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Parallel Electric Field in Flux Restoration during Ultrafiltration

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Abstract

Ultrafiltration membrane permeability may be restored by applying an electric field parallel to the plane of the membrane in the feed compartment of ultrafiltration cells. Two different electrode arrangements are described. Under some conditions, flux restoration is complete. An electric field parallel to the membrane can thus be used to eliminate membrane polarization and fouling.

INTRODUCTION

Ultrafiltration (UF) is used (*1*) to concentrate, to purify, and to fractionate proteins, carbohydrates, synthetic polymers, and colloids of various types. In every case, effuent flux declines with time due to retentate accumulation over the membrane. Membrane fouling (*2*) is troublesome and decreases the efficiency of ultrafiltration. Mechanical and electrical methods have been proposed to counteract fouling and to improve separation methods.

Electrophoresis combined with filtration was first proposed by Manegold (*3*). Beechold (*4*) utilized a combination of electrophoresis and electroosmosis to purify colloids. Theoretical treatments have been done by Moulik, Cooper, and Bier (*5*). Henry et al. (*6*) introduced a process they called crossflow-electrofiltration; this process combines fluid shear due to crossflow filtration with electrophoresis. Radovich et al. (*7*) coupled electrophoresis with UF in order to increase the flux and improve selectivity in protein purification. Grodzinsky and Weiss (*8*) presented a review of the membrane separation process in which an electric field acts not only on

the solutes to be transported but also on the membrane matrix itself. Electroadsorption on porous electrodes was utilized by Soffer et al. (*9*) to purify aqueous dispersions of colloidal particles. Recently, Bowen et al. (*10*) described *in-situ* electrolytic membrane restoration, using electrical pulses (0.92 $kA \cdot m^{-2}$ for 7.5 s) to clean up the membranes. In this case, as well as in all the other cited methodologies, the membrane was mounted between the electrodes; the electrical field was thus perpendicular to the membrane plane, with one electrode in the feed compartment and the other in the permeate side.

This paper shows that *in-situ* cleaning of ultrafiltration membranes can be done even when both electrodes are mounted in the feed compartment. This increases the versatility of electrical techniques for membrane recovery.

EXPERIMENTAL

Materials

Granulated cellulose acetate was kindly supplied by Rhodia and identified by its FTIR spectrum. Its molecular weight was 3.5×10^4 daltons, as obtained by viscosity measurements. Acetic acid and acetone were purchased from Vetec. Blue Dextran, nominally of MW 2×10^6, was from Sigma. The water was deionized, doubly distilled, and its conductivity was in the range of 3–3.5 μs.

Membrane Preparation

Asymmetric cellulose acetate membranes were prepared (*11*) by film coagulation in water. The film was formed by spreading a solution of 56% acetic acid, 18% acetone, and 26% water over glass plates. Spreader thickness was 0.3 mm. Membrane thickness, determined with an optical microscope, was 124 ± 24 μm. The water flux was between 3.8 and 4.1 $mL \cdot min^{-1} \cdot cm^{-2}$ when the pressure was 2.5 kPa.

Apparatus

The membrane cell utilized in this work was made of an acrylic cylindrical tube (Fig. 1). Two different electrode geometries were tested (Fig. 2). In both cases the platinum electrodes were parallel and 4 mm away from the membrane surface in the feed compartment. The membrane area was 6.34 cm^2.

The feed solution was introduced through an upper inlet perpendicular to the membrane surface. The driving force was a hydrostatic pressure of 2.5 m of liquid column (Fig. 3). The filtrate was collected into graduated tubes, and volume measurements were made as a function of the time.

