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Comparison of fouling rates for pressurized and submerged ultrafiltration membranes

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ABSTRACT

Recently, microfiltration (MF) and ultrafiltration (UF) are widely used for water treatment because of their advantages including small footprint, ease of operation, and high removal efficiency of bacteria and pathogenic protozoa. MF and UF membrane modules generally use hollow fibers that can be operated in either pressurized or submerged modes. In this study, we focused on comparison of pressurized and submerged membrane modules in terms of fouling rates. Synthetic feed waters were used for accelerated fouling tests. Lab-scale pressurized and submerged modules were fabricated using same UF fibers. In additions, a special module that allows the application of both positive and negative pressures was prepared. In the three systems (pressurized, submerged, and combined modules), the permeate flux was adjusted to be constant and the increase in transmembrane pressure was continuously monitored. Experimental results showed that the efficiency of the submerged module was better than that of the pressurized module. This may be attributed to the compaction of foulant layer due to the external pressure in the pressurized module. Accordingly, the fouling rate may depend on the ratio of external positive pressure to negative suction pressure in the combined module.

Keywords: Microfiltration; Ultrafiltration; Submerged hollow fiber module; Pressurized hollow fiber module; TMP

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1. Introduction

Hollow fiber membranes are of great commercial interest with many applications such as water treatment, hemodialysis, gas separation, and pharmaceutical industries [1,2]. Among them, microfiltration (MF)/ultrafiltration (UF) hollow fiber membranes have been used to potable water treatment, wastewater treatment and reclamation, and desalination pretreatment. This is attributed to their small footprint, ease of operation, high removal efficiency of bacteria and pathogenic protozoa, and effluent of excellent quality [3,4]. MF and UF membrane modules are operated in either pressurized or submerged modes.

Nevertheless, hydrodynamics in MF/UF hollow fiber membranes is difficult to understand, leading to problems of fouling control [5,6]. In MF/UF membranes, membrane fouling results from the mixtures of

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particles, colloidal materials, organic matters, and microorganisms [7]. The accumulation and deposition of these foulants are affected by the hydrodynamic conditions in hollow fiber MF/UF membranes, which are known to be more complex than those in other types of membranes. In addition, cake compressibility must be considered if the foulants are compressible [8].

The objective of this study is to compare pressurized and submerged hollow fiber membranes to provide insight into the design of membrane modules. The effect of external and suction pressures on membrane permeability and fouling rates was investigated using synthetic feed water. A combined membrane module, where both pressurized and submerged modes exist, was designed and compared with the other modules.

2. Materials and methods

2.1. Laboratory operation of submerged membrane system

A schematic diagram of the laboratory-scale, submerged hollow fiber membrane system for feed water treatment in this study is shown in Fig. 1. A tank having a working volume of 2 L was used for the filtration test of submerged hollow fiber membrane module. A submerged module consisting of UF fibers was immersed and suspended vertically in the reactor. The UF fibers, made of polyvinylidene fluoride, were supplied by the Cheil Samsung Industry, Korea. They have a nominal pore size of 0.03 μm, an internal diameter of 0.9 mm and an external diameter of 2.1 mm as shown in Table 1. The whole tests were carried out using the same membranes. Permeation from the membrane module was pulled by a peristaltic pump (EW-07551-00, Cole-Parmer, USA). A permeate volume was frequently measured by collecting permeate weight with a balance. The transmembrane pressure (TMP) was continuously measured by a pressure transducer (ISE40A-01-R, SMC, Japan) and a data logger (usb-6008, NI. USA) connected to a computer for data analysis. The temperature of solution was kept constant at 20℃. A constant flux mode, where both the TMPs were increased by foulant deposition and then permeate flux was gradually declined by membrane fouling, was adopted to keep the membrane performance during the operation time.

2.2. Laboratory operation of pressurized membrane system

Using same UF fibers, pressurized and submerged membrane modules were fabricated in a laboratory scale. As shown in Fig. 1, both pressurized and submerged modules were simultaneously operated in a same system. The TMP and flux were continuously measured and the temperature of the solution was kept constant at 20℃.

