# Pilot Study on Drinking Water Advanced Treatment by GAC-MF System

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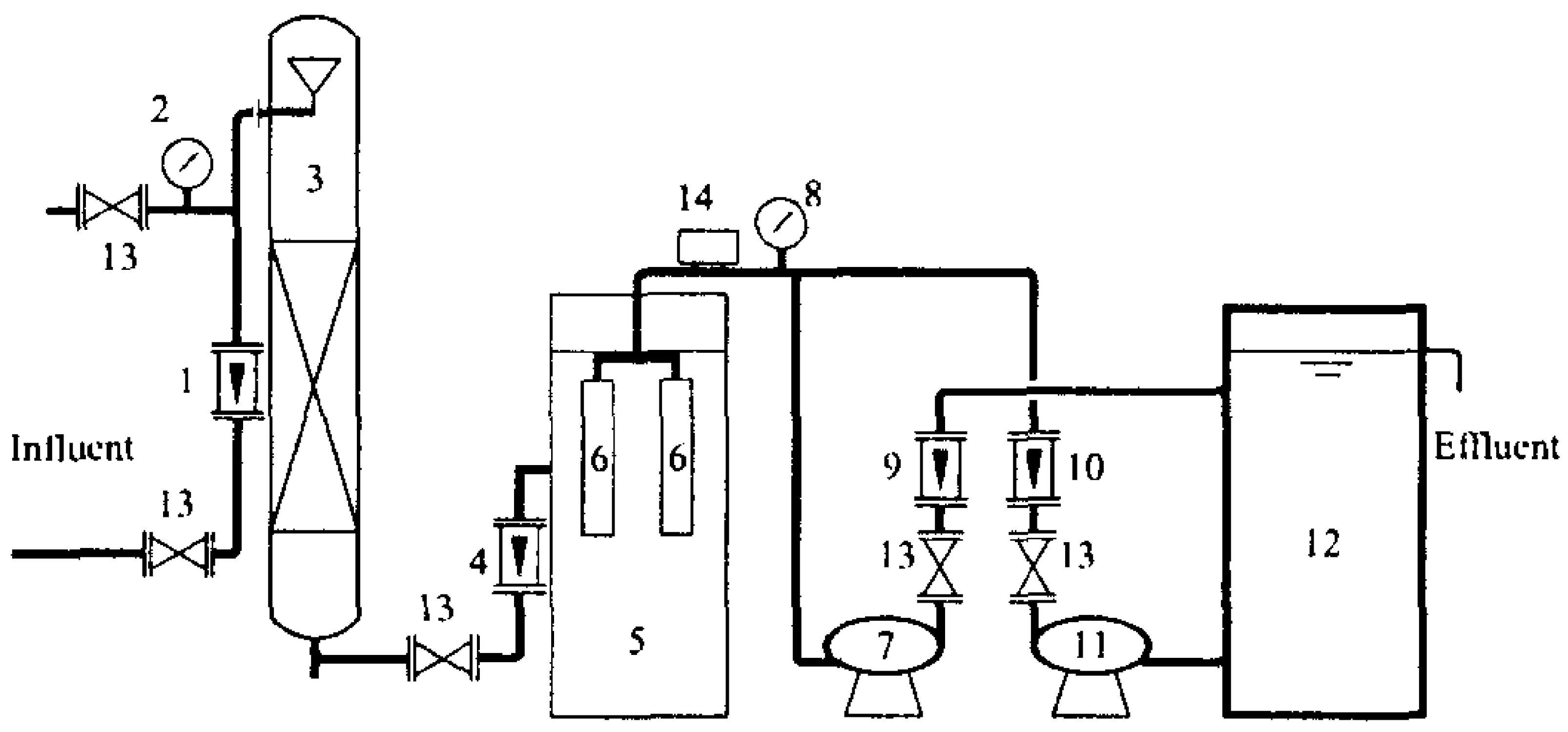
**The pilot performance of the combined GAC-MF membrane process for drinking water advanced treatment was described. In the process of GAC adsorption, under the conditions of 20 min HRT and 6 m/h filtration rate, the removal efficiencies of $UV_{254}$ and trichloromethane could reach 40% and 50% respectively and the $UV_{254}$ and trichloromethane in system effluent was less than 0.015 $cm^{-1}$ and 5 $\mu g/L$ respectively. In the post MF membrane process, MF membrane effectively retained the particles and bacteria in raw water. The effluent turbidity was less than 0.2 NTU and no bacteria were detected at all in permeate. A computer-controlled system was employed to control this system. The membrane operating parameters of backwash interval, duration and flux were studied. The backwash interval of 10-min, 20-min and 60-min was researched respectively, and the variation of trans-membrane pressure was also analyzed. Consequently short backwash interval was recommended under the same water consume.**

***Keywords:*** *granular activated carbon adsorption, MF membrane, drinking water advanced treatment*

## Introduction

With the economic development and the improvement of people's living standard level in China, the advanced drinking water treatment (ADWT) technology was getting more attention in recent years. ADWT technology in China had its own characteristics compared with that of other countries. Besides the Ministry of Construction of China promulgated Water Quality Standard for High Quality Drinking Water (CJ 94 - 1999) in 1999, which was much more stringent than the former drinking water hygienic standard (GB 5749 - 85). Many new residential areas have built dual water supply systems since it was hard to meet such strict standard. One water supply system provided municipal water for common use; the other provided high quality drinking water, which had been further treated by ADWT technology to be used as potable water. The removal of organic matter and pathogenic microorganisms was the main objective of ADWT. In Water Quality Standard for High Quality Drinking Water, $KMnO_4$ index is less than 2 mg/L, and total coliform is 0 cfu/100 mL. Granular activated carbon (GAC) adsorption and membrane filtration were thought to be most effective technology[1], which had been employed by many ADWT systems to meet these demands. From September 1999 to February 2000, on the basis of small scale tests[2, 3], a pilot study of the combined system of GAC adsorption and MF membrane filtration was conducted in the water treatment plant of Beijing Yanshan petrol-chemical Complex. The main purpose of the study was to provide information to the performance of the GAC-MF system on pilot scale.




