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Performance evaluation of water treatment ultrafiltration pilot plants treating algae-rich reservoir water

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Abstract

Three different water treatment ultrafiltration (UF) pilot plants were investigated to treat algae-rich reservoir water. Coagulation, coagulation–sedimentation and coagulation–sedimentation–filtration were applied prior to UF respectively. Based on the permeate water quality and the specific flux of UF, coagulation/settling process was selected as the best pretreatment method for UF membrane. Filter played a negative role in pretreatment for UF membrane fouling control.

Keywords: Ultrafiltration (UF); Coagulation; Pretreatment; Specific flux; Fouling

1. Introduction

Use of low-pressure membrane filtration, ultrafiltration (UF) has been steadily growing in recent years [1–11]. UF membrane fouling can severely reduce the efficiency and limit its wide application. Especially for the reservoir water treatment, which usually contains algae and organic matters, UF membrane fouling is a practical impediment [1]. Coagulation in water treatment is a process of combining small particles into larger aggregates for better settlability. The mechanisms of particle destabilization for the coagulation of colloid particles or NOM were reported: charge-neutralization and sweep flocculation [2]. And in-line coagulation means the use of a coagulant before UF membrane filtration without sedimentation or pre-filtration [5]. Many studies have addressed the combined treatment of in-line coagulation and UF [4–6]. It was concluded that UF could be a potential replacement of filters or the entire process [10].

However, during our study on the treatment of algae-rich reservoir water, it was found that in-line coagulation could not solve the problem of algae fouling. And little literature was reported on the solution for UF fouling by algae. Minimization of natural organic matters (NOM) and algae

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concentration has emerged as the critical issue in treatment of reservoir water for drinking purposes [10]. And necessary barriers should be included, such as sedimentation and pre-filtration, to reduce the fouling.

The objective of this study was to evaluate the performance of water treatment UF pilot plants for algae-rich reservoir water treatment: coagulation, coagulation–sedimentation and coagulation–sedimentation–filtration were applied prior to UF membrane respectively.

2. Experimental

2.1. Raw water characteristics

The raw water was obtained from algae-rich reservoir located in Guangdong Province (South China) in this study. A summary of the raw water quality is shown in Table 1.

2.2. Membrane and UF process

All membrane units used were hollow-fiber and made of polyacrylonitrile (PAN) hollow fiber with a molecular weight cut-off (MWCO) of 100,000 Dalton and an effective surface area 2.8 m^2. Membrane units were operated at constant flux (109 L m^{-2} h^{-1}) and variable TMP with 1 h backwashing cycle.

An explanatory sketch of the UF facility is shown in Fig. 1. Aluminum chloride (alum) was adopted and the dosage was 8 mg/L calculated as alum, which was based on the results of jar tests. Coagulation, coagulation–sedimentation and coagulation–sedimentation–filtration were applied prior to UF respectively. Coagulant was dosed in the mixer and coagulation time was 18 min. Settling tank was adopted with 10 min residence time. Sand filter was filled with two kinds of different filter materials: the upper layer consisted of 0.5 m of anthracite with particle size of 1.0–1.5 mm. In the lower was a 0.7 m layer of quartz sand (particle size of 0.5–0.8 mm). In the experiments, the filter velocity was 9.6 m/h. The settling tank operated with 40 h sludge discharge cycle and filter with 40 h backwashing cycle.

Table 1
Feed water characteristics

Turbidity (NTU)	3.20–5.41
pH	7.40–7.92
COD_{Mn} (mg/L)	2.5–2.9
Algae count (×10^4 cell/L)	890–1460
Temperature (°C)	24.2–28.0

Specific flux was used to provide comparisons between pretreatment conditions for UF, which is the ratio of permeate flux at 20°C to TMP.

$$J_{sp} = \frac{J_{20}}{\mathrm{TMP}}$$

where J_{sp} is the specific flux (L m^{-2} h^{-1} kPa^{-1}), J_{20} is the permeate flux corrected for 20°C (L m^{-2} h^{-1}). Permeate flux was corrected for temperature effects using the following equation [11,12]:

$$J_{20} = \frac{Q_p e^{-0.0239(T-20)}}{S}$$

where Q_p is the permeate flow (L/h), T is the feed water temperature (°C), and S is the membrane effective surface area (m^2).

