Drinking water production by ultrafiltration of Songhuajiang River with PAC adsorption

XIA Sheng-j1, LIU Ya-nan2, LI Xing3, YAO Juan-juan1

1. State Key Laboratory of Pollution Control and Resources Reuse, Tongji University, Shanghai 200092, China. E-mail: xiashengji@yahoo.com
2. School of Environmental Science and Engineering, Dong Hua University, Shanghai 201620, China
3. School of Architecture and Civil Engineering, Beijing University of Technology, Beijing 100083, China

Received 29 May 2006; revised 8 September 2006; accepted 18 September 2006

Abstract

In recent years, membrane ultrafiltration (UF) of surface water for drinking water treatment has become a more attractive technology worldwide as a possible alternative treatment to conventional clarification. To evaluate the performance of ultrafiltration membranes for treatment of surface water in North China, a 48-m² low pressure hollow fiber membrane ultrafiltration pilot plant was constructed. Ultrafiltration was operated in cross-flow and with powdered activated carbon (PAC) adsorption. Turbidity was almost completely removed to less than 0.2 NTU (below Chinese standard 1 NTU). It was found that PAC addition enhanced organic matter removal. The combined process of PAC/UF allowed to 41% removal of CODMn, 46% removal of DOC and 57% decrease in UV254 absorbance. The elimination of particles, from average 12000/μl in the raw water to approximately 15/μl in the permeated, was observed. When PAC concentration was below 30 mg/L, backwashing could recover the membrane flux with backwash interval/backwashing duration of 1/30.

Key words: surface water; drinking water treatment; ultrafiltration; powdered activated carbon

Introduction

As the economic conditions improve and the living standard rises every year in China, people are more and more concerned about food and drinking water quality. However, the tap water quality is not as satisfactory as other aspects because of the poor quality of raw water due to unfit soil and water conservancy; therefore, advanced water treatment should be constructed to replace the conventional clarification. In recent years, ultrafiltration process applied to water treatment has become a more attractive technology worldwide to produce potable water. Compared to the conventional treatment, ultrafiltration process seems to have many advantages such as smaller space requirements, invariable quality of produced water, savings of water purification chemicals and operation cost and easy automation (Wiesner and Chellam, 1992; Lahoussine-Turcaud et al., 1990). However, an important obstacle to further incorporation of membrane process into water treatment plants is the problem of membrane fouling, especially in case of using surface water. Control of fouling is of utmost importance. A technique for fouling alleviation is pretreatment of feed water with powdered activated carbon (PAC) adsorption.

In South Africa, aiming at the rural and pre-urban communities, alternative process for water purification to conventional water treatment was investigated. Botes et al. (1998) has taken evaluation of a ultrafiltration (UF) pilot plant for potable water production. The results of a 15-m² UF membrane have shown the removals, >95% turbidity, 92%–97% apparent color, 97%–99% iron, and 60%–80% natural organic matters. All fecal and other coliform bacteria were also removed. A 15%–20% average specific flux loss was observed, and the membrane life was estimated to be more than 5 years.

For the design and construction of a membrane water potabilization facility, Arual et al. (2002) carried out some tests with a UF plant to analyze the UF performance. The plant has an ultrafiltration module equipped with a polysulfone spiral wound membrane with a cut-off of 100 kDa. According to the results, it can be said that membrane performance is very satisfactory; especially bearing in mind that the water used in those tests has very unfavorable characteristics. The rejection of test UF membrane to the microbiogical component of water was gotten to 100%.

Tomaszewksa and Mozia (2002) found that the application of PAC/UF system is very effective in the removal of organic substances with both low and high molecular weights. Humic acids were removed in about 90% and phenol was removed completely for the same PAC dosage equal to 100 mg PACl (powdered activated Cl). In the UF
process conducted without PAC addition only 40% of HA were rejected, while the total amount of phenol passed through a membrane.