1. Influent flow meter (400 - 4 000 L/h); 2. Pressure gauge (0 - 600 kPa); 3. GAC filtration column; 4. membrane influent flow meter; 5. Submerged membrane filtration tank; 6. Membrane module; 7. Suction pump; 8. Pressure gauge (100 - 150 kPa); 9. Membrane permeate flow meter (160 - 1 600 L/h); 10. Membrane backwash flow meter (400 - 4 000 L/h); 11. Membrane backwash pump; 12. Permeate tank; 13. Electromagnetic valve; 14. Electromagnetic flow meter

Fig. 1 Pilot scale experimental installation

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## Materials and Methods

### 1 Pilot GAC-MF system description

The pilot scale GAC-MF system is showed in Fig. 1. The raw water was from the municipal water supply system and treated by GAC adsorption unit and MF membrane filtration unit in series. The final treatment water was reserved in permeate tank. The characteristics of GAC and membrane are showed in Table 1 and Table 2 respectively. The hydraulic retention time (HRT) of GAC adsorption bed was 20 min, and filtration velocity was 6 m/h. Membrane filtration was driven by the suction pump 7. When conducting backwash, both the suction pump 7 and valve 13 in connection were closed and both the backwash pump 11 and valve 13 in connection were opened to operate after that.

**Table 1** Characteristics of GAC - ICT 14×40

| Item | Characteristic |
|---|---|
| Real density | ≈$2.2\times10^3$ kg/m$^3$ |
| Apparent density | ≈$0.65\times10^3$ kg/m$^3$ |
| Iodine value | >900 mg/g |
| Size | 14 - 40 mesh |

**Table 2** Characteristics of hollow fiber MF membrane

| Item | Characteristic |
|---|---|
| Material | Polysulphone |
| Total outer membrane area (m$^2$) | 4.5 |
| Thickness (mm) | 0.3 |
| Average pore diameter (μm) | 1 |
| Number of fiber | ≈3 200 |
| Length of fiber (m) | ≈0.5 |

### 2 Computer-controlled system

In this experiment, a computer-controlled system was employed to control the whole system's operation, which is showed in Fig. 2.

### 3 Analytical methods

The main contaminants present in raw water (influent) from conventional treatment, which consists of coagulation or flocculation, sedimentation, sand filtration, and chlorine disinfection, are organic matters and disinfection by-products such as trichloromethane and carbon tetrachloride. In this experiment, the turbidity, $KMnO_4$ index, $UV_{254}$, trichloromethane and tetrochloromethane were an alyzed. Turbidity and $UV_{254}$ were measured with HACH2100P turbidity-meter and 752 UV-visible spectropho-tometer made in Shanghai, $KMnO_4$ index was measured with oxidation-reduction titration method. Trichloromethane and tetrochloromethane were measured by gas-chromatography and bacteria were analyzed by plate count method.

