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Optimization of backflushing conditions for ceramic ultrafiltration membrane of disperse dye solutions

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Abstract

In the ultrafiltration (UF) of disperse dye solutions using ceramic membrane, backflushing is necessary to minimize the formation of fouling by disperse dye, and to enhance the permeate flux. In this work, the effects of backflushing on the ultrafiltration performance and decolorization were investigated. In the optimum backflushing condition, the permeate flux increased slightly and the filtration performance was stable during filtration process.

Keywords: Backflushing; Ceramic membrane; Disperse dye; Ultrafiltration (UF)

1. Introduction

Textile wastewater is known to have strong color, a large amount of suspended solids (SS), highly fluctuating pH, high temperature, and high COD concentration [1]. Ultrafiltration (UF) process has been adopted as an effective alternative technology for the reuse as well as for the treatment of textile wastewater. However, the UF process also has some drawbacks such as the flux decline resulted from the concentration polarization and fouling by dyes [2]. Chemical cleaning with strong acid and physical and hydrodynamic methods have been proposed and used to minimize flux decline. Several studies have been attempted to solve the flux decline in membrane processes, such as change in the surface interactions between particles, change in the hydrophobicity of the membrane, and change in the hydrodynamics in the membrane module for the increase of the turbulence close to membrane [3].

The usual cleaning process of membrane is rinsing and cleaning. The water rinse is performed

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by the mechanical action and the universal solvent power of water after the end of the production process [4]. Backflushing is an in situ cleaning method reversing periodically the transmembrane pressure drop. The permeate is forced in the reverse direction through the membrane, thereby lifting off the cake layer and cleaning the membrane surface. The cake lifted would normally be resuspended by tangential flow. As a result, the average permeate flux obtained per cycle is much higher than the long-term flux with no reverse filtration. Backflushing is a physical method using periodical backward flow in order to remove foulants from membrane surface and pores. The performance of this method depends on the frequency and the interval time of the operation [5].

In this work, the optimum condition of backflushing was investigated to increase the flux and finally to enhance the ultrafiltration of disperse dye solutions.

2. Materials and methods

2.1. Dye solutions

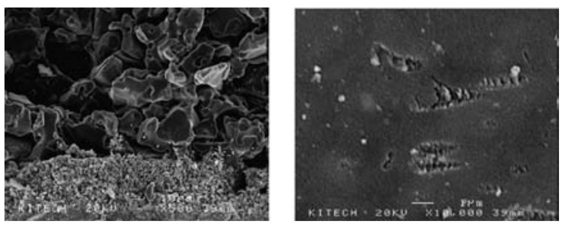
The composition of wastewater from the dyeing and textile processes varies greatly from day to day and hour to hour, depending on the dyestuff type, the fabric type and the concentration of fixing compounds which are added. The commercially available disperse dyes, Suncron Blue RD-400, were obtained from company (O Ind. Ltd., Korea). The color index number is disperse blue 106 (DB106). Distilled water was used to prepare the desired concentration (100 and 500 mg/L) of dyestuff solutions.

2.2. Ceramic membrane

Ultrafiltration (UF) process has been adopted as an effective alternative technology for the reuse as well as for the treatment of textile wastewater. However, the conventional polymeric membranes have a low chemical stability with respect to corrosive media like strong acid and organic solvents. It is generally recognized that inorganic materials are inherently more stable than polymers. The ceramic membrane used is composed with inorganic materials such as titania (TiO_2), alumina (Al_2O_3) and zirconia (ZrO_2), etc. Ceramic ultrafiltration membrane (Pall Co., USA) of one channel, with 7 mm inner diameter and 250 mm long, was used for experiments. The membrane was made up of selective layer of titania (TiO_2) with pore size of 5 nm on an α-alumina (α-Al_2O_3) porous support. The total surface area was 0.005 m^2. The characterization of membrane is summarized in Table 1 and the SEM images are shown in Fig. 1.

Table 1
Characterization of the ceramic membrane

Classification		Membrane
Material	Active layer	Titania (TiO_2)
	Support layer	α-Alumina (α-Al_2O_3)
Module type		Tubular single channel
Tube characteristics	Channel diameter	7 mm
	Length	250 mm
	Inner surface area	0.005 m^2
	Pore size	5 nm



(a) (b)

Fig. 1. SEM images of (a) the cross-section and (b) the surface of ceramic membrane.

