Experimental Study on UF-NF Filtration Purification of Pipe Drinking Water

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Abstract: With the municipal tap water of a residential community in northern China as the research object, this study used UF-NF (ultrafiltration-nanofiltration) double-membrane separation technology to assemble and produce the drinking water device. The quality of tap water was compared with the quality of direct drinking water in pipelines. The removal effect of pollutants in water was analyzed, and the relationship between the operating pressure and pollutant removal was studied. It was verified that UF-NF combination is an ideal filtration and purification process for direct drinking water system.

1. Introduction
The current pollution of China's drinking water is relatively serious, and organic micro-pollutants, ammonia nitrogen, pathogenic microorganisms and other pollutants are increasing. Most of the traditional water treatment technologies can no longer meet the current needs of people for water quality, so new water treatment technologies need to be developed. Membrane technology is a major technological breakthrough in water treatment technology in recent years, with features of high separation efficiency, easy control, simple process, flexible use and so on.

Membrane types include microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), reverse osmosis (RO), dialysis, electrodialysis, pervaporation and gas separation, and other filtration techniques. In this paper, the conventional ultrafiltration and nanofiltration commonly used in water treatment were studied experimentally, and the ultrafiltration and nanofiltration combined with UF-NF double membrane technology were used to perform the filtration purification and disinfection experiments.

2. UF-NF Double-membrane Treatment Technology
The principle of ultrafiltration is the solution separation process with the pressure difference between both sides of the membrane as the driving force, and the mechanical separation as the basis. The pressure is about 0.25 MP, and the sieve pore size is 0.01-0.1μm. It can remove colloids, bacteria, viruses, macromolecule organics, etc., but it cannot remove small molecular organics or ionic pollutants.

The principle of nanofiltration is to use a pressure drive to remove a nanometer or so of solute particles, which can effectively remove low-molecular organics, pesticides and inorganic salt
pollutants and have a good removal effect on bacteria. Therefore, it is a better physical disinfection method that replaces chemical disinfection.

The nanofiltration membrane is used in conjunction with the pretreatment system, with the advantages of advanced technology, energy conservation and environmental protection, low cost, retention of beneficial elements on the human body, high water yield, simple operation, low operating costs, and easy maintenance [1-5]. The process flow of the nanofiltration system consists of a pretreatment process, a membrane separation process, and a post-treatment process. As a kind of fine membrane filtration technology, the nanofiltration device has more stringent requirements for pretreatment of raw water. In order to ensure a good pretreatment effect and to protect the efficiency and stability of the nanofiltration process, an ultrafiltration membrane was designed as a pretreatment process. In this paper, a series of research work was conducted with the municipal tap water in a northern community as a study object, using the UF-NF double-membrane process. In the experiment, the operating pressure of the ultrafiltration membrane was set to 0.2 MPa, and the nanofiltration membrane was used as a key device for energy consumption and system operation effects. The effect of the operating pressure of the nanofiltration membrane on the system’s effluent water indicator of the system was mainly examined.

3. Devices and Methods

3.1 Comparison of Water Qualities of Influent and Effluent Water

The influent water was the municipal tap water of a residential community in the north, and it was to be tested according to the Standards for Drinking Water Quality, and the Standard Test Method for Drinking Water GB/T5750-2006. The water quality must meet the Water Quality Standards for Urban Water Supply CJ/T206-2005 and the water quality of the water generated from the experiment must meet the requirements of the Water Quality Standard for Fine Drinking Water (CJ94-2005). Refer to Table 1 for the qualities of specific influent and effluent water.