Karimi et al. recommended the use of the equation to correct for the effects of temperature on water viscosity ($T > 20$°C), and J_{20} could be calculated as the equation [13]:

$$J_{20} = \frac{Q_p e^{-0.021(T-20)}}{S}$$

And in this study, the equation corrected by Karimi was adopted to calculate the specific flux.

3. Results and discussion

3.1. Specific flux comparisons

Fig. 2 shows the comparative results of specific flux for the three water treatment ultrafiltration

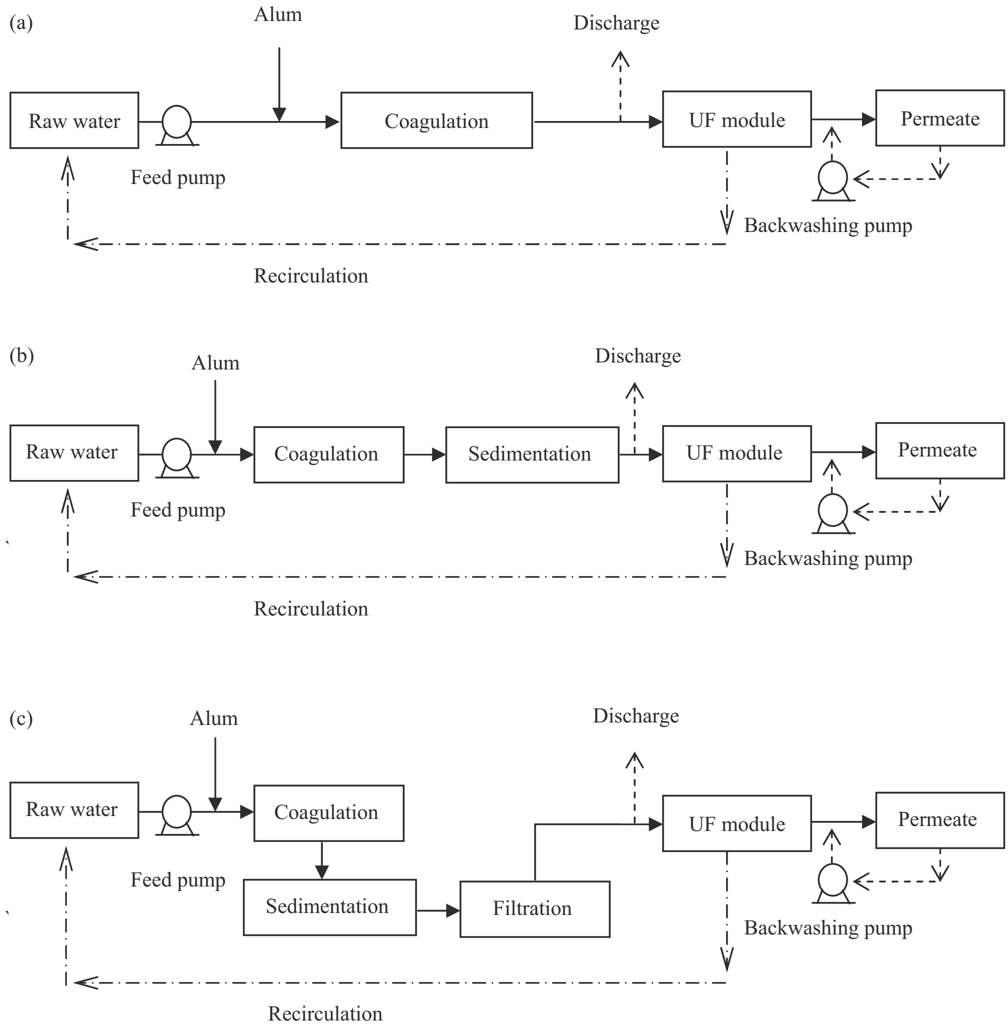

Fig. 1. Schematic diagram of the experiment.