In this paper we report the results of UF experiments with modified polyvinyl chloride (PVC) membranes. Our earlier study (Xia et al., 2004a, 2004b), a capacity of 100 L/h, has shown ultrafiltration was very efficient to produce drinking water with a raw water in North China. In this research, a capacity of 5 m³/h ultrafiltration process was constructed. This paper presents results concerning the pilot plant investigation.

1 Materials and methods

1.1 Membranes and PAC

Ultrafiltration membranes (from Lisheng Co. Ltd.) made of PVC were used in the experiments. The nominal molecular weight cut off of these membranes as reported by the manufacture is 80000 Dalton. Characteristics of the membranes are shown in Table 1. The powdered activated carbon was obtained from Ninde Xinsen Co. Ltd. Its characteristics are given in Table 2.

1.2 Ultrafiltration test apparatus and procedure

Fig. 1 shows a schematic diagram of the UF experimental facility. The system consists of three parts: a reactor unit, a cross-flow UF unit with a recirculation and permeate backwashing. PAC was added as pretreatment for membrane filtration. Sufficient and rapid mixing is provided by a static mixer. The reactor tank was 1 m³ and the reacting time was 10 min. Water was prefiltrated to 200 µm, and then injected in the circulation loop by the feed pump. In the ultrafiltration phase, the water was filtrated from inside to outside of the hollow fiber with a constant transmembrane pressure 0.12 MPa. In the backwash phase, the washing water was sent to pressurize from the outside about 0.2 MPa to the inside of the hollow fiber. Pressure gauges and electromagnetic flow meters were used to control the operating performances. The raw water used was Songhuajiang River water nearby Harbin in North China. A and B were the points of water sampling which indicated the raw water and ultrafiltrated water.

1.3 Analytical methods

All water samples were analyzed for chemical oxygen demand (CODₘₐₙ), UV absorbance at 254 nm and dissolved organic carbon (DOC) concentration. CODₘₙ was determined according the method described in USEPA (1983). DOC was analyzed on filtered samples (0.45 µm) in a TOC analyzer (Shimadzu TOC-Vcpan). UV absorbance was measured in an UV/Vis spectrophotometer (Lengguang 752N), also on filtered samples (0.45 µm). Quartz cuvette with a path length of 1 cm was used. The turbidity was measured with the help of the HACH turbid meter, model 2100AN. Particle counting was done with a PCX 2200 (HACH). The particle counter has 8 channels from 2 µm to 750 µm.

2 Results and discussion

2.1 Effect of PAC added on permeate flux

Variations of the permeate flux for different carbon dosages are presented in Fig.2. The ultrafiltration flux decreased from approximately 90–65 L/(m²·h) after 60 min. There is no difference between them with different PAC concentration. These results were consistent with the results by Tomaszewska and Mozia (2002). It can be explained by a relatively loose structure and high porosity of PAC cake deposited on the membrane. The thickness of the PAC cake was probably independent on the PAC dosage applied because the outer layer of the cake was

![Fig. 1 Schematic flow diagram of the experiment.](image-url)
continuously removed by flowing retentive. According to Sylwia and Tomaszewska (2004), the porosity of the PAC cake formed on the membrane surface was much greater than the maximum pore size of the membrane, which was the reason that the PAC cake structure should not affect the process performance.

2.2 Turbidity reduction during experimental time

In this study, turbidity was used to monitor the membrane separation efficiency. Turbidity is a qualitative measurement of the amount of dissolved solids in a process stream and is measured in nephelometric turbidity units (NTU). Fig. 3 shows a sharp reduction in the turbidity: more than 99% of turbidity is eliminated. The permeate turbidity is usually around 0.15 NTU and below 0.5 NTU under all experimental conditions studied.

