purpose of not only improving the removal of DOMs but reducing membrane fouling. The application of the coagulants for the raw water pretreatment may bring about the improvement of permeates quality. It is very important, especially in the case of drinking water production. Control of coagulant addition is often developed empirically using jar testing and is only achievable by monitoring the raw water quality and performing proportional adjustments of chemical dosages [5]. Automated coagulant control using the streaming current detector (SCD) has been extensively researched. Since natural organics are nearly always anionic over the usual range of natural water pH, they interact strongly with cationic additives, especially hydrolyzing metal coagulants and cationic polyelectrolyte. The charge has to be neutralized in order to give effective precipitation coagulation of the organics. This forms the basis of the SCD method of determining optimum coagulant dosages [6]. When coagulation conditions are not optimal, smaller colloidal and soluble iron species may be present which are free to affect and clog the membrane. In other cases colloidal iron may be found in the feed water source itself.

This paper present a 120 m^3/d pilot drinking water treatment using coagulation/UF process with a SCD to controlling the coagulant dosing. Results have shown the relationship between the SC value and the membrane permeate turbidity, organic matter removal and membrane flux.

2. Experiment

2.1. Raw water characteristics and membrane characteristics

The Songhuajiang River water was used as raw water and the qualities of the raw water were turbidity 6.3–570 NTU, COD_{Mn} 2.4–8.2 mg/L, pH 6.4–7.9 respectively. The membranes used in this study were UF membranes. They were made of polyvinyl chloride (PVC) with nominal cut-off values of 80,000 Dalton. The flow of the feed water was from inside of the fiber to the outside of the fiber. The capillaries could operate over a pH-range of 4–9 and had internal and external diameter of 0.9 mm and 1.5 mm, respectively. The membrane area was 48 m^2.

2.2. The process

Fig. 1 shows the schematic diagram of the UF facility used for the treatment of the Songhuajiang River water. Two pumps are used for feed and backwash, respectively. The river water was pumped into the raw water tank for UF. Cross flow filtration inside the hollow-fiber module divided the feed into permeate and retentate which were recycled to the raw water tank. Backwashing was performed by pumping the permeated water from the storage tank to the shell side of the hollow-fiber membranes in the module. After washing the fouling from the membrane, the water was discharged from the recirculation loop. Alum was used as coagulant and the SC was detected after

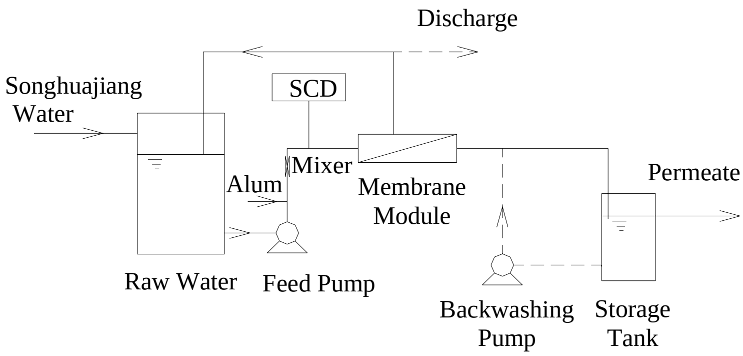

Fig. 1. Schematic flow diagram of the experiment.

coagulants were mixed. Fig. 2 shows the photo of this 120 m^3/d pilot plant.

2.3. Streaming current detector

Extremely small particulates suspended in a solution will often have a surface charge. Flocculants, containing particles with the opposite charge, can be added to neutralize this charge. When the overall surface charge is balanced, the suspended particles will then bind with the flocculants and settle out. A measurement of the charge on particles in solution can be made by measuring the current produced when the particles are rapidly moved.

A SCD (Danyingzhi, Beijing) was used to quantify the amount of coagulant dose required for colloidal charge reversal due to addition of metal coagulants (i.e., positively charged coagulants).The SCD uses a piston reciprocating in a closed chamber to create a high rate of flow along the chamber wall. The sample is introduced into and ejected from the cylinder through holes in the cylinder walls, by the pumping action of the piston. The current between the electrodes at the upper and lower ends of the cylinder is monitored and this is related to the electrokinetic charge of colloidal materials in the sample. This moving charge is a current (called the streaming current) and it can be measured between the two electrodes at opposite ends of the chamber. This signal is amplified and processed to give a reading that is a direct indication of the flocculant dosage required to exactly neutralize the surface charge on particles in the solution (Fig. 3).The charge analyzer has a reciprocating piston in a cylinder (both

Fig. 2. Photo of the 120 m^3/d pilot plant.

