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A Study of the Development of a Radial Pleat Module for Low Pressure Using an Ultrafiltration Membrane

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Abstract : A radial pleat module using a polysulfone membrane was developed. The permeation characteristics of the radial pleat module were compared with those of a flat plate module. The average module efficiency of the radial pleat module for the applied pressure range was 82% and was always greater than that of the spiral wound module. For the radial pleat module, in general, as the applied pressure increases, the flux increases and the rejection reduces. The concentration polarization causes the decrease of the flux for the long time operation. But it has been found that the radial pleat module is more efficient for the reduction of the concentration polarization because it has the more effective area per unit volume and can induce the turbulent flow in the module.

Keywords : ultrafiltration, radial pleat module, module efficiency, concentration polarization

1. Introduction

The ultrafiltration membrane, in general, locates between the reverse osmosis membrane and the microfiltration membrane [1-3]. It is similar to the diffusion-dialysis membrane. In principle, the membrane separation uses the difference between the pore size of membranes and the size of solutes. The ultrafiltration membrane can separate the materials which have the range of the molecular weight of 300~300,000 and that of the molecular size of 0.001~0.1 μm [4].

The basic theory of the ultrafiltration using membranes was established by Ferry in 1936 [5]. After the development of the prominent membrane materials and the membrane modules in the middle of 1970s, this technique has been accepted as one of the practical separation processes. Presently, interest in the ultrafiltration rapidly is growing. This method has the advantages of the room temperature and an aseptic condition operation. It also does not need any thermal treatment. Therefore, it is able to separate and refine the materials without the damage or the destruction of the materials. Due to that, the ultrafiltration can apply for the food, the biological, and the medical industries. The specific application areas are the food condensation, the bacteria and enzyme refining, the separation of the plasma protein, the artificial kidneys, the bio-membrane reactor, the ultrapure manufacturing, etc. The concentration polarization, however, is an obstacle for the application of the ultrafiltration. It is the accumulation of the solute on the membrane

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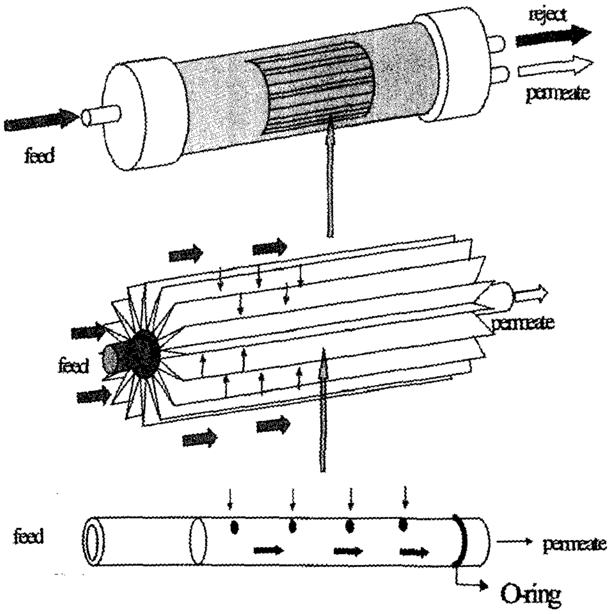

Fig. 1. The schematic diagram of the radial pleat module.

surface [6-9]. This work, therefore, was designed to reduce the concentration polarization by developing a new type module, a radial pleat module. The permeation characteristics of the radial pleat module were studied and the efficiency of the module was determined.

2. Experimental

2.1. Materials

The membrane used in this work was a commercial polysulfone ultrafiltration (UF) membrane manufactured by Fluid Dynamics Co., USA. The spiral wound module manufactured by Film Tech. Co., USA was used to compare the efficiency of that with the efficiency of the radial pleat module prepared in this work. A flat plate module was also prepared for the determination of the efficiency. The solute examined was the polyethylene glycol (PEG) of Aldrich and the solvent was the distilled water. The concentration of the PEG solution was 0.0001 M, prepared using the PEG molecular weights of 12000. Refractive Index detector (SP8430, Spectra-Physics co.) was used for the measurement of rejection coefficient (%) with this PEG solution.