pilot plants. A high relatively high and stable specific flux was the main criteria for selecting the best pretreatment process, and then process B (coagulation–sedimentation + UF) would be recommended. It was thought that process C (coagulation–sedimentation–filtration + UF) was more efficient for controlling membrane fouling. Filtration could remove colloids and particles prior to UF. However, Fig. 2 also shows an interesting point that process C was not the best selection. Filtration may play a negative role in the process.

Process A (coagulation + UF) did not show any predominance compared with process B and C. Many literatures reported that coagulation conditions can affect the flux decline [4–6]. However, in the algae-rich reservoir water treatment, it seemed that sedimentation was also needed before UF. During the UF fouling by algae, if the algae cells could not be removed sufficiently,

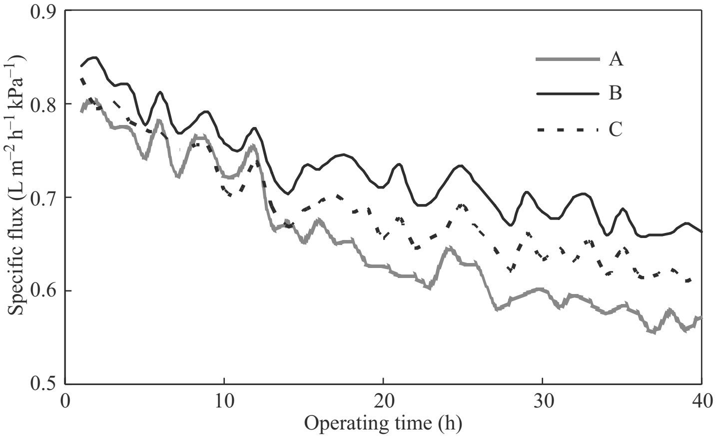

Fig. 2. Comparisons of specific flux profiles (corrected for 20°C) between water treatment ultrafiltration pilot plants (A: coagulation + UF; B: coagulation–sedimentation + UF; C: coagulation–sedimentation–filtration + UF).

the cells deposited on the membrane surface and released extracellular polymetric substances (EPS) which played an important role in UF fouling. Coagulation could only form large-floc to pack the algae cells and the large quantities of cells can still release EPS even if they were packed by flocs. In process A, adsorptive fouling could take place. And the gel layer formed by EPS on the surface is difficult to remove during backwashing. Sedimentation can remove algae cells and 75% algae removal was observed in the experiment, which could reduce the cells fed into UF membrane. Cake layer formed by flocs may be the main fouling mechanism in process B.

It seemed contradict that filtration played a negative role in process C. Filtration could remove algae cells on the basis of sedimentation barrier. It could reduce the amount of algae fed into UF, while the effect was opposite. It was postulated that no available cake layer could form and neutral hydrophilic compounds could directly adhere to the surface of the membrane, which was difficult to remove. Also, pore blocking by minute particles is also the mechanism for UF fouling in process C.

Based on the previous results, coagulation–sedimentation is the best selection as the pretreatment method for UF during algae-rich reservoir water treatment. And the process B is the right choice for the algae-rich waters, while not for the water rich in NOM. In-line coagulation could satisfy with the needs of the cost and the effects when the water rich in NOM was treated [4–6].

3.2. Permeate water quality comparisons

The removal of NOM represented by COD_{Mn} and UV_{254} on the conditions of three water treatment UF plants was shown in Figs. 3 and 4. In 40 h operation time, samples were collected for measurement every 4 h. And the results were consistent with the results of specific flux comparisons. Process B could achieve the best efficiency of NOM removal.