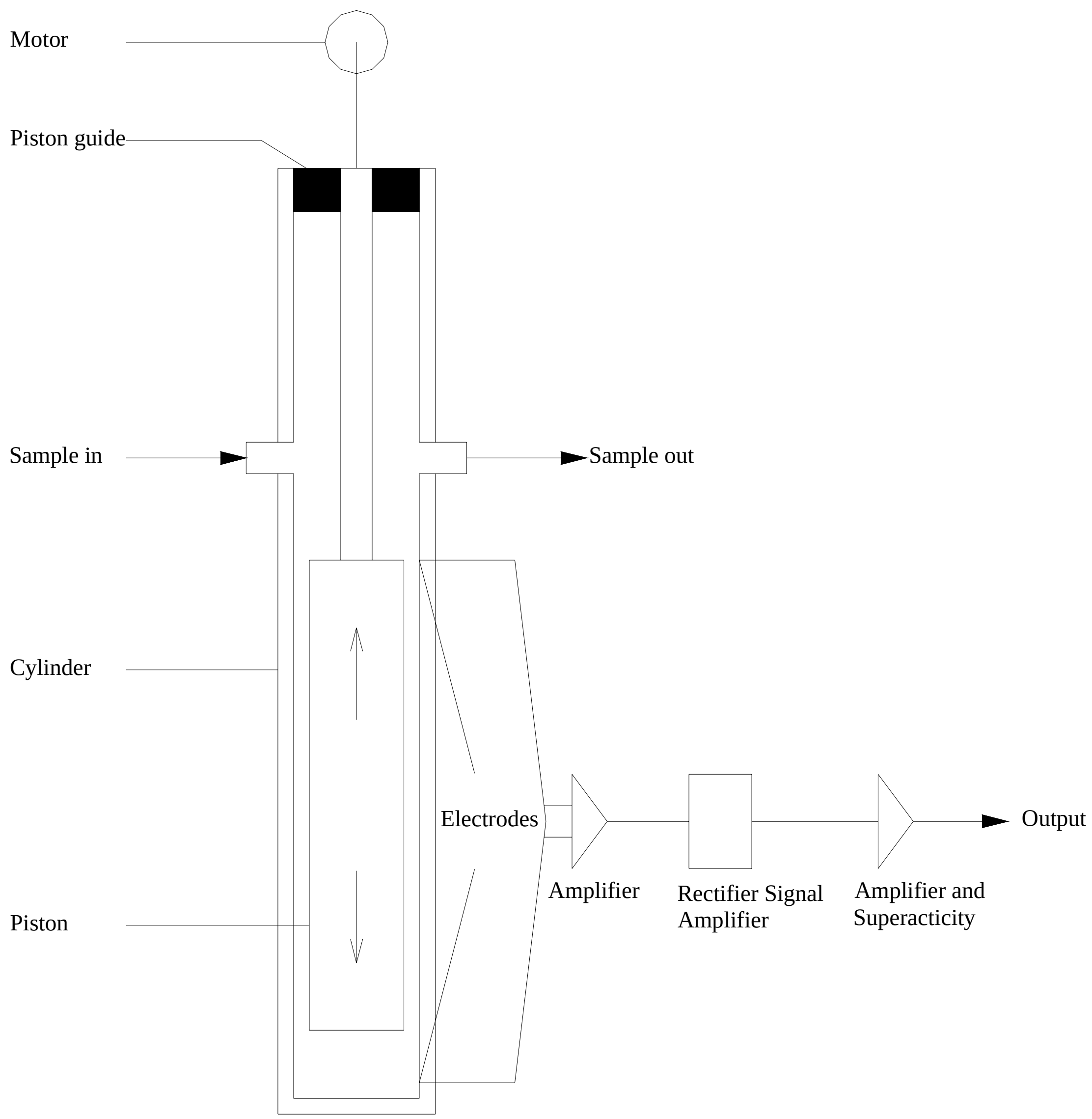

Fig. 3. Components of the streaming current detector.

of Teflon). When the streaming current is around zero, it can usually be assumed that the colloidal charge has been neutralized.