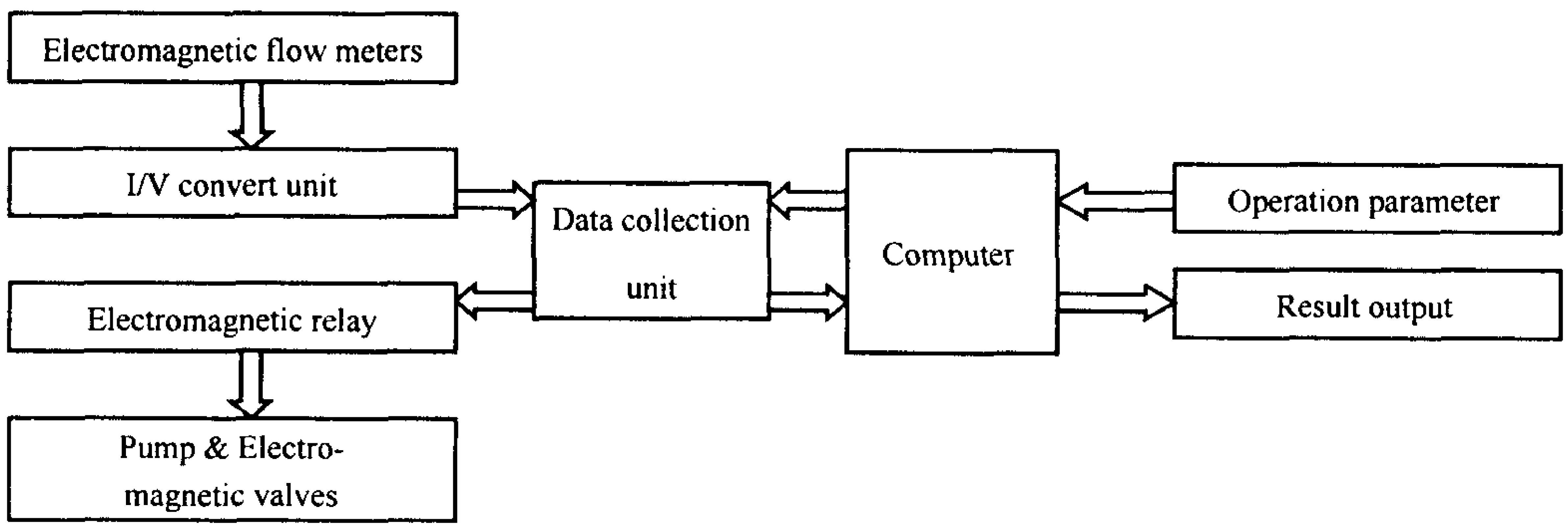


Fig. 2 Computer-controlled system

## Results and Discussion

### 1 Turbidity removal

Turbidity removal is showed in Fig. 3. It shows that the turbidity of raw water was somewhat high caused by pipe contamination because of lower turbidity in tap water after the conventional treatment. However, GAC adsorption and MF membrane shows obvious removal efficiency, and the filtrate turbidities of GAC and MF are about 0.2 NTU and 0.15 NTU respectively. In December

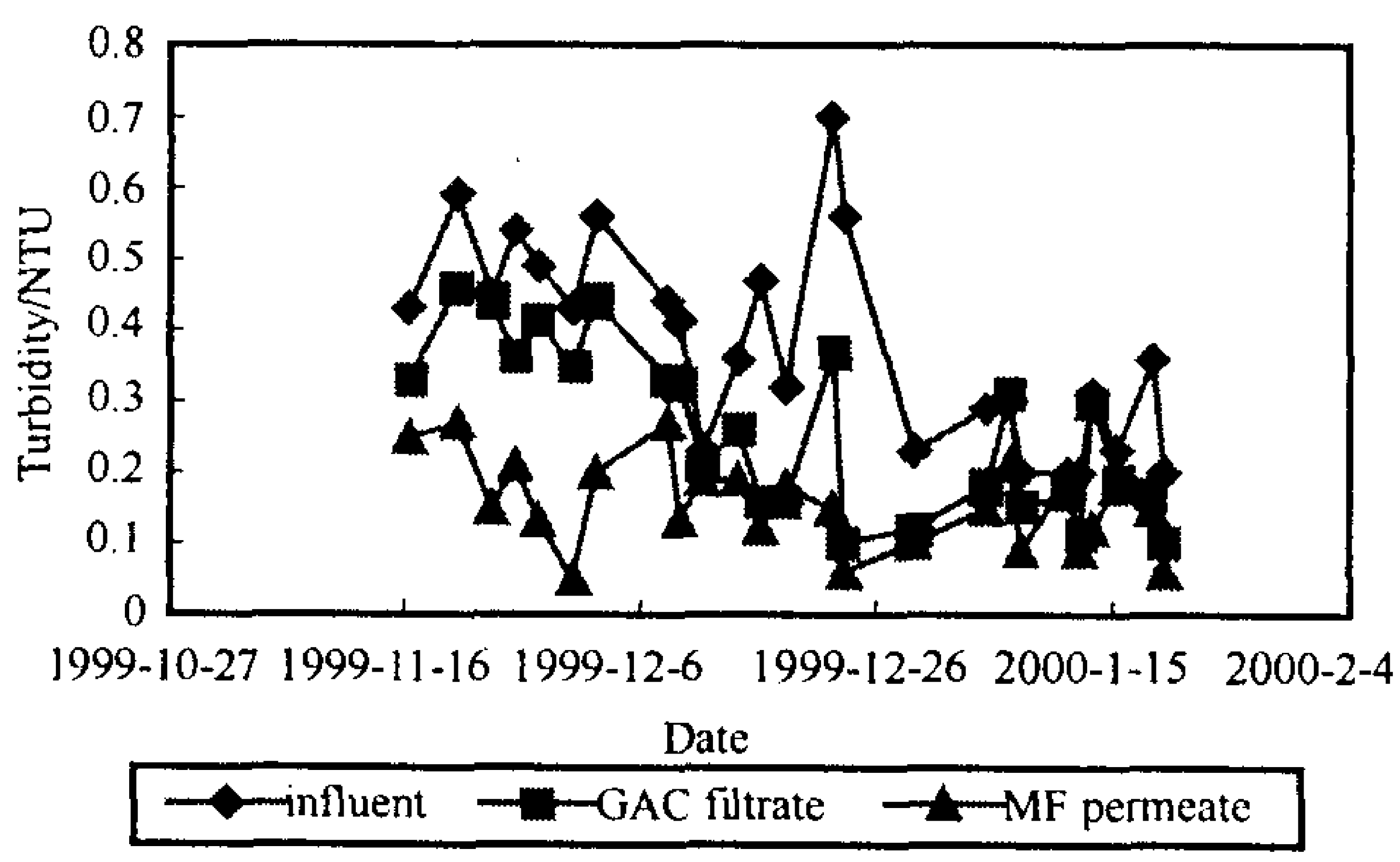


Fig. 3 Variation of turbidity

21st 1999, the higher turbidity was caused by the impurity from the inner side of steel pipe after 3-day break.

## 2 Organic matter removal

$KMnO_4$ index and $UV_{254}$ stand for the total organic matter and THMFP concentration respectively. As shown in Fig. 4 and Fig. 5, GAC shows good treatment performance for $KMnO_4$ index, while MF membrane does not show high removal efficiency. For $UV_{254}$, the MF removal efficiency is higher than $KMnO_4$ index and the $UV_{254}$ of final MF permeate is lower than 0.015 $cm^{-1}$.