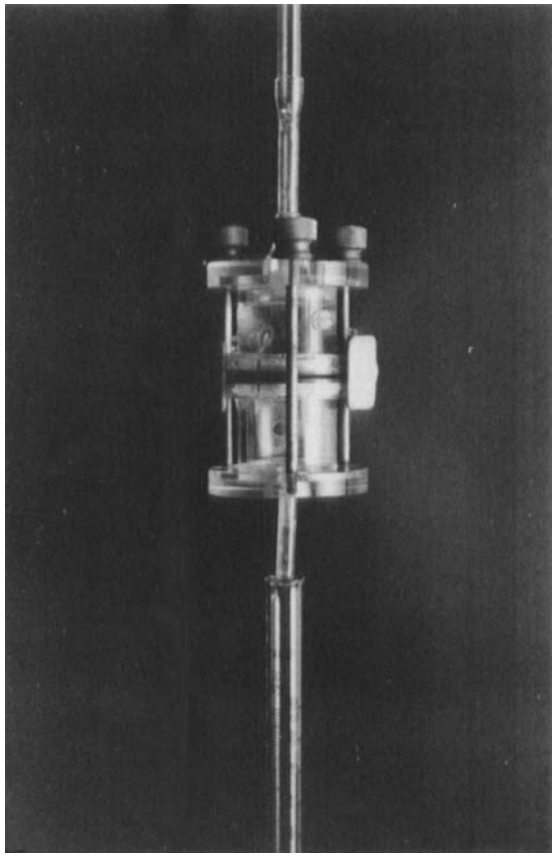


FIG. 1. Membrane test cell: internal diameter = 2.84 cm, total length = 6.20 cm.

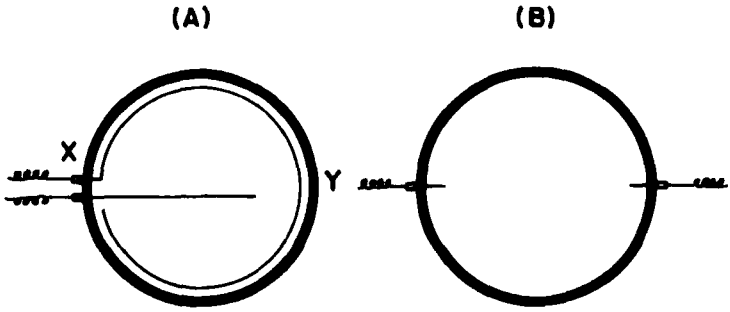


FIG. 2. Electrode geometries used in this work: (A) circular, (B) parallel.