3. Results and discussion

3.1. Effect of coagulation on turbidity removal

The coagulation process has traditionally been used to remove turbidity from drinking water supplies. Fig. 4 shows the relationship between the SC value and the dosage of alum coagulant. With increasing of the coagulant dosage, the SC value changes from negative to positive and then increases monotonically. As can been seen, 6 mg/L alum gives complete charge neutralization, the point of zero charge (PZC). Turbidity results for the jar tests (settled turbidity), presented in Fig. 4, show a good correlation with the streaming current readings. Optimum turbidity removals corresponded nearly with zero SCD values. At the optimum dosage of coagulant, the particle charge is just neutralized and the collision efficiency reaches a maximum value. The dosage of optimum turbidity removals, which was higher than that of zero SCD values, may be due to the fact that a little more coagulant performs as the "sweep floc". Charge reversal as indicated by the SCD corresponded to increased final turbidities.

The turbidity of the membrane permeate is also shown in Fig. 4. In contrast, the ultrafiltered turbidity was almost the same and the coagulation had no effect on the permeate turbidity. The average total feed turbidity of 58 NTU was consistently reduced to below 0.2 NTU and 87.5% of the time, the product water turbidity was below 0.15 NTU. Ultrafiltration is a treatment process that primarily relies on a physical sieving barrier to remove particulate. Particulate materials larger than the pore size of the membrane are removed. Consequently, in the hybrid process of coagulation and ultrafiltration, the excessive addition of coagulant is not serious because ultrafiltration performs as the last effective barrier for particle and colloid removal. The control of coagulant addition with the SCD method may be not subject to PZC in the coagulation/UF process.

3.2. Effect of coagulation on DOC removal

The pretreatment by coagulation led to higher DOC removal. Fig. 5 presents the raw water DOC concentration and DOC concentration after ultrafiltration for different coagulant dosages. For all the applied coagulant doses a significant increase in organic matter removal was observed. A combination of UF with coagulation at 8 mg/L alum increased the DOC removal from 8.5% (UF only)

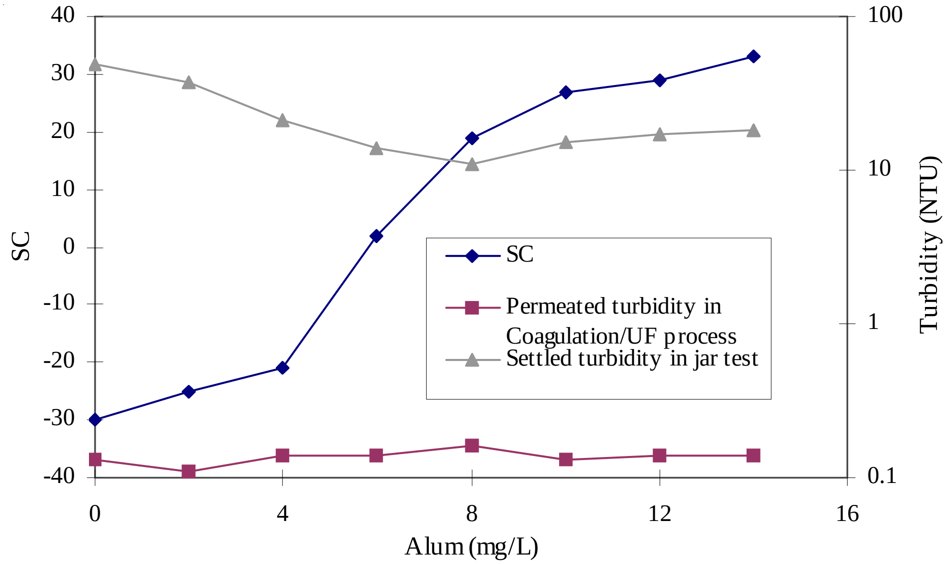

Fig. 4. Comparison of SC values and turbidity as a function of the alum dosage.