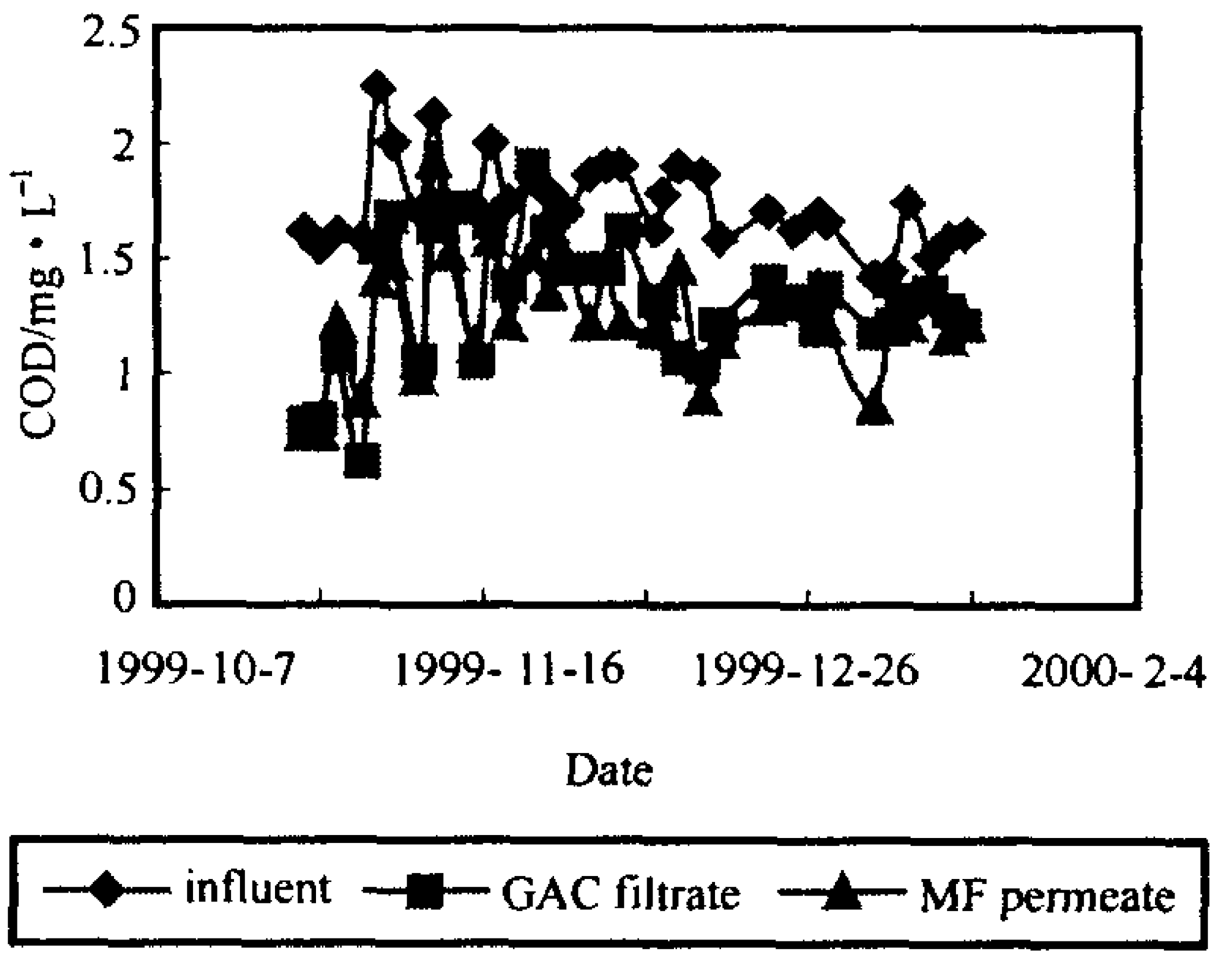


Fig. 4 Removal of $KMnO_4$ index

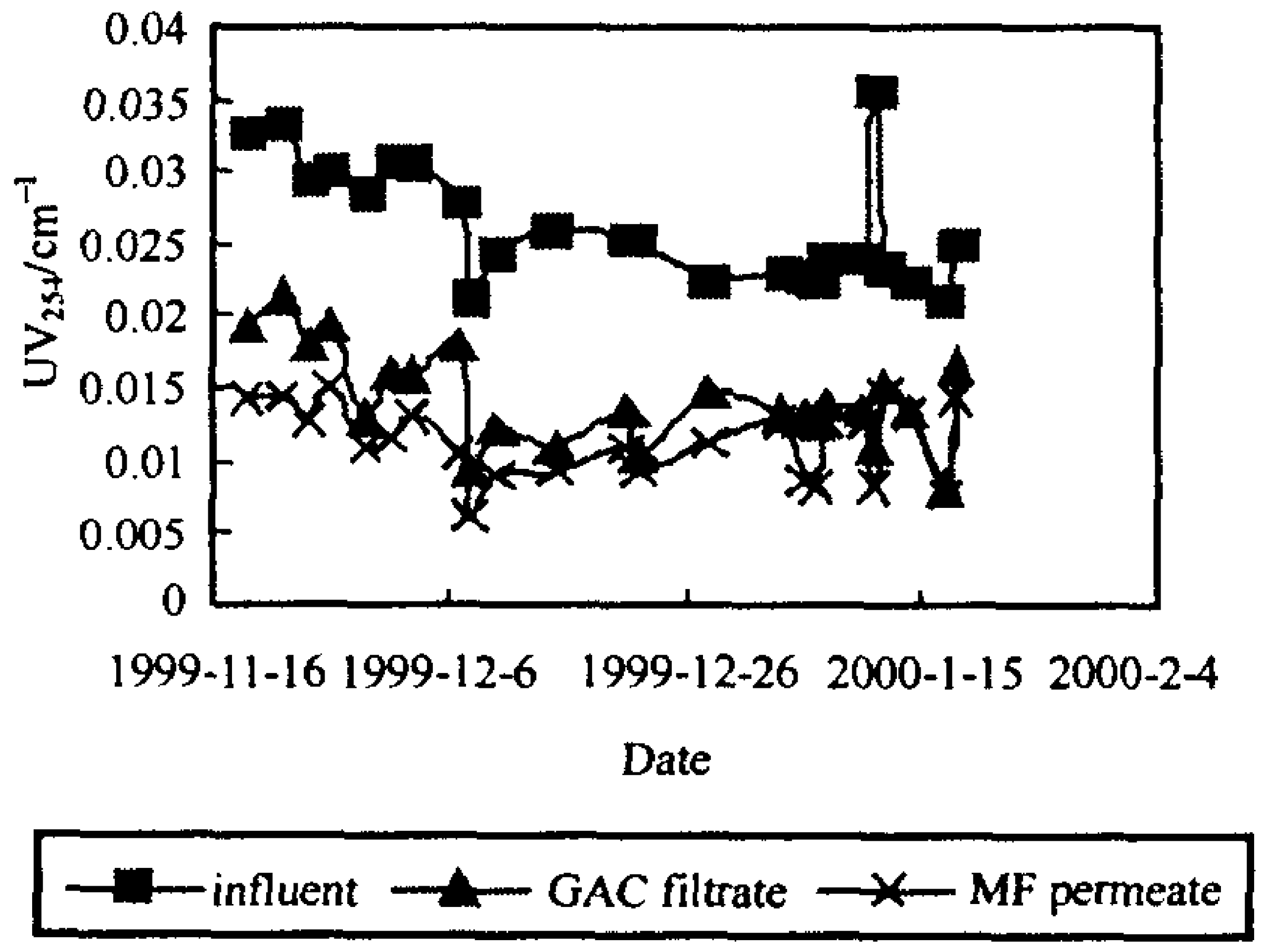


Fig. 5 Removal of $UV_{254}$

MF membrane is not capable of retaining the soluble organic substances due to the pores being too large. The organic matter removed by MF membrane constitutes only part of organic matters which includes some natural aromatic matter with high molecule or some organic matter adhering to particles, and it is less than the analytical error of $KMnO_4$ index. So the removal of $UV_{254}$ by membrane process did not decrease the $KMnO_4$ index obviously.

In order to analyze the organic compound species removed by GAC and MF membrane, the GC-MS analysis was conducted and the result is showed in Table 3.

**Table 3** Summary of GC-MS analysis result

| Organic matter type | Number of peaks | | |
|---|---|---|---|
| | Influent | GAC filtrate | MF membrane permeate |
| hydrocarbon | 17 | 13 | 14 |
| benzoic ether | 6 | 6 | 6 |
| hydroxybenzene | 2 | 1 | 1 |
| fatty acid | 3 | 1 | 1 |
| ester | 8 | 8 | 6 |
| alcohol | 3 | 0 | 0 |
| aether | 0 | 1 | 0 |
| others | 3 | 2 | 1 |
| Total number of peaks | 42 | 32 | 29 |
| Total peak area | 4 753 919 | 1 826 441 | 1 342 992 |