| Item                                    | Tap Water Limit | Drinking Water Quality Limit |
|-----------------------------------------|-----------------|-----------------------------|
| Chromaticity (fold)                     | 15              | 5                           |
| Odor                                    | No odor, acceptable to user | No odor                      |
| Turbidity (NTU)                         | 1.0             | 0.5                         |
| Substances visible to the naked eye     | None            | None                        |
| pH                                      | 6.5-8.5         | 6.5-8.5                     |
| Total hardness (with CaCO3 as the example) (mg/L) | 450             | 300                         |
| Iron (mg/L)                             | 0.3             | 0.20                        |
| Manganese (mg/L)                        | 0.1             | 0.05                        |
| Copper (mg/L)                           | 1.0             | 1.0                         |
| Zinc (mg/L)                             | 1.0             | 1.0                         |
| Aluminum (mg/L)                         | 0.2             | 0.20                        |
| Volatile phenols (with phenol as the example) (mg/L) | 0.002           | 0.002                       |
| Anionic synthetic detergent (mg/L)      | 0.3             | 0.20                        |
| Sulfate (mg/L)                          | 250             | 100                         |
| Chloride (mg/L)                         | 250             | 100                         |
According to Table 1, the indicators for water quality difference in the *Tap Water Limits* and the *Drinking Water Quality Limits* are: chroma, turbidity, total hardness, iron, manganese, sulfate, chloride, total dissolved solids, oxygen consumption, chloroform, and total amount of bacteria. This experiment focused on examining the limits of the above indicators with large differences in municipal tap water in a residential community in the north. The analysis results are shown in Table 2.

### Table 2 Influent and Effluent Water Values of Experimental System

| Item                        | Chroma (mg/L) | Turbidity (NTU) | Total hardness (mg/L) | Iron (mg/L) | Manganese (mg/L) | Sulfate (mg/L) | Chloride (mg/L) | TDS (mg/L) | CODMn (mg/L) | Chloroform (mg/L) | Total number of bacteria (cfu/mL) | Total coliform bacteria | Fecal coliform |
|-----------------------------|---------------|-----------------|-----------------------|-------------|-------------------|----------------|-----------------|------------|--------------|---------------------|-------------------------------|-------------------------|-----------------|
| Raw water                   | 5             | 1.0             | 458                   | 0.37        | 0.06              | 142            | 145             | 286        | 3.73         | 0.05                | 98                           | Any is unacceptable        | Any is unacceptable |
| Effluent                    | 5             | 0.5             | 300                   | 0.2         | 0.05              | 100            | 100             | 250        | 2.0          | 0.03                | 50                           | Any is unacceptable        | Any is unacceptable |

### 3.2 Experimental Flow

The experimental process flow is shown in Figure 1.

![Experimental Process Flow Chart](AttachedDiagram)
The membrane module used in the experimental study was one ultrafiltration membrane and two NF membranes, with a first-stage one-section continuous configuration. The performance of the membrane module is shown in Table 3.

### Table 3 UF-NF Membrane Model Parameters

| Item                             | Ultrafiltration membrane | Nanofiltration membrane |
|----------------------------------|--------------------------|-------------------------|
| Model                            | GM-4040F                 | GE-DL8040F              |
| Membrane Area (m²)               | 1.5                      | 0.34                    |
| Pore Diameter (um)               | 0.01                     | 0.001                   |
| Molecular cut-off (Da)           | 40000-50000              | 200-500                 |
| Pure water flux (L/h)            | ----                     | 189.25                  |
| MgSO₄ Removal Rate (2500ppm) (%) | ----                     | 96.4                    |

3.3 Analysis Methods

**Turbidity:** HACH2100Q portable turbidity analyzer; **Sulfate ion:** Barium chromate spectrophotometry; **Total iron ion:** o-phenanthroline spectrophotometry; **Manganese ion:** Atomic absorption spectrophotometry; **TDS:** Weighing method; **Conductivity:** HACH5100-18 conductivity meter; **Chloride:** silver nitrate titration method; **Chemical oxygen consumption:** potassium dichromate oxidation titration method; and **total hardness:** EDTA complexometric titration method [6].