2.3. Laboratory operation of combined membrane system

Fig. 2 illustrates a module which combines both pressurized and submerged filtration modes. This

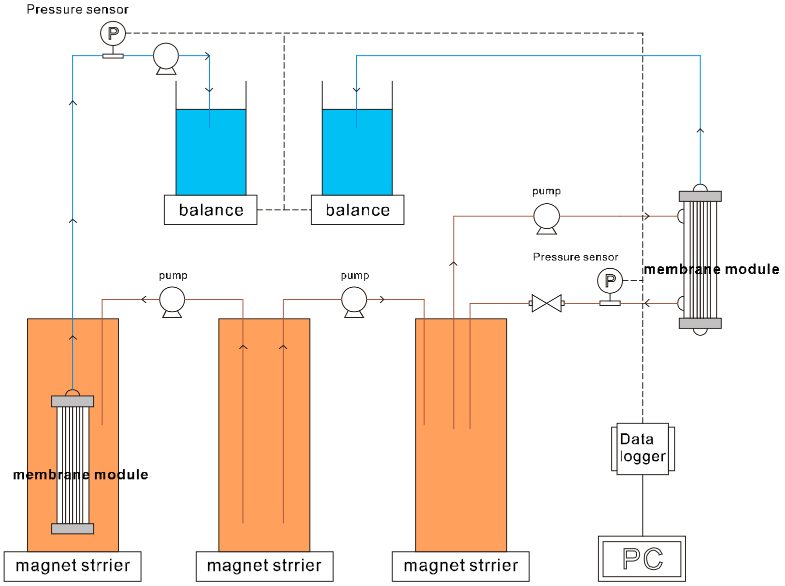

Fig. 1. Schematic diagram of experimental set-up for UF tests.

Table 1
Specification of the UF hollow fiber membrane

Module	Submerged module	Pressurized module
Filtration method	Dead-end	Dead-end
Flow type	Outside-in	Outside-in
Material type	PVDF/hollow fiber	PVDF/hollow fiber
Length of the module	150 mm	150 mm
Area of the module	0.01 m^2	0.01 m^2
Number of fibers	10ea	10ea
Flux	50 L/m^2-h	50 L/m^2-h
Pore size	0.03 µm	0.03 µm
I.D/O.D	0.9 mm/2.1 mm	0.9 mm/2.1 mm

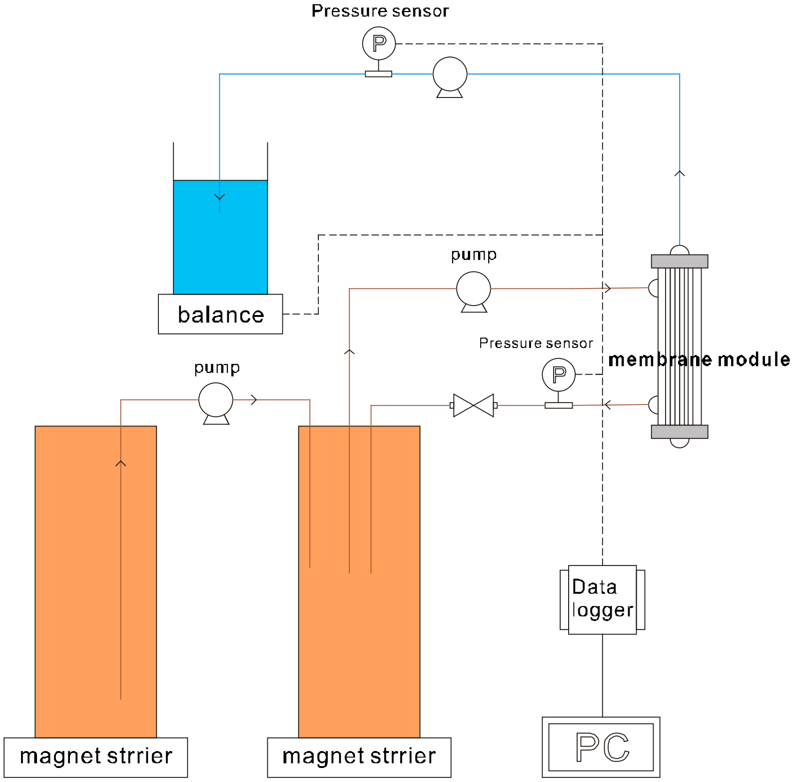

Fig. 2. Schematic diagram of experimental set-up for combined module tests.

module was operated by two driving forces, including suction pressure and external pressure. To enable this, two pumps were used at the same time. The ratio of external pressure to suction pressure changes as the permeability of the module decreases. Initially, filtration is controlled by the suction pressure. As the TMP increases, the contribution of external pressure to total pressure increases. Accordingly, the combined module is an intermediate between pressurized and submerged modules.

