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TECHNICAL NOTE

Periodic Ultrafiltration by Single-Pass Flow Using Hollow Fiber Membrane Module

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ABSTRACT

Periodic ultrafiltration of bovine serum albumin (BSA) solutions by single-pass flow was conducted using a hollow fiber membrane module. In this method the filter cake formed on the membrane surface during filtration was disrupted by periodically interrupting filtration. Thus, a much higher filtration rate, which led to an increased concentration ratio of protein solutions, was provided by periodic operation compared with what was produced by continuous operation. Influences of filtration times (θ_f) and sweeping times (θ_d) on the filtration performance were examined.

INTRODUCTION

A colloidal solution becomes dramatically concentrated at the exit of a hollow fiber membrane module by flowing the solution through the module at an extremely small flow rate because the filter cake overlying the membrane is exfoliated continuously due to the principle of inclined ultrafiltration (1–3). However, a filter cake forms on the membrane even in this method.

Periodic operation in which the filter cake is exfoliated intermittently by interrupting filtration is becoming an increasingly attractive method for obtaining a higher filtration rate (4–6). Thus, a higher concentration of solutions would be obtained by a combination of periodic operation and single-pass flow with an extremely small velocity. This method helps

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to improve filtration performance by cleaning the membrane without putting undue stress on the membrane, and it is suitable for processes involving proteins and other biological molecules that may be denatured by the generation of heat or air bubbles caused by the use of a circulation pump. It should also be noted that the method requires less energy compared with closed recycle-flow operation with a relatively large velocity as employed in conventional crossflow filtration. In this article the physical process in which filtration is stopped periodically is examined under the single-pass flow condition in order to concentrate protein solutions efficiently, and it is compared to the continuous operation.

EXPERIMENTAL

A schematic layout of the experimental setup is essentially the same as described in another publication (3). A hollow fiber module (SLP-0053, Asahi Chemical Ind.) with a total membrane area of 150 cm^2 was used. The module contains 50 polysulfone hollow fibers with molecular weight cutoff values of 10 kDa. The inner diameter of the fibers is 1.4 mm. The module was placed on the angled plate vertically. In this case the direction that the filtrate flows is horizontal at every position along the membrane. Ultrafiltration experiments were carried out for a time θ_f under a constant pressure of 98 kPa by applying compressed nitrogen gas via a reducing valve to the feed reservoir connected to the module. The concentrate was drawn out using a Masterflex peristaltic pump (7553-20, Cole Parmer Instruments) with an extremely small flow rate. The system was then depressurized, and the permeate flow was stopped over a specified period of time θ_d while maintaining the tangential flow across the membrane. Then filtration ensued for a further time θ_f. This cyclic process of filtration followed by sweeping away the filter cake was repeated. The effects of filtration times (θ_f) and sweeping times (θ_d) on the filtration rate and the concentration of protein solutions were investigated. For comparison, continuous ultrafiltration experiments without depressurizing were also performed.

The filtrate and concentrate were each measured gravimetrically with electronic balances at set intervals. The solute concentrations in the concentrate were detected spectrophotometrically using the flow cell connected to the peristaltic pump. The volume (2 cm^3) in the tubing connecting the outlet of the concentrate with the short path flow cell is small enough to avoid time delay of the concentration measurements. The filtrate was collected in triangular flasks over measured time intervals. Sub-

sequently, the solute concentrations in the filtrate and feed were determined spectrophotometrically.

The protein employed in the experiments was bovine serum albumin (BSA; Fraction V) with a molecular weight of ca. 67 kDa and an isoelectric point of ca. 5.1 provided by Katayama Chemical Ind. The protein was dissolved in water prepared by an ultrapure water system for laboratory use (Puric-R, Olgano Corp.).

RESULTS AND DISCUSSION

Figure 1 illustrates the reciprocal filtration rate ($d\theta/dv$), which is a direct measure of the flow resistance, versus the cumulative filtrate volume v collected per unit active membrane area for different values of the filtration time θ_f. In the figure, s_i is the mass fraction of the solutes in the feed fluid, p is the applied filtration pressure, and q_{wo} is the mass flow rate of the concentrate. For continuous operation the plots are virtually linear

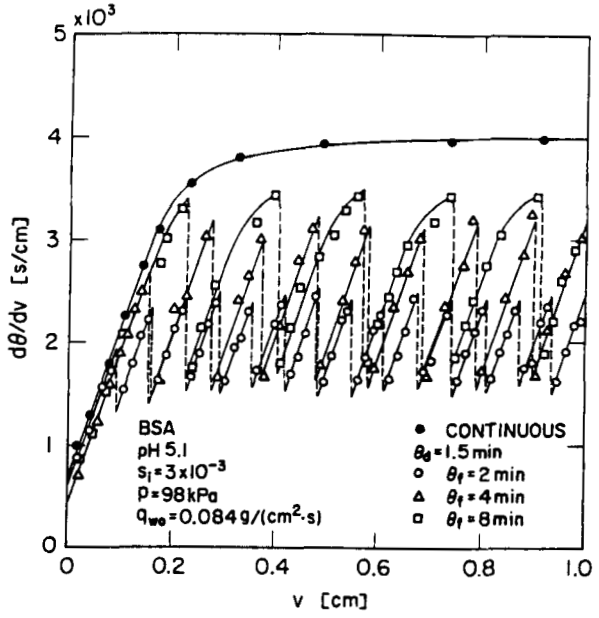

FIG. 1 Reciprocal filtration rate as a function of the filtrate volume per unit membrane area.

during the initial phase of filtration. As the filtration process continues, however, the plots begin to depart from this linear relationship, and then the filtration rate tends to approach a plateau value due to the principle of inclined membrane filtration (1–3). For periodic operation the plots yield straight lines with nearly the same slope for each filtration time θ_f. In this period the filter cake builds up at the surface of the membrane. Filtration was interrupted before the steady filtration rate was reached. As a result, the filtration rate increases dramatically, since the filter cake formed during the filtration period is removed for the time θ_d. The filtration rate increases to almost the same level, independent of the value of θ_f. This result suggests that the thickness of the remaining part of the cake is constant after sweeping operation irrespective of the filtration time.