The result can be explained as follows: Algae cells are difficult to coagulate due to their negative surface charge. In process A without sedimentation, large quantities of algae cells could plug the outlet of UF module, and NOM removal is also affected for algae could increase NOM concentration by releasing action. During settling phase, sufficient algae removal efficiency can be achieved by solid–liquid separation, and the

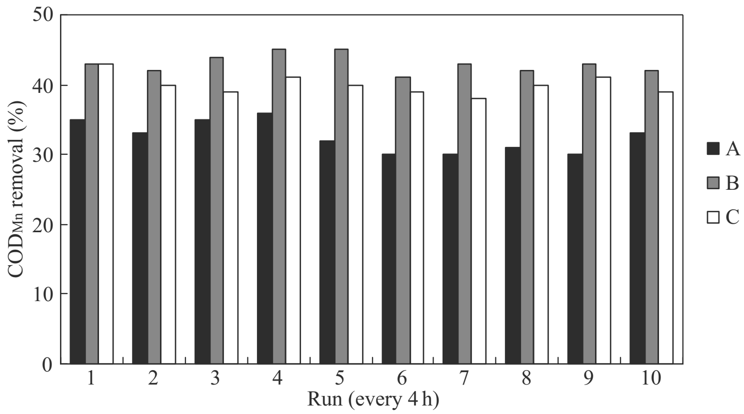

Fig. 3. Comparisons of COD_{Mn} removal between water treatment ultrafiltration pilot plants (A: coagulation + UF; B: coagulation–sedimentation + UF; C: coagulation–sedimentation–filtration + UF).

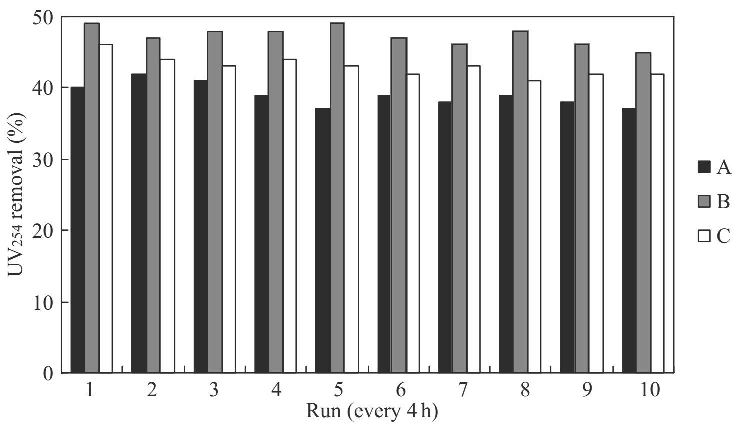

Fig. 4. Comparisons of UV_{254} removal between water treatment ultrafiltration pilot plants (A: coagulation + UF; B: coagulation–sedimentation + UF; C: coagulation–sedimentation–filtration + UF).

flocs could form a porous cake layer to reduce the filtration resistance. However, filtration could not enhance the effects for NOM removal in process C. The reason should be that filtration could remove algae, flocs and larger particles, while minute particles could be fed into UF. Minute particle have its drawbacks for UF operation: It is difficult to form a cake layer, and pore blocking or adsorbing could increase the resistance. On the other hand, minute particle is unfavorable for its back-transport action. Back-transport is very important for reducing the adsorbing and depositing of NOM on membrane surface. And the velocity of back-transport is related with particle diameter. The bigger particle diameter, the faster is back-transport velocity.

4. Conclusions

(1) Based on specific flux and permeate water quality comparisons, coagulation–sedimentation is selected as the best pretreatment method.

(2) For algae-rich reservoir treatment, coagulation + UF could not be the satisfied choice like other water bodies treatment.
(3) Filtration could play a negative role for UF pretreatment for the minute particles' adverse effects.

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