2.3. Apparatus

The schematic of the experimental apparatus (MEMBRALOX, Pall Co., USA) used in this study is shown in Fig. 2. The system was composed of a 3 L feed tank, where the dye solution was circulated at a constant speed, circulating pump and crossflow membrane module. The membrane of tubular type with a pore size of 5 nm was used. Backflushing (4 bar) was made with a mixture of nitrogen gas and permeate using various frequencies and interval times. The transmembrane pressure value (TMP) was controlled constantly.

2.4. Analysis

An UV-spectrophotometer (DR 4010, HACH, USA) was employed to measure the concentration of the dyestuff solution. The decrease of the absorbance peaks was directly proportional to the reduction of the dye concentration. The TOC analyzer (Multi N/C 3000, Analytikjena, Germany) was used to measure the concentration of organic compounds.

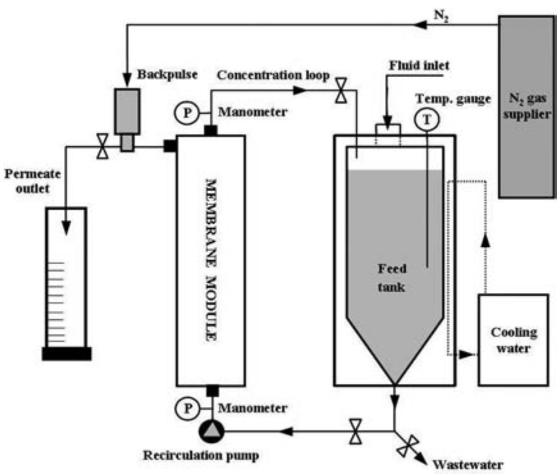


Fig. 2. Schematic diagram of experimental apparatus.

3. Experiments

3.1. Clean water flux

Clean water flux is an important factor to determine process design and capacity. Clean water flux was determined over a period of at least 2 h at 1 bar and 20°C. The filtration experiments were performed using cross flow method at constant pressure.

3.2. Membrane molecular weight cut-off

The tests to determine molecular weight cut-off (MWCO) were performed by retention measurements using a mixture of polyethyleneglycols (PEG) with average molecular weight of 400, 600, 1000, 2000, 4000, 4600, 6000 and 8000 Daltons. The concentration of mixture was 5000 mg/L. TOC analyzer was used to measure concentration of PEG mixture. The rejection of PEG was calculated using Eq. (1):

$$R_i = \left(1 - \frac{C_{i,p}}{C_{i,0}}\right) \times 100 \quad (1)$$

where $C_{i,p}$ is the concentration of PEG fraction in the permeate (g/L) and $C_{i,0}$ is the concentration of PEG fraction in the feed (g/L).

3.3. Backflushing

During an actual separation, e.g. a pressure driven process, the membrane performance can change with time, and a typical flux–time behavior may be observed which is the decrease of the flux through membrane over time. Flux decline can be caused by membrane fouling, which is categorized into reversible and irreversible fouling. Reversible fouling, due to accumulation of particles and build-up of a cake on the membrane surface, can be reduced by backflushing of the membrane. Irreversible fouling is caused by accumulation of particles inside the membrane pores during the penetration of small particles

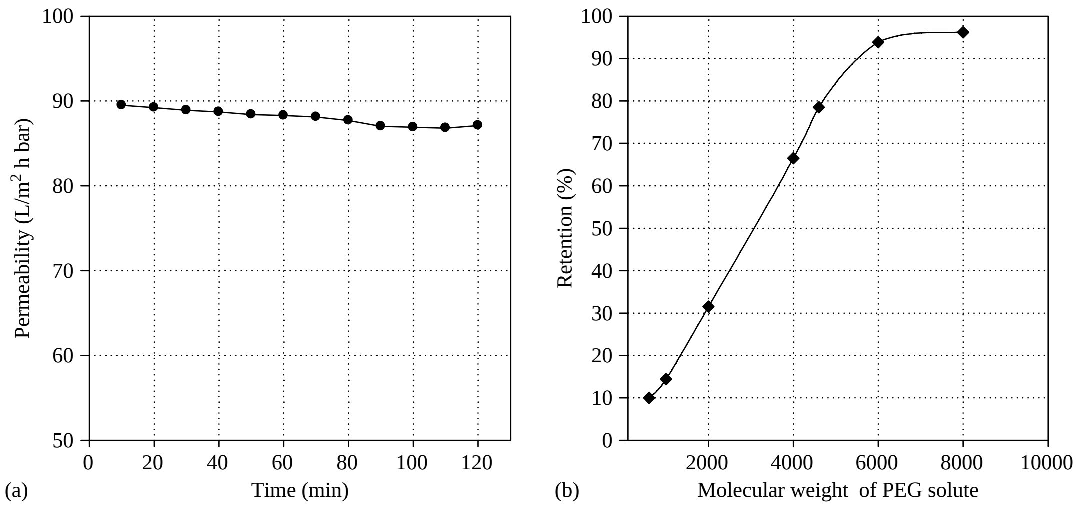


Fig. 3. Clean water flux (a) and MWCO (b) of ceramic membrane.