GAC has large specific surface area, which can remove much organic matter by physical adsorption. As hydrophobic matter, GAC could easily adsorb hydrocarbon and hydroxybenzene, while hydrophilic and biodegradable matters such as fatty acid and alcohol are probably removed by microorganisms growing on the GAC surface. Benzoic ether is hydrophilic and difficult to be biodegraded, so the removal efficiency is very low. The MF membrane showed insignificant efficiency in the removal of organic compound species number. But the total peak areas of membrane permeate decreased markedly, which shows that some organic matters were partly removed, and the probable removal mechanism is adherence in membrane pores.

## 3 Trichloromethane and carbon tetrachloride removal

Trichloromethane is produced in the chlorine disinfection, whose removal mechanism in the system is complex. Different studies got varied results[4, 5]. The treatment results are shown in Fig. 6 and Fig. 7, from which it can be seen that although the trichloromethane concentration in the experiment duration decreased, the concentration in the GAC filtrate increased slowly.

However its concentration still meets the standard because the influent concentration was very low. Compared with trichloromethane, the carbon tetrachloride concentration was also low. GAC adsorption showed negligible removal of carbon tetrachloride, as shown in Fig. 7. Further study is needed when the influent concentration is higher. MF membrane showed no efficiency in removing both of them due to its pore size is much larger than the molecule size of trichloromethane and carbon tetrachloride.