2.2. The Radial Pleat Module

In order to manufacture the radial pleat module, first the polysulfone UF membrane with 105 cm long and 25 cm broad was prepared. It was folded using the membrane folding apparatus made of the stainless steel. This folding apparatus looks like railroad. A part of plate on rail moves forward and backward and this plate is folding the membrane. This is followed by the attachment of the permeate spacer to the folded membrane. A mesh spacer in the permeate side of folded membrane sheet is inserted and then this mesh spacer with folded membrane sheet is glued around the edges by Araldite. This permeate spacer is a polyproylene spacer. The membrane with the spacer was radially attached to the surface of the outlet using an adhesive. After the complete dry, the membrane was installed inside the module housing. The schematic diagram of the radial pleat membrane module manufactured in this study is presented in Fig. 1.

The examination of the permeability of the radial pleat module was performed using the pure water and the PEG solution. In the pure water permeability test, the pure water permeability coefficient (A) was obtained by:

$$J_v = Permeated\ volume\ /\ (Area \times Time) \qquad (1)$$

$$A = J_v\ /\ \Delta P \qquad (2)$$

where J_v is the volume flux; ΔP is the pressure difference.

2.3. Definition of the Module Efficiency

The module efficiency of the radial pleat module and the spiral wound module was determined and compared. The module efficiency has been defined as the ratio of the pure water permeability coefficient of each module to that of the flat plate membrane module. It can be expressed by:

$$\eta = \frac{A_j}{A_i} \times 100 \qquad (3)$$

where η is the module efficiency; A_j is the pure water permeability coefficient of the each module; A_i is that of the flat plate membrane module.

3. Results and Discussion

3.1. Pure Water Permeability Test

For the increase of the compression rate of the membrane, the pressure treatment of the membrane was performed at the pressure of 6 atm for 1 hour before the pure water permeability test. Fig. 2. shows the effect of the applied pressure on the pure water flux for the flat plate and the radial pleat module of permeate space with 0.30 and 0.35 μm thickness. It could be seen that the thickness difference of 0.05 μm did not affect the pure water flux of the radial pleat module. The average module efficiency of the radial pleat module for the range of the applied pressure of 1 and 5 kg$_f$/cm^2 was 82%. In Fig. 3, the effect of the applied pressure on the module efficiency is presented and the module efficiency of the two modules is compared. The module efficiency of the radial pleat module is always quite higher for the pressure range. Also, it can be seen that for the range of the pressure, the module efficiency of the two modules does not depend on the pressure. The higher module efficiency of the radial pleat module means that the geometry of the radial pleat module is more efficient.

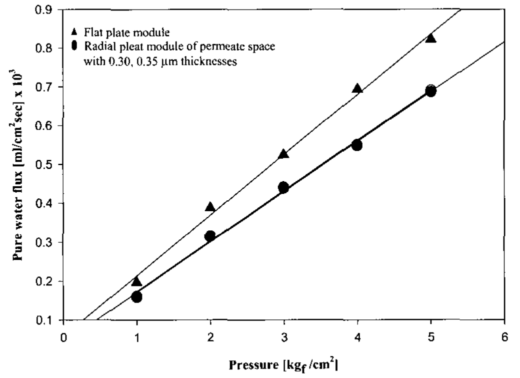

Fig. 2. The pure water flux as a function of the applied pressure for the flat plate membrane and the radial pleat module of permeate space with 0.30 and 0.35 μm thickness.

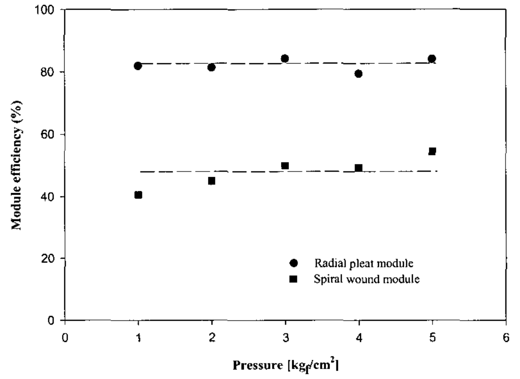

Fig. 3. The module efficiency of the radial pleat and the spiral wound module as a function of the applied pressure.

3.2. Solute Permeability Test

The MWCO of the polysulfone membrane obtained

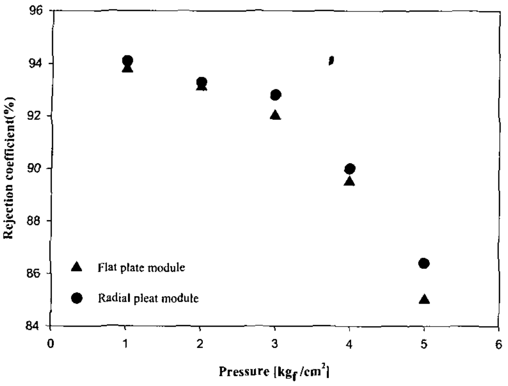

Fig. 4. The rejection as a function of the applied pressure using the 0.0001 m peg solution. The peg molecular weight was 12,000.