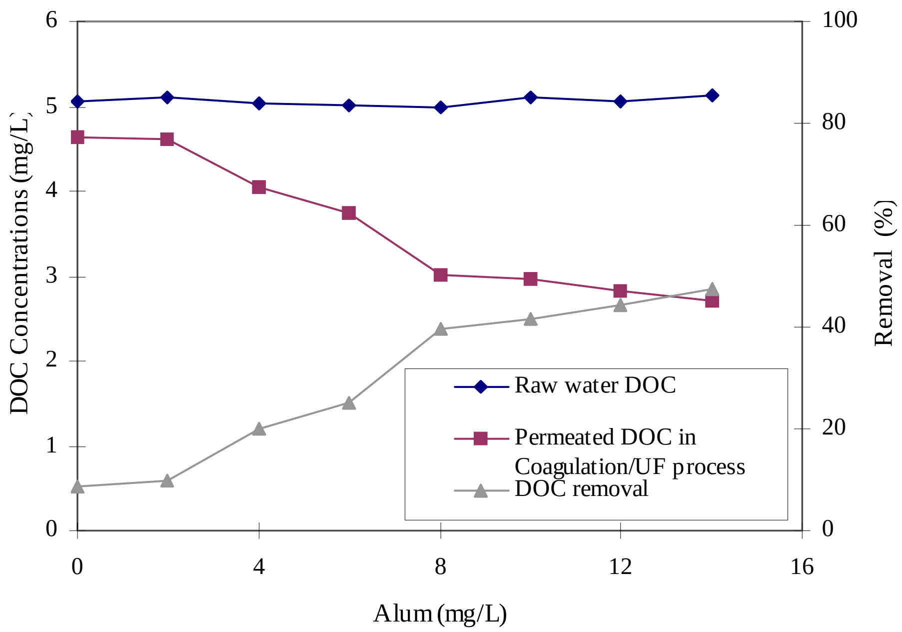

Fig. 5. Effect of coagulation on DOC removal in the coagulation/UF process.

to 39.5%. The rise of the alum dose up to 14 mg/L resulted in an increase of DOC elimination to the level of 44.5%. As can be inferred from Fig. 5, the removal of organic substances from the water during coagulation/UF with alum was strongly affected by the coagulant dose. These results are similar as those reported by Park et al. [7]. Comparing Fig. 4 and Fig. 5, it can be seen that only 25.1% of the DOC was removed when effective turbidity was achieved, the SCD value got to nearly zero. To remove more organic matter, an automatic chemical dosing system should be based on that the SCD value gets to a positive value.

3.3. Effect of coagulation on UV removal

The UV absorbance at 254 nm was also measured in this study as an indication of the removal of organics from the water. Although the dissolved organic carbon in the water was less than 6 mg/L, a 10–65% reduction in UV absorbance was observed (Fig. 6). UV254 removal was higher than DOC removal. UV absorbance is a popular method used as an index of the aromatic level. It is thought that humic acids were removed easily in comparison with the non humic portion for the same concentration of DOC. Analyzing the influence of the alum dosage on organic matter separation in the coagulation/UF process, it might be stated that higher doses of coagulant result in a higher process efficiency. It should be noted that UF did not remove organics due to its too large cut-off.

3.4. Effect of coagulation on membrane flux decline

The effect of coagulation condition on UF behavior for the PVC membrane is shown in Fig. 7 where the measured flux is plotted against time with coagulated water. A series dose of coagulant was added in the coagulation/UF process, with doses ranging from ineffective coagulation to enhanced coagulation. We can see from Fig. 7 that the rates of permeate flux decline were different according to the coagulant dose added. With the

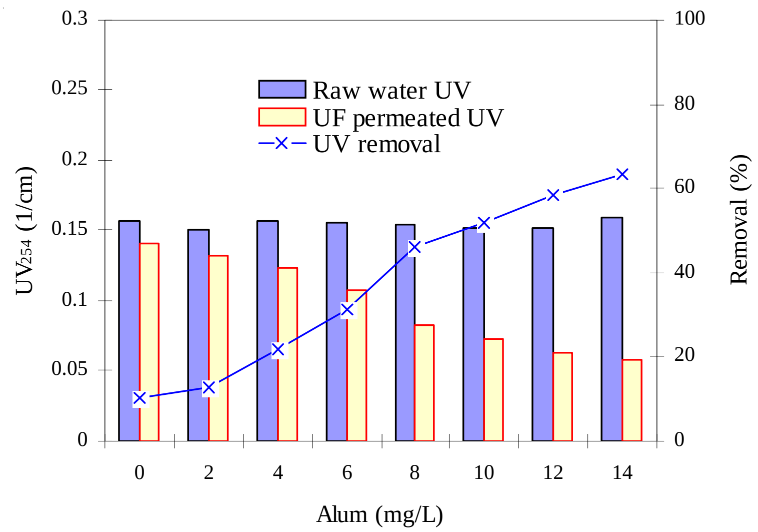

Fig. 6. Effect of coagulation on UV254 removal in the coagulation/UF process.