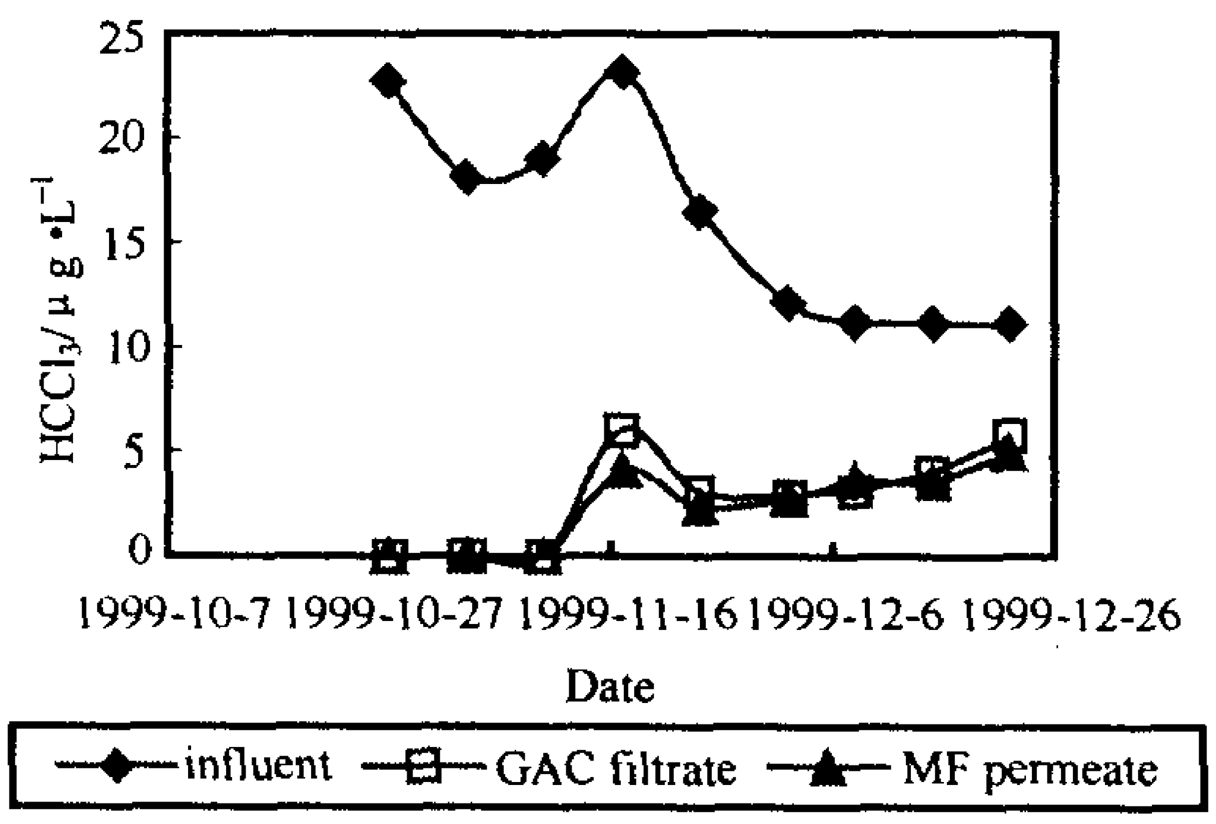


Fig. 6 Removal of $HCCl_3$

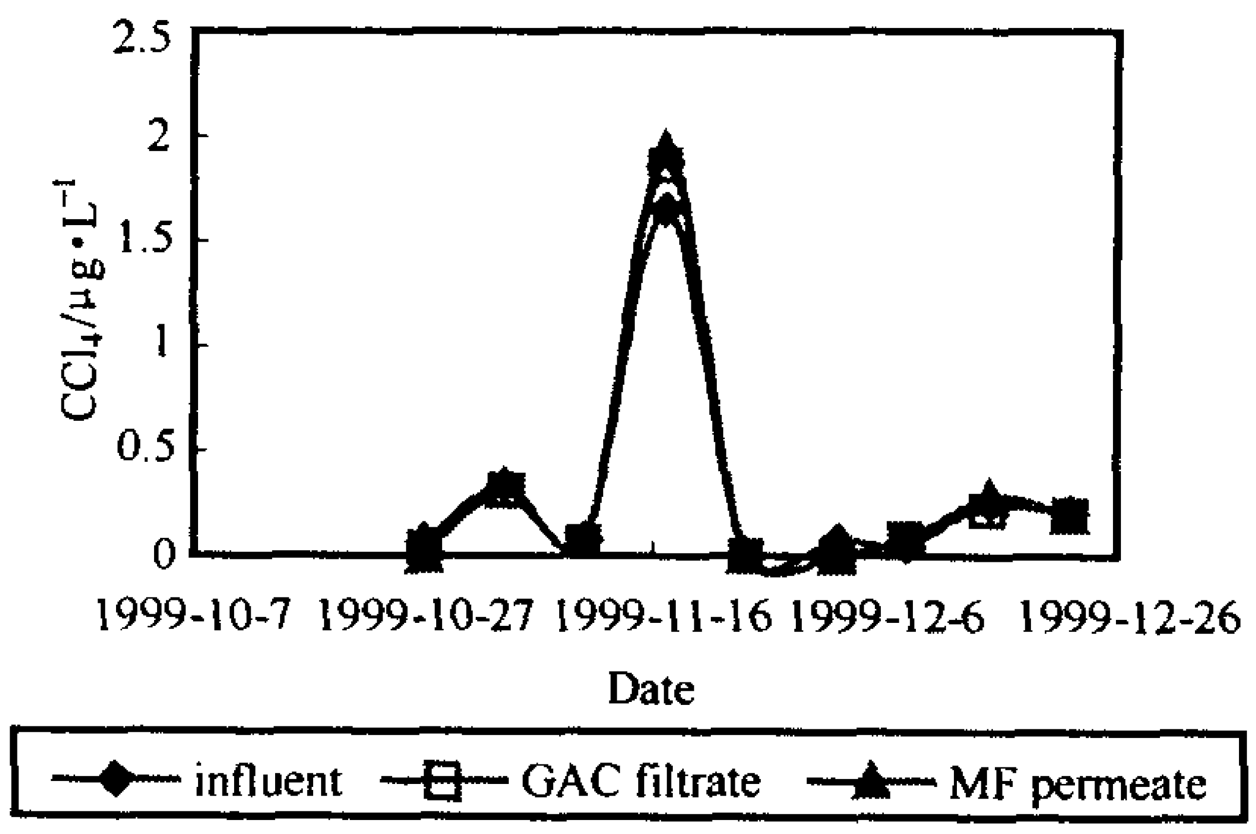


Fig. 7 Removal of $CCl_4$

## 4 Bacteria removal

Bacteria may grow on the large surface of GAC, which is helpful to remove organic matter and improve the performance of GAC. But in the Water Quality Standard for High Quality Drinking Water promulgated by Ministry of Construction of China, the total coliform was 0 cfu/100 mL and total bacteria is less than 50 cfu/mL. The analytical results are showed in Table 4. The bacterial growth in the first days was caused by the pipe contamination. MF membrane can retain all the bacteria left from the GAC adsorption unit, which has been proved by some authors[6].