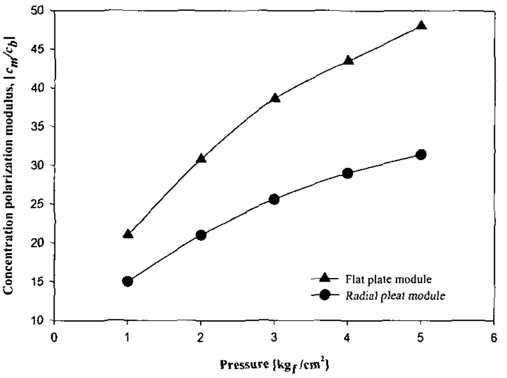

Fig. 5. The effect of the applied pressure on the concentration polarization modulus using the 0.0001 m peg solution. the peg molecular weight was 12,000.

in this work is about 6,000. Fig. 4 presents the effect of the pressure on the rejection coefficient for the radial pleat and the flat plate module using the 0.0001 M PEG solution. As the pressure is increased, the rejection coefficient is decreased. The rejection coefficient of the radial pleat module is slightly higher than that of the flat plate module.

Fig. 5 shows the concentration polarization modulus as a function of the applied pressure. The concentration polarization modulus is defined as the ratio of the solute concentration at the membrane surface (c_m) to the solute concentration in the bulk feed (c_b) [1]. This ratio increases as the flux and the retention increase and as the mass transfer coefficient reduces. For the complete retention of the solute by the membrane, it can be represented by:

$$\frac{C_m}{C_b} = \exp\left(\frac{J}{k}\right) \qquad (4)$$

where c_m is the solute concentration at the membrane surface; c_b is the solute concentration in the bulk feed; J is the flux; k is the mass transfer coefficient. It is known that Equation (4) is the basic equation for the concentration polarization. Simply, it can be understood that the two factors of the flux and the mass transfer coefficient are responsible for the concentration polarization [1]. In Fig. 5, as the pressure is increased, the concentration polarization modulus is also increased. It means that as the pressure is increased, the solute concentration at the surface of the membrane is increased. It was believed that this solute accumulation on the membrane surface was caused by low back-diffusion and more accumulated solutes at high pressure. The low back-diffusion reduced the reverse diffusion rate from the membrane surface.

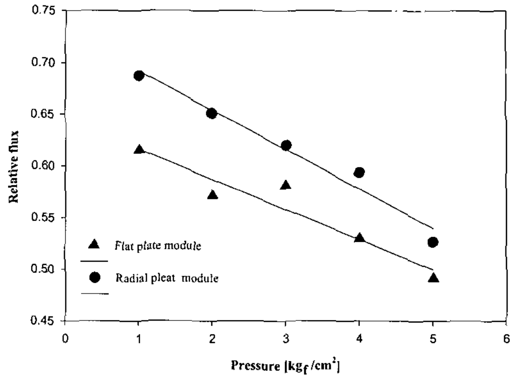

Fig. 6. The relative flux as a function of the applied pressure using the pure water and the 0.0001 m peg solution. The peg molecular weight was 12,000.

Fig. 6 presents the relative flux as a function of the pressure. The relative flux was the ratio of the PEG flux to the pure water flux. For the radial pleat module, the relative flux is higher. It was understood that compared with the flat plate module, the radial pleat module generated more turbulent flows in the module; therefore, the concentration polarization in the radial pleat module more reduced.

4. Conclusions

A new radial pleat module using a polysulfone membrane was developed and the permeation characteristics of that were studied. The module efficiency of the radial pleat module was 82% while that of the spiral module was 48% for the applied pressure range of 1 and 5 kg_f/cm^2. It indicates that the structure of the radial pleat module is more efficient. Also, for the pressure range, the module efficiency of the radial pleat module and the spiral wound module was independent of the applied pressure. As the applied pressure increases, the rejection of the radial pleat module reduces. The concentration polarization of the radial pleat module increases with increasing the pressure. The turbulent flow inside the radial pleat module is greater than that inside the flat plate module. This turbulent flow reduces the concentration polarization or the membrane contamination of the radial pleat module.

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