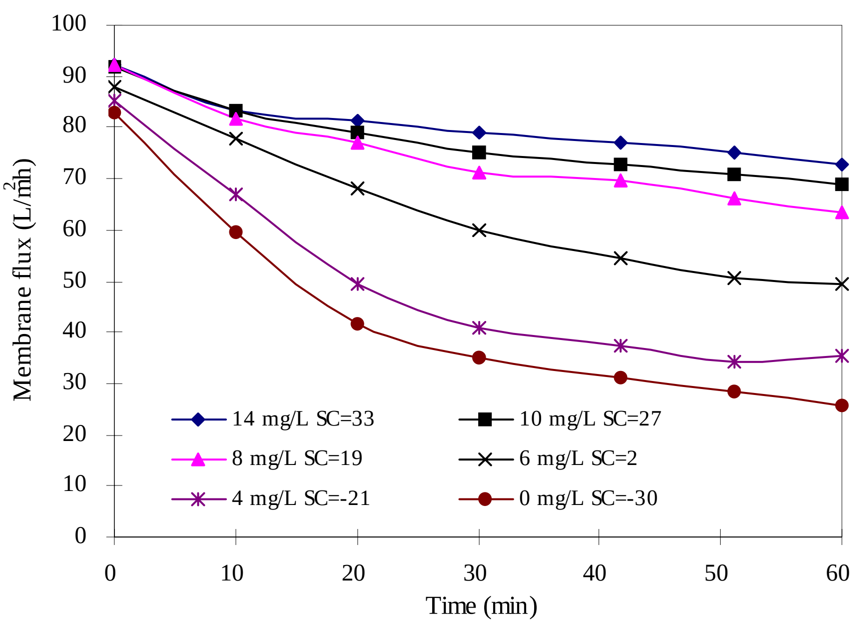

Fig. 7. Effect of coagulation on membrane flux decline.

coagulant of 8 mg/l, the membrane flux decreased to about 69% of the initial flux after 60 min, in contrast to 0 mg/l, the membrane flux decreased to 31% of the initial flux for the same time. Higher doses reduced the extent of flux decline with the same time compared to ineffective coagulation.

The dose for enhanced coagulation resulted in the flux decline to 79% of the initial permeability. On comparing Fig. 4 and Fig .7, it seems that the membrane flux declines slowly with coagulant added to get a positive value in the coagulation/ UF process. This may be due to the fact that coagulation helps to remove the organic matter which reduces the membrane fouling.

4. Conclusion

It has been observed that the application of coagulation as a pretreatment of ultrafiltration contributes to improvement of treated water quality and enhancement of the membrane performance. Organic matter removal was increased from 8.5% DOC removal to 47.5% DOC removal with the coagulant added from 0 mg/L to 14 mg/L. UV absorbance removal was even higher. However, the membrane permeated water turbidity was not affected by the coagulation unit, because the membrane performance physical sieving barrier removed the particulate. So in the coagulation/UF process the control of coagulant addition may be not restricted with settled turbidity, which may be often conducted in the conventional water treatment: coagulation, sedimentation, sand filtration and chlorination.

The SCD method was introduced to indicate the extent of coagulation. The study shows that membrane performance was improved with the coagulant added to get the positive SC value, since the positive SC removed more organic matters.

References

[1] K. Kimura, Y. Hane, Y. Watanabe, G. Amy and N. Ohkuma, Irreversible membrane fouling during ultrafiltration of surface water, Water Res., 38 (2004) 3431–3441.

[2] S. Xia, J. Nan, R. Liu and G. Li, Study of drinking water treatment by ultrafiltration of surface water and its application to China. Desalination, 170 (2004) 41–47.

[3] S. Vigneswaran, H.K. Shon, S. Boonthanon, H.H. Ngo and R. Ben Aim, Membrane flocculation adsorption hybrid system in wastewater treatment: micro and nano size organic matter removal, Water Sci. Technol., 50(12) (2004) 265–271.

[4] D. Sakol and K. Konieczny, Application of coagulation and conventional filtration in raw water pretreatment before microfiltration membranes, Desalination, 162 (2004) 61–73.

[5] J.C. Vickers, M.A. Thompson and U.G. Keikar, The use of membrane filtration in conjunction with coagulation processes for improved NOM removal, Desalination, 102 (1995) 57–61.

[6] S. Kyukam and J. Gregory, The interaction of humic substances with cationic polyelectrolyte, Water Res., 35 (2001) 3557–3566.

[7] P.-k. Park, C.-h. Lee, S.-J. Choi, K.-H. Choo, S.-H. Kim and C.-H. Yoon, Effect of the removal of DOMs on the performance of a coagulation-UF membrane system for drinking water production, Desalination, 145 (2002) 237–245.