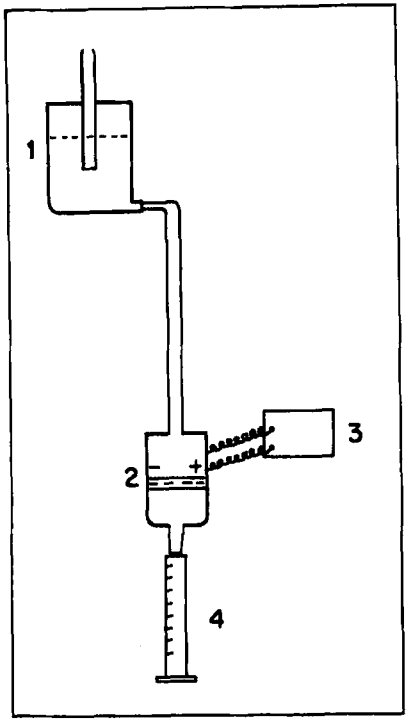


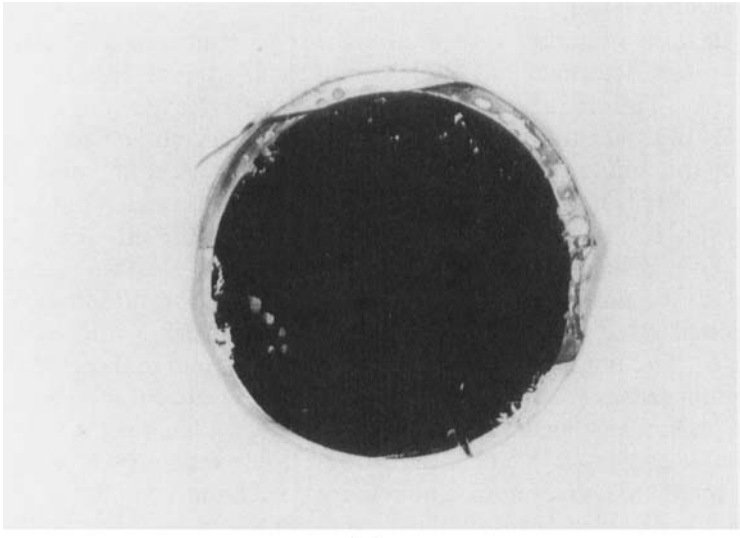
FIG. 3. Experimental apparatus. 1: Feed reservoir. 2: Ultrafiltration cell. 3: Power supply. 4: Graduated tube for permeate volume measurement.

The dc voltage source was a Hewlett-Packard model 712B power supply (0–500 V). All experiments were carried out at 25 ± 1°C in an air-conditioned room.

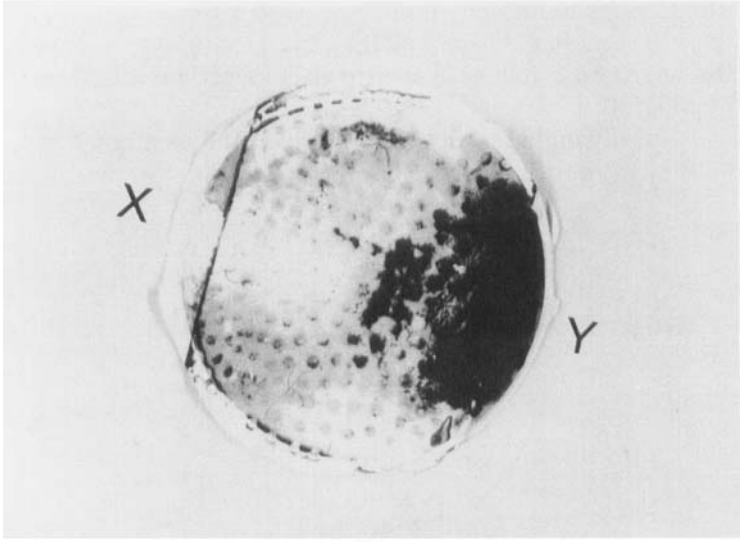
RESULTS

Visual Observations

Some experiments were carried out by using a carbon black dispersion to allow visual observations. That procedure showed that particle migration begins when the voltage is ~60 V. A larger portion of clean membrane surface is obtained when the circular electrode is the anode. Figure 4 presents two membrane pictures: both show membranes used in carbon UF, one of which was cleaned by switching on the electric field. Notice that the particles were driven away from the membrane surface by the electric field.



(a)



(b)

FIG. 4. Membranes used in carbon UF. (a) Normal UF. (b) Electric field-coupled UF, circular geometry.

Flux Measurements

Blue dextran solutions were used for flux determinations. Water flux was previously determined as a function of time; a typical result is shown in Fig. 5(A). The characteristic filtration rate–time decay is registered for a 0.025% Blue Dextran solution (Fig. 5B). The membrane retention is 100% for this solute (checked by absorbance readings at 650 nm). After 40 min the flux is half of the initial value. If the UF is carried out for 1 h, a steady flux is obtained in the range of $1.5–1.8 \times 10^{-2}$ mL·min^{-1}·cm^{-2}, that is, 30% of the initial flux. When the same Blue Dextran solution is filtered but the voltage is applied after 60 min filtration, the flux returns to the initial value and remains at this level for as long as the voltage is on (Fig. 6). The time lag for flux restoration is ~20 min in this case. Field interruption causes a new flux decline. The electric current is in the range of 5 to 7 mA, which means a power consumption of less than 0.5 W. This value can be decreased by a change in the electrode geometry. B geometry, with its small area, gives a maximum current of 2.5 mA for 100 V. In this case the coupled electrical field UF again shows flux restoration (Fig. 7), but now a steady flux is soon obtained at values 1.48 and 1.74 times the flux measured prior to turning on the voltage (for 100 and 150 V, respectively). Flux restoration is thus voltage- and electrode-area dependent. Flux is also increased if voltage is applied after longer ultrafiltration times, up to 17 h (Fig. 8).