Table 4 Microbial removal

| Date | Influent (cfu/mL) | GAC filtrate (cfu/mL) | MF permeate (cfu/mL) | Date | Influent (cfu/mL) | GAC filtrate (cfu/mL) | MF permeate (cfu/mL) |
|---|---|---|---|---|---|---|---|
| 1999-10-25 | 2 | 7 | 46 | 1999-12-01 | 6 | 3 | 0 |
| 1999-11-01 | 10 | 32 | 0 | 1999-12-07 | 8 | 4 | 0 |
| 1999-11-10 | 1 | 1 | 0 | 1999-12-13 | 0 | 0 | 0 |
| 1999-11-22 | 7 | 15 | 0 | 1999-12-21 | 1 | 8 | 0 |
| 1999-11-24 | 1 | 3 | 0 | 1999-12-27 | 7 | 7 | 0 |
| 1999-11-27 | 5 | 7 | 0 | 2000-01-03 | 1 | 32 | 0 |
| 1999-11-29 | 5 | 3 | 0 | 2000-01-10 | 1 | 15 | 0 |

## 5 Membrane operation performance

Fouling is a problem in the application of membrane unit, which is caused by the organic or inorganic matter adsorbed on the membrane surface. The direct effect is that the membrane flux is reduced under the same trans-membrane pressure. In order to reduce the membrane fouling, periodical backwash with MF permeate water was carried out. The backwash interval of 10-min, 20-min and 60-min was researched respectively. A typical operation cycle with 10-min backwash interval is showed in Fig. 8. The filtration pressure was 50 kPa, and the water pressure for backwash was 150 kPa.

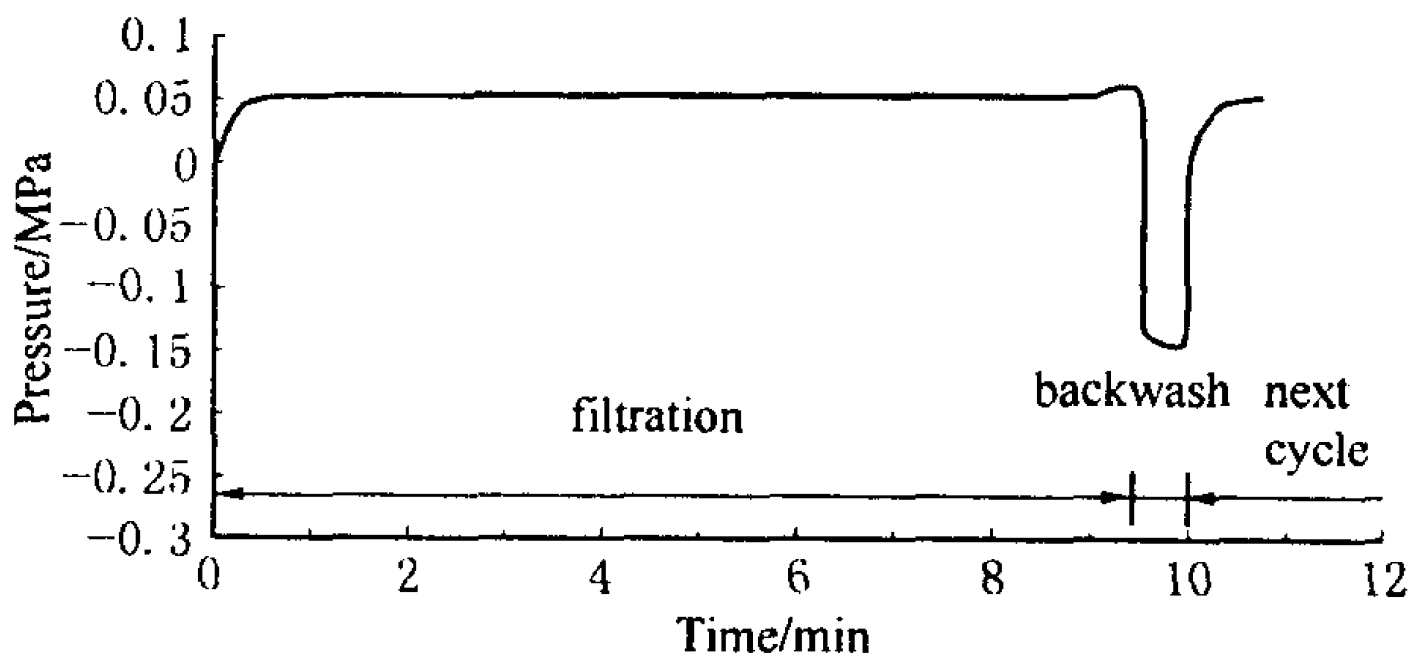


Fig. 8 Pressure variation in one typical cycle

Water viscosity has influence on the membrane flux, which is the function of temperature. Temperature correction to 20℃ for trans-membrane flux is made according to Equation 1, which is based on the variation of water viscosity with temperature[7]:

$$J_{tm}(\text{at } 20℃) = Q_p e^{-0.0239x(T-20)}/S \quad (1)$$

In which $J_{tm}$ is instantaneous flux ($L/h/m^2$), $Q_p$ is permeate flow rate (L/h), $T$ is temperature (℃) and $S$ is total membrane surface area ($m^2$).