2.4. Procedure for hollow fiber membrane test

Feed solution was prepared using deionized (D.I.) water and alginate (Alginic acid sodium low viscosity, Sigma–Aldrich) with a concentration of 0.2 g/L. Initial permeabilities of the membranes were measured using the D.I. water during 1 h operation. Then, the modules were tested using the feed solution for 1 h.

2.5. Analysis of compressible foulant

To examine the compressible characteristics of the model foulant (alginate), filtration was performed using a dead-end filtration cell(HP4750 Stirred Cell, STERLITECH), which has a working volume of 250 mL. The inside of the cell was pressurized by high pressure nitrogen gas. A flat sheet membrane (CVWP00010, Millipore) with a pore size of 0.22 μm was used. A permeate volume was measured using an electronic balance. The temperature of the solution was kept constant at 20℃. Each membrane resistance was determined before and after filtration by measuring the flux of a permeate water at 0.4, 0.7, 1.0, and 1.3 bar, respectively. The specific cake resistance was measured using the single pass, steady state method as described earlier [9].

3. Results and discussion

3.1. Filtration characteristics of UF modules using compressible foulant

3.1.1. Submerged membrane filtration system

Fig. 3(a) shows the dependence of flux and suction pressure on time in the submerged membrane module. The flux was set to be constant at 50 L/m^2-h. The changes in the suction pressure were not significant during the operation, indicating that the fouling was not serious. Using the flux and pressure profiles, the permeability of the membrane was calculated as a function of time as shown in Fig. 3(b). The initial permeability was approximately 550 L/m^2-h-bar and decreased to 350 L/m^2-h-bar after 50 min. These results suggest that the fouling of the membrane in the submerged filtration mode was not substantial.

3.1.2. Pressurized membrane filtration system

Fig. 4(a) shows the profiles of flux and applied pressure in the pressurized membrane module. Although the same hollow fiber membranes were used (same fibers with the same length), the flux and pressure were significantly changed with time. Initially, the flux was set to 50 L/m^2-h but it could not be maintained due to rapid increase in the pressure. Accordingly, the final flux was only 22 L/m^2-h. The pressure increased up to 1.4 bar, which is the maximum pressure for the pump in the system. It is evident from these results that the fouling propensity in the pressurized module is different from that in the submerged module.

The permeability of the membrane was calculated by using the results in Figure 4(a) and shown in Figure 4(b). At the beginning of operation time, the permeability decreased and maintained under less than 20 L/m^2-hr-bar. This may be attributed to the difference in the pressure outside of the fiber. In the submerged module, the pressure outside the fiber is the atmospheric pressure. On the other hand, in the pressurized module, the pressure outside the fiber is initially higher than the atmospheric pressure. Moreover, the pressure increase if fouling occurs, leading to rapid decrease in the membrane permeability. Accordingly, membrane fouling may be sensitive to the types of the module.

3.1.3. Combined membrane filtration system

To further investigate the effect of membrane modules, experiments using the combined module were carried out. Fig. 5(a) shows the flux and TMP in the combined module. The TMP in this combined module is the sum of suction pressure and the applied external pressure as illustrated in Fig. 6. Similar to the pressurized module, the flux could not be maintained constant and the final flux was 28 L/m^2-h. Nevertheless, the