through the membrane. The flux decline of the membrane can be converted into the membrane resistance R_t, which is calculated by Eq. (2):

$$J \equiv \frac{1}{A}\frac{dV}{dt} = \frac{\Delta P}{\mu\left(R_m + R_c + R_p + \cdots\right)} = \frac{\Delta P}{\mu\left(R_t\right)} \quad (2)$$

where μ is water viscosity at the operation procedure (cp), ΔP is transmembrane pressure, R_t is total resistance, R_m is intrinsic membrane pressure, R_c is cake layer resistance and R_p is pore plugging resistance.

It seems that the membrane fouling was caused by both the cake layer (the effect which backflushing can decrease) and by adsorption or pore plugging (the effect which backflushing cannot remove). In this work, we investigated the effect of backflushing on filtration performance. The backflushing was achieved using pressurized air and permeate mixture to push small amounts of permeate through the membrane for variable time conditions. The pressure of the backflushing air was adjusted to 6 bar.

3.4. Rinsing

The equipment and membrane were rinsed with tap water. Between the tests the membrane was soaked in 10 wt% NaOH solution for 24 h, and then the membrane and equipment were rinsed with deionized water at high cross-flow velocity until the pH became stable.

4. Results and discussion

4.1. Clean water flux and molecular weight cut-off

In Fig. 3(a) the clean water flux is shown as a function of filtration time. The flux was maintained constant approximately at the value of 88.1 L/m^2 h bar. During 2 h the change of pressure from 1 to 3 bar linearly increased the flux from 88.1 to 580.6 L/m^2 h bar. Fig. 3(b) shows that the ceramic membrane, with 90% MWCO of 5500 Dalton, can be defined as an ultrafiltration membrane.

4.2. Effect of the backflushing

The permeate flux was measured as a function of filtration time using different initial dye concentrations of 100 and 500 mg/L (Fig. 4). Higher permeate flux was obtained at low initial dye concentration of 100 mg/L due to the lower amount of dye particles.

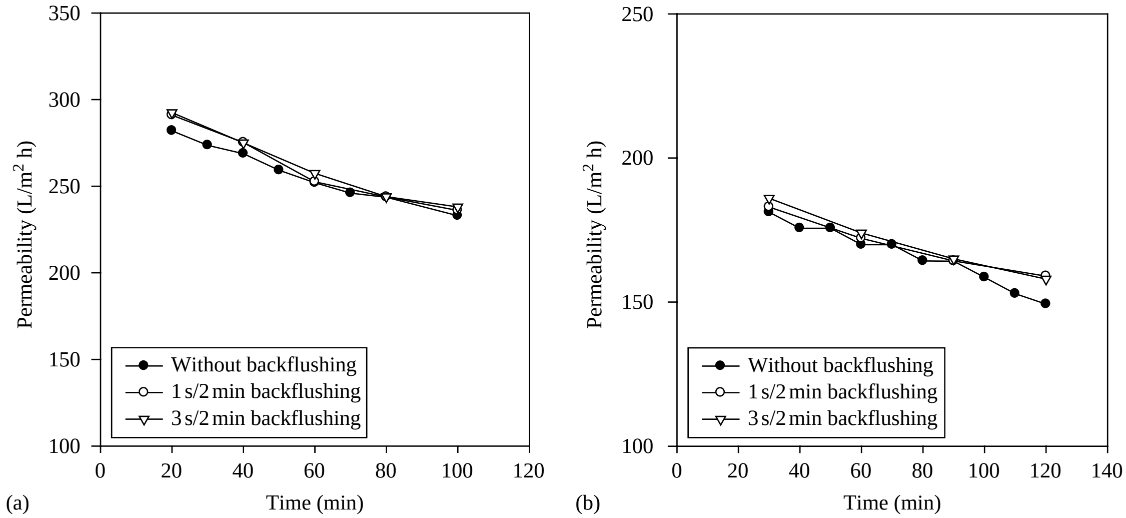


Fig. 4. Effect of backflushing on flux: (a) DB106 (100 mg/L) and (b) DB106 (500 mg/L).