4. Results and Analysis

4.1 Relationship between System Effluent Water Conductivity and NF Operating Pressure

The conductivity measurement is convenient and intuitive, it is an important indicator to measure the salt content in water, and is also one of the important monitoring indicators to measure the treatment effect of the double-membrane system. During the experimental operation, the operating pressure of the NF membrane was changed and the effect of the operating pressure on the desalination performance of the nanofiltration membrane was examined. The test results are shown in Figure 2.

As shown in Fig. 2, the removal efficiency of NF on salt ions in tap water reached over 90%.
Compared with ultrafiltration, nanofiltration has a better removal effect on salt ions. With the increase of the operating pressure, the change trend of the nanofiltration water conductivity value was decrease first and then increase. This may be due to the increase of the membrane flux with the increase of the pressure on the water influent side of the nanofiltration membrane within the working pressure range of the nanofiltration membrane, as the rate of water molecules passing through the membrane is faster than that of the inorganic salt, the early desalination rate increased and the effluent water conductivity decreased. With consideration of the safety, stability and energy saving requirements of the system operation, the operating pressure of the nanofiltration system should not exceed 0.45 MPa. From the experimental data, ultrafiltration had almost no influence on the conductivity, and the average value of effluent water conductivity in nanofiltration was 32 μs/cm.

4.2 Relationship between system membrane flux and pressure

The municipal tap water was treated by the UF-NF double membrane system. The relationship between the nanofiltration membrane flux and the pressure is shown in Figure 3.

![Figure 3 Curves for Relation of Nanofiltration Membrane Flux and Operating Pressure](image)

It can be seen from Figure 3 that the membrane flux increased with the increase of the operating pressure, and 0.3 Mpa was the inflection point of the membrane flux increase. When the operating pressure was small, a loose filter cake layer was formed on one side of the membrane, and the rate of rising of the fouling plug was slow, and the cleaning of the membrane was relatively thorough [7]. From the flux change curves, it is known that the larger the membrane pore is, the larger the corresponding hydraulic radius and the smaller the resistance will be. That means, when large membrane pore resistance <intermediate membrane pore resistance <small membrane pore resistance experimental operating pressure is very small, the water flows through the large pore. Due to the small number of large pores, so the flux was very small. As the operating pressure increased, the amount of water flowing through the large membrane pore increased as well, but it was not enough to overcome the resistance of the small and intermediate membrane pores, so the resulting flux increase was also small. When the operating pressure was increased enough to overcome the resistance of the intermediate membrane pore, there is water flowing through the largest number of intermediate membrane pores, and the flux increased rapidly as the operating pressure increased.

4.3 System Analysis of Effective TDS Removal

The removal rate of TDS (total dissolved solids) in the influent water in the double-membrane system is shown in Figure 4.
Figure 4 Relationship between TDS Removal Rate and Operating Pressure

TDS refers to the total amount of minerals contained in water, mainly including calcium, magnesium, zinc, chromium, copper, selenium and so on. There is a high rejection rate for these divalent ions and high-valent nanofiltration membranes. From Figure 4, it can be seen that the removal rate of TDS in the double-membrane system process was above 85%. The removal rate of the TDS by the nanofiltration membrane decreased slightly with the increase of the operating pressure, and the relationship between the removal rate and the conductivity was similar, indicating a positive correlation between TDS and the conductivity.

4.4 System Analysis of Total Hardness Removal Effect

The change in the total hardness of the system effluent under different operating pressures is shown in Figure 5.

Figure 5 Relationship between total hardness removal rate and operating pressure
From Figure 5, it is known that 0.35MPa was the inflection point of the operating pressure. When the pressure exceeded 0.35MPa, the removal rate of the total hardness of the nanofiltration membrane decreased, which is related to the pore size distribution of the nanofiltration membrane. When the operating pressure was small, the water passed through the microfiltration-level pore and the ultrafiltration-level pore, so the removal rate of the total hardness began to increase. When the operating pressure increased, the water started to pass through the nanofiltration-level pore with the largest number, and the removal rate of the total hardness of the nanofiltration-level pore was much higher than those of the microfiltration-level and ultrafiltration-level pores, so the removal rate of the total hardness of the water and other indicators rapidly increased in addition to the rapid increase the water production.