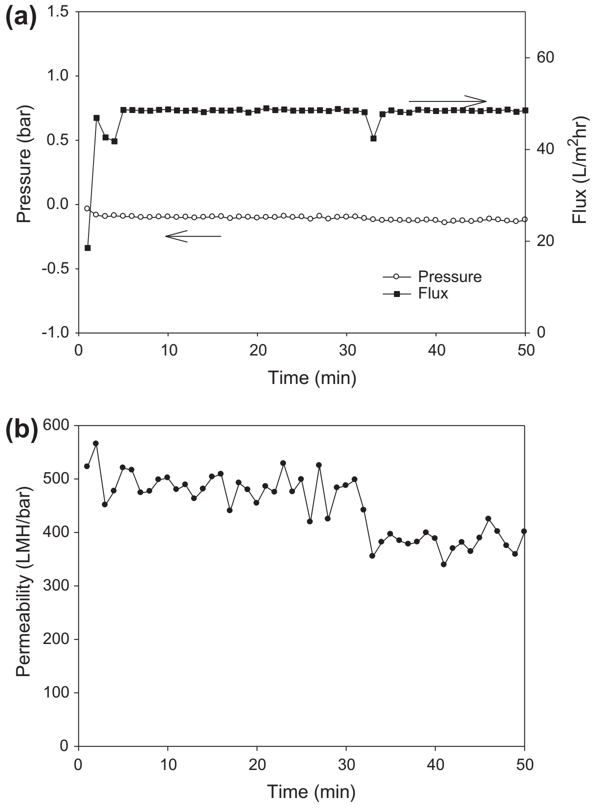

Fig. 3. Variations of flux, pressure, and permeability with time in the submerged membrane module: (a) flux and pressure and (b) permeability.

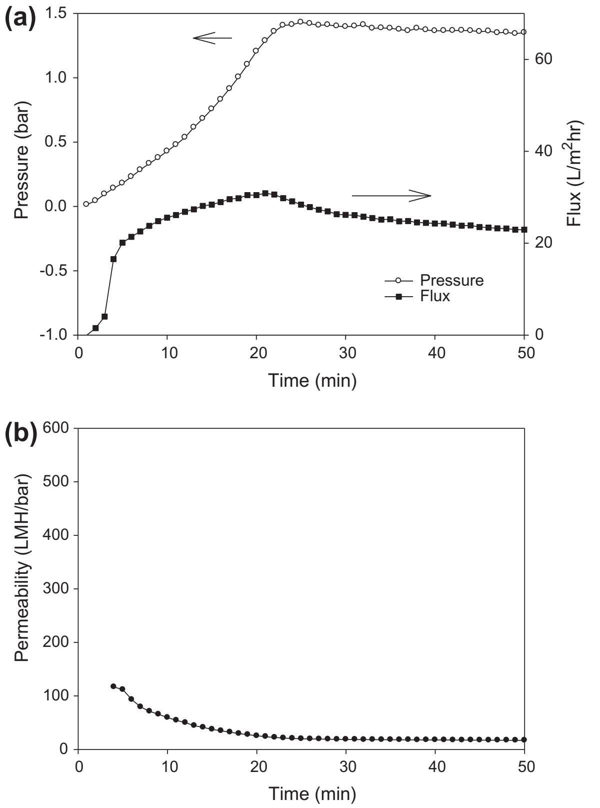

Fig. 4. Variations of flux, pressure, and permeability with time in the pressurized membrane module: (a) flux and pressure and (b) permeability.

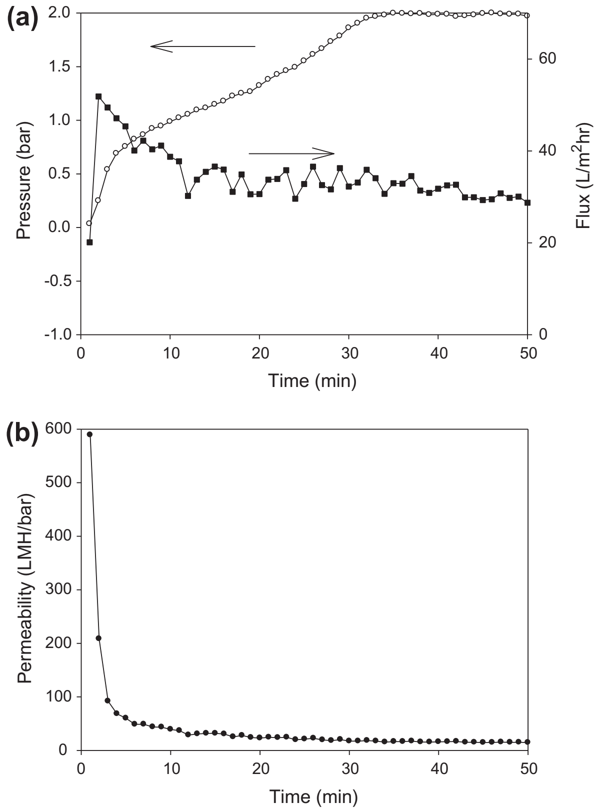

Fig. 5. Variations of flux, pressure, and permeability with time in the combined membrane module: (a) flux and pressure (○: pressure; ■: flux) and (b) permeability.

average permeability was slightly higher than that of pressurized module.