In experiment, membrane flux decreased from 20 L/h/$m^2$ quickly in the first days of operation. Fig. 9 shows the membrane flux (at 20℃) variation at different backwash interval after 5 days' operation respectively. And 25% of permeate water was used for every backwashing. Before changing the operation condition, chemical clean method was used to recover the membrane flux to about primary value.

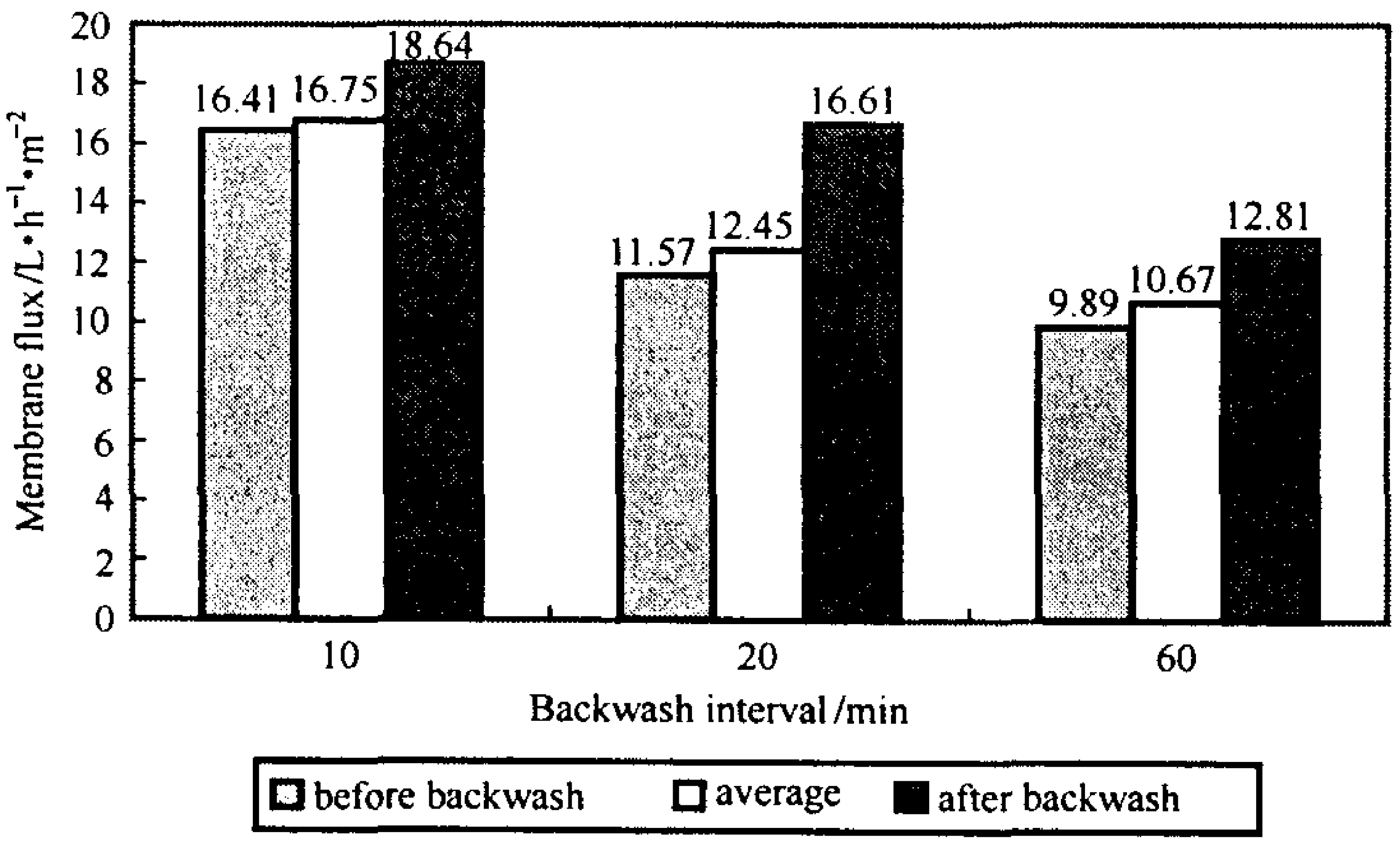


Fig. 9 Trans-membrane flux variation in different backwash interval

From Fig. 9, it can be seen that short backwash interval made MF membrane operating in relatively high flux. Membrane fouling can be divided into irreversible and reversible, reversible fouling can be removed by water backwash. Irreversible fouling severity is related with operation condition. Frequent backwash was beneficial to delay membrane irreversible fouling under the condition of consuming same volume of permeate water.

## Conclusions

The combined process of GAC adsorption and MF membrane can remove organic matter and turbidity effectively in drinking water. The bacteria fell off from the GAC can be retained by MF membrane completely. The effluent meets Water Quality Standard for High Quality Drinking Water (CJ94 - 1999), and this process is preferable as drinking water advanced treatment technology in direct drinking water system.

The research of MF membrane operation performance showed that short backwash interval could abate the membrane fouling effectively under the condition of consuming same volume of permeate water. It is necessary to employ automatic control system for 10 - min backwash interval membrane system.

The research results can be used as references in design of advanced drinking water treatment plant with MF membrane technology.

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