4.5 Analysis on the System Removal Effect of COD_{Mn}

The removal rates of COD_{Mn} from the system under different operating pressures are shown in Figure 6.

![Figure 6](image_url)

**Figure 6** Relationship between COD_{Mn} removal rate and operating pressure

From Figure 6, we can see that there was no significant change in COD_{Mn} removal rate when the NF operating pressure was less than 0.40MPa. Since ultrafiltration has no removal effect on small-molecule organic contaminants [8], experiments show that ultrafiltration has no obvious removal effect on COD_{Mn}; as with other pollutants, the system removal rate decreased after the operating pressure exceeded 0.40 MPa due to change of pore size.

4.6 Analysis on system’s iron removal effect

The removal rates of iron in tap water by the UF-NF double-membrane system are shown in Figure 7.

![Figure 7](image_url)

**Figure 7** Relationship between iron removal rate and operating pressure
Through testing, it can be found that there were red film-like, floccular iron-containing substances on the surface of the ultrafiltration membrane, but there was little on the nanofiltration membrane. The ultrafiltration membrane had significant effects of iron removal. It also shows that most of the iron in the water existed in the form of flocs or complexes, and there were few iron ions in the free state. The iron content of NF effluent was between 0.01-0.025 mg/L, which meets the corresponding water quality standards.

4.7 Analysis on System Cl⁻ Removal Effect

Under different operating pressures, the removal effect of Cl⁻ in raw water in nanofiltration is shown in Figure 8.

![Figure 8](image)

**Figure 8** Relationship between Cl⁻ removal rate and operating pressure

From Figure 8, it can be seen that as the operating pressure increased, the removal rate of Cl⁻ from the system slightly increased, which was not consistent with the change rule of other pollutants. This may be due to the increase in membrane operating pressure. The change of salt concentration on both sides led to a decrease in the transmissivity of chloride ions, or as the pressure increased, the pore size of the nanofiltration membrane changed, resulting in an increase in the removal rate of chloride ions.

4.8 Analysis on System SO₄²⁻ Removal

The removal of SO₄²⁻ in municipal tap water using the UF-NF double membrane system is as follows.

![Figure 9](image)

**Figure 9** Relationship between SO₄²⁻ removal rate and operating pressure

The experiments show that ultrafiltration basically did not remove any SO₄²⁻. From Figure 9 we
can see that nanofiltration had a higher removal rate for $SO_4^{2-}$. With the pressure increase, the $SO_4^{2-}$ removal rate slightly decreased.

5. Conclusion

From the UF-NF double-membrane system process experiments, the following conclusions were drawn:

1. The difference between the quality of the tap water from municipal pipe network and the quality of the direct drinking water from pipeline is mainly reflected in TDS, conductivity, total hardness, CODMN, iron salt, manganese salt, $SO_4^{2-}$, $Cl^-$, and total number of bacteria. The UF-NF double-membrane system can effectively remove the pollutants in municipal tap water, and the system effluent water quality meets or exceeds the standard for direct drinking water in pipelines.

2. The removal rate of most pollutants decreases with the increase of the operating pressure, and the system membrane flux increases with the increase of the operating pressure. As the operating pressure increases, the energy consumption will gradually increase, resulting in a corresponding increase in water production costs. Through experimental analysis, it is recommended that the NF operating pressure should be stable at about 0.45 Mpa.

The UF-NF combined process experiments show that the ultrafiltration-nanofiltration double-membrane process is an ideal choice for the filtration purification process, with the advantages of low water quality requirements, excellent quality of water production, high recovery, etc.; NF membrane removes organic and inorganic contaminants while keeping a proper amount of life elements, meeting the standards for high-quality drinking water; therefore, the UF-NF combined process is suitable for the design of direct drinking water systems.

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