The instantaneous concentration ratio (s_o/s_i) of the experiments described in Fig. 1 is shown as functions of the mass W of the concentrate in Fig. 2, where s_o denotes the mass fraction of the solutes in the concentrate. For continuous operation the concentration ratio initially increases

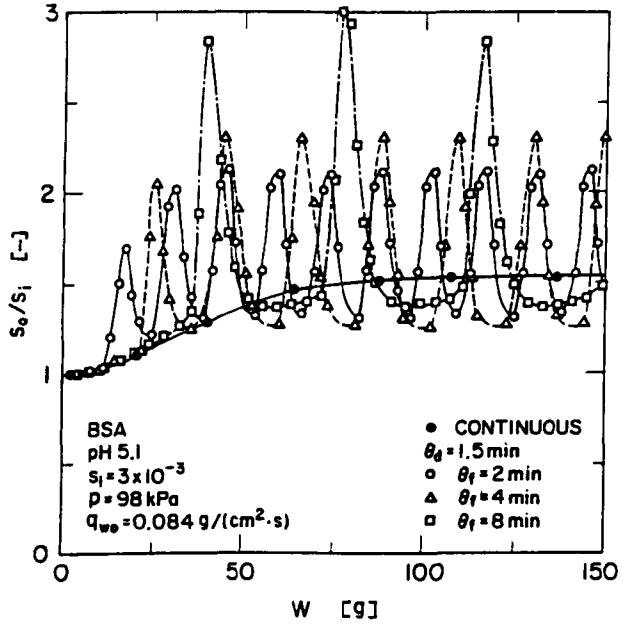

FIG. 2 Instantaneous concentration ratio as a function of the mass of concentrate.

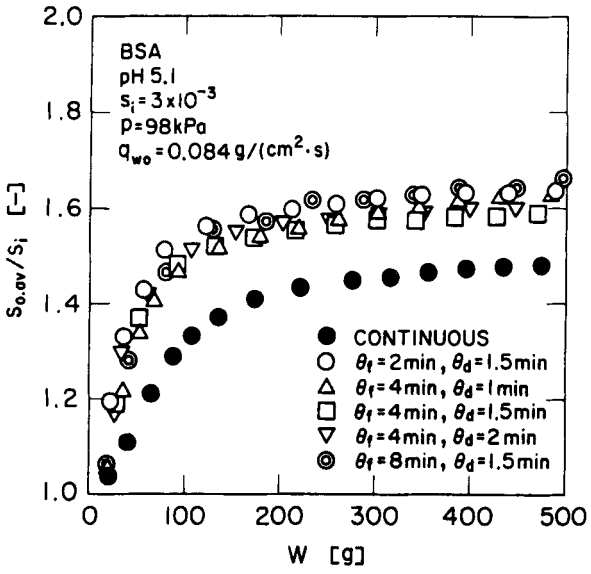

FIG. 3 Average concentration ratio as a function of the mass of concentrate.

gradually and eventually settles to an approximately constant value. The steady state can be obtained because the growth of the filter cake stops, and hence all the solutes are swept away. Interestingly, for periodic operation, the concentration ratio increased dramatically for the sweeping time compared with that of the continuous operation because the cake layer was disrupted. It should be noted that an increase in θ_f results in an increase in the concentration ratio. This is because the amount of the filter cake formed on the membrane is increased with increasing θ_f, and then a large amount of cake is removed.

In Fig. 3 the average values ($s_{o,av}/s_i$) of the concentration ratio of the whole concentrate collected are plotted against the mass W of the concentrate for various values of θ_f and θ_d. The average concentration ratio in the periodic operation increases compared with that in the continuous operation. It is found that θ_f and θ_d appear to have little effect on the average concentration ratio within the experimental range used in this study.

CONCLUSIONS

Periodic ultrafiltration in which filtration was stopped intermittently, combined with the single-pass flow, was found to be efficient for the concentration of protein solutions because the filter cake formed during filtration was disrupted. It can be expected that a concentrate with a high concentration will be obtained if one collects only the concentrate containing the filter cake swept away for the time θ_d.

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NOMENCLATURE

p	applied filtration pressure (Pa)
q_{wo}	mass flow rate of concentrate [kg/(m^2·s)]
s_i	mass fraction of solute in feed fluid
s_o	instantaneous mass fraction of solute in concentrate
$s_{o,av}$	average mass fraction of solute in concentrate
v	cumulative filtrate volume collected per unit active membrane area (m^3/m^2)
W	mass of concentrate (kg)

Greek Symbols

θ	time (s)
θ_d	operating time for sweeping away filter cake (s)
θ_f	filtration time (s)

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