Fig. 6 shows how the pressure profiles changes with time. At the beginning, the absolute value for the suction pressure rapidly increases while the external positive pressure slowly increases. When the suction pressure approaches −0.9 bar, which is close to the maximum value, the external pressure rapidly increases. It is evident from the results that the combined module utilizes both suction and positive pressures. Further study will be necessary to optimize the design and operation of this combined module.

3.2. Compressibility of alginate

As mentioned above, the difference in the permeability between pressurized and submerged modules is likely to be related to the compressibility of foulants. To confirm this hypothesis, specific cake resistances were measured under different pressures. Fig. 7 shows the filtration results using the batch filtration cell. As illustrated, the permeability decreases as increasing the applied pressure.

The dependence of the specific cake resistance on the pressure is shown in Fig. 8. With increasing the pressure, the specific cake resistance increases. The compressibility index from this plot was calculated to 0.96.

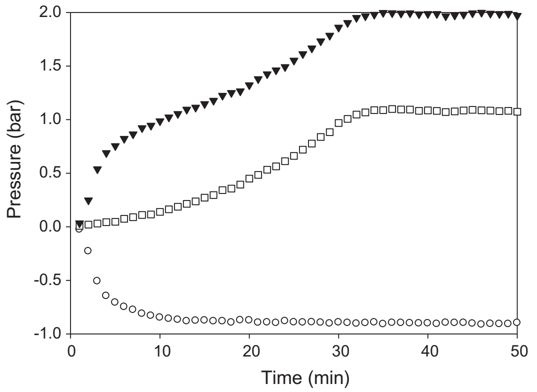

Fig. 6. Pressure profiles in the combined module (○: suction pressure; □: external pressure; ▼: total TMP).

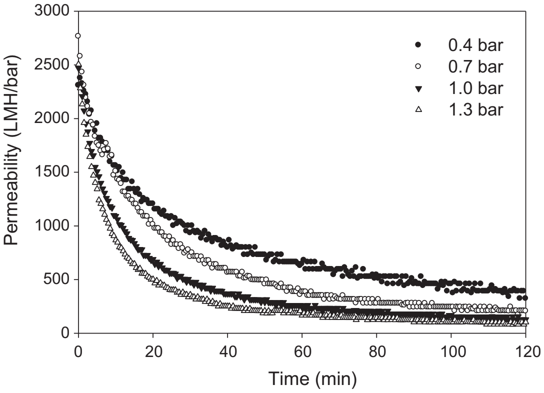

Fig. 7. Variation of permeability depending on pressure for alginate.

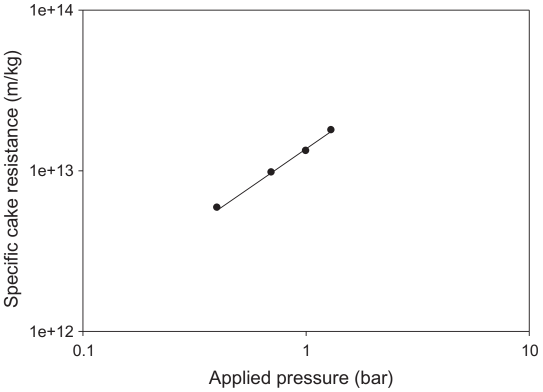

Fig. 8. Variation of permeability depending on pressure for alginate.

4. Conclusions

The following conclusions were withdrawn:

(1) Although same hollow fiber membranes were used, the filtration characteristics were different between submerged and pressurized modules. Slower fouling was observed in the submerged module than in the pressurized module.

(2) The difference in the membrane permeabilities between two modules may be attributed to the difference in the pressures outside of the fiber.

(3) A higher fouling propensity in pressurized module was observed than in submerged module. The compressibility of foulant is likely to be closely related to these phenomena as reported in the literature [8].

(4) The combined module showed the intermediate characteristics between the two modules. Nevertheless, further study is required to optimize this.

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