2.3 UF and PAC/UF on organics removal

An improvement of UF permeated quality in the combination of powdered activated carbon with UF process has been observed in several studies (Lin et al., 2000; Hagen, 1998; Krystyna and Grzegorz, 2002). The membrane provides a physical barrier preventing the passage of the PAC, and therefore retaining the organic commands absorbed on the PAC, which otherwise would be trapped by the membrane. In Fig. 4 the effectiveness of the removal of COD$_{Mn}$, DOC and UV$_{254}$ absorbance ($A_{UV_{254}}$) during UF and PAC/UF progress were presented. The PAC dosage was equal to 30 mg/L with raw water of COD$_{Mn}$ 4.20 mg/L, DOC 9.31 mg/L and UV$_{254}$ 0.154 cm$^{-1}$. It was found that PAC addition enhanced organics removal. When the UF process was conducted without PAC addition, 30% of COD$_{Mn}$, 35% of DOC and 43% of UV$_{254}$ absorbance were removed. The combined process of PAC/UF allowed to 41% removal of COD$_{Mn}$, 46% removal of DOC and 57% decrease in $A_{UV_{254}}$. Comparing COD$_{Mn}$, DOC to UV$_{254}$ rejection, a higher rejection of UV absorbing compounds was observed, this indicated a preferential removal of larger and more aromatic compounds. UV$_{254}$ measures mostly molecules with conjugated double bonds like aromatics. DOC measures all total dissolved organic carbon, therefore, more small molecules are not probably retained. COD$_{Mn}$ again measures even inorganic material, which can be oxidized, and therefore retention according to COD$_{Mn}$ is low with UF membranes.

2.4 Removal of particles by ultrafiltration

In addition to the measurement of turbidity and organic matters, particle retention per ml was determined in the test. The raw water was pumped in from the Songhuajiang River. Typical particle distribution by number percentage is shown in Fig. 5. The specific distribution (Fig. 5) was based on average 60 measurements during one run. As was expected, fine particles larger than 2 $\mu$m were significantly removed by membrane filtration. Particles between 2–3 $\mu$m occupied approximately 53% in the raw water, and were 56.3% in the permeated. The percentage of particles between 3–6 $\mu$m in the permeated were less than those in the raw water imply that those particles had a tendency to be removed. Particles larger than 7 $\mu$m were almost completely removed through qualitative analysis. As can be seen, around 99.8% of the counted number of particles was found in the range of 2–8 $\mu$m in the raw water. An example of the particle number (particle size >2 $\mu$m) in raw water, and ultrafiltrated water with two operations run

---

**Fig. 2** Permeate flux decline with different PAC.

**Fig. 3** Turbidity reduction during experimental time.

**Fig. 4** Organic matter removal with UF and PAC/UF.

**Fig. 5** Particle distribution of raw water and permeate water.
Production of drinking water by ultrafiltration of Songhuajiang River with PAC adsorption

3 Effect of backwashing on the flux recovery (L/(m²·h))

<table>
<thead>
<tr>
<th>Backwash interval</th>
<th>PAC 10 mg/L Before washing</th>
<th>After washing</th>
<th>PAC 30 mg/L Before washing</th>
<th>After washing</th>
<th>PAC 50 mg/L Before washing</th>
<th>After washing</th>
</tr>
</thead>
<tbody>
<tr>
<td>20 min</td>
<td>73.4</td>
<td>90</td>
<td>74.1</td>
<td>92</td>
<td>79.4</td>
<td>91</td>
</tr>
<tr>
<td>40 min</td>
<td>69.0</td>
<td>92</td>
<td>68.3</td>
<td>89.5</td>
<td>73.1</td>
<td>87</td>
</tr>
<tr>
<td>60 min</td>
<td>67.1</td>
<td>89</td>
<td>66.2</td>
<td>88.7</td>
<td>65</td>
<td>81</td>
</tr>
</tbody>
</table>

Results showed that turbidity was almost completely removed to about 0.15 NTU independent of raw water quality. It was found that PAC addition enhanced organic matter removal. The combined process of PAC/UF reached to 41% removal of COD$_{Mn}$, 46% removal of DOC and 57% decrease in UV$_{254}$ absorbance. Comparing COD$_{Mn}$, DOC to UV$_{254}$ rejection, a higher rejection of UV absorbing compounds was observed. The particles between 3 and 6 µm seemed to have a tendency to be efficiently removed.

In China, for surface water of high turbidity and fairly variable quality, PAC adsorption prior to UF should be considered.

References