When the backflushing was performed, a slight increase in the average permeate flux was observed (Fig. 5). The backflushing was more efficient for the decrease of foulants and also for the increase of the permeate flux. The highest flux value was achieved when the backflushing time was 3 s per 2 min. This result showed the backflushing experiments gave higher fluxes than tests without backflushing. However, the effect of the backflushing was not obvious because the dye particle existed as soluble state in solution. Moreover, it was likely that with too short filtration times, the fouling sufficiently did not occur on the membrane surface.

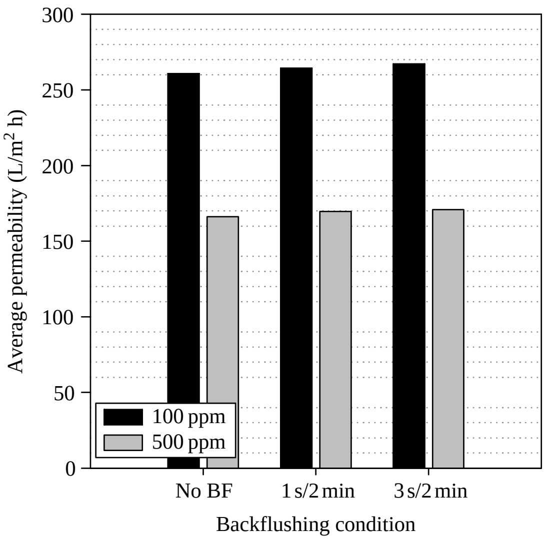


Fig. 5. Average permeability of DB106 according to backflushing condition.

In Fig. 6, the color removal efficiency is shown as a function of filtration time. When the backflushing was periodically performed, the removal efficiency decreased relatively slowly with filtration time. The filtration performance was stable during filtration process. Because the feed tank was small and the filtration time was a little short, it was difficult to show any difference of color removal efficiency according to backflushing conditions.

5. Conclusions

The performance of ultrafiltration with backflushing for treatment of dye solution was investigated. Backflushing is the one of the most important factor in the UF as well as other membrane process [6]. Through the investigation of backflushing effect, the backflushing easily removed dye particles from the surface of

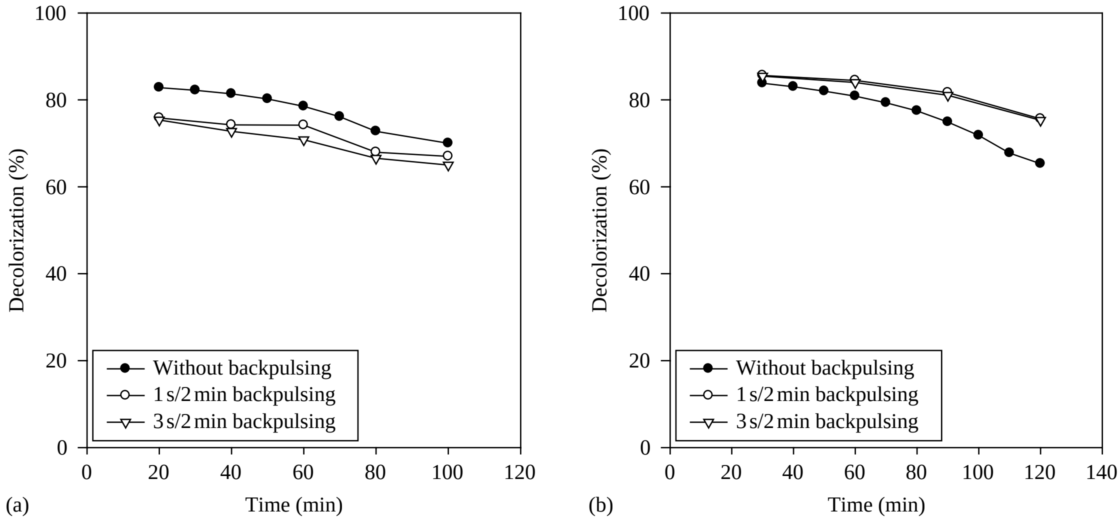


Fig. 6. Effect of backflushing on decolorization: (a) DB106 (100 mg/L) and (b) DB106 (500 mg/L).

membrane and enhanced permeate flux. The effect of backflushing conditions was not as clear, but it seemed that the backflushing increased the permeate flux and stabilized the filtration performance for treatment of dye solution.

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