We have also attempted to fit electrodes over the membrane in a Millipore (ϕ = 5 cm) ultrafiltration cell. Flux restoration by applied voltage

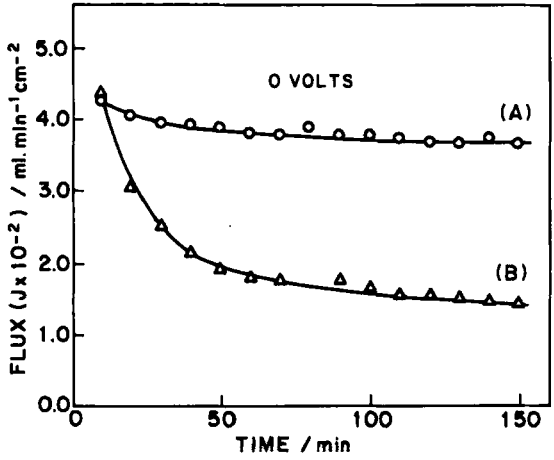


FIG. 5. (A) Water flux through cellulose acetate membrane. (B) Flux decrease in Blue Dextran ultrafiltration.

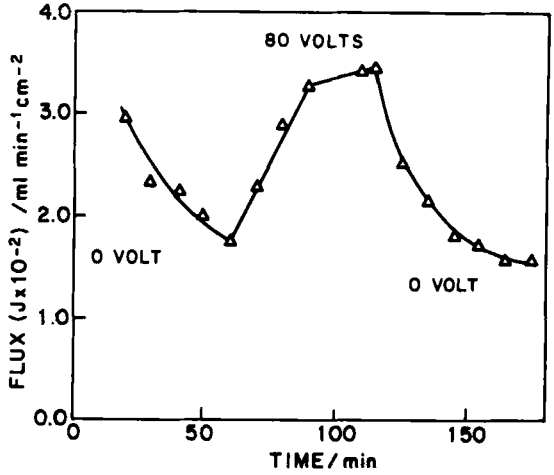


FIG. 6. Electric field effect upon Blue Dextran UF (Geometry A).

was not observed in this case, perhaps due to the fins fitted in this cell which prevent fluid motion parallel to the membrane.

DISCUSSION

Flux restoration during ultrafiltration can occur by coupling an electric field perpendicular to the direction of permeate flow. Both electrodes are located in the feed compartment.

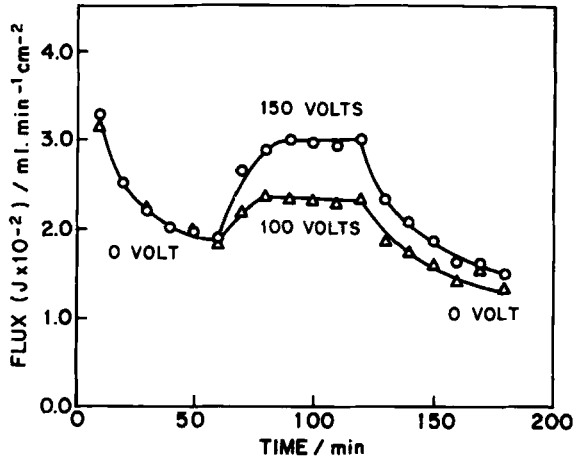


FIG. 7. Voltage effect on flux restoration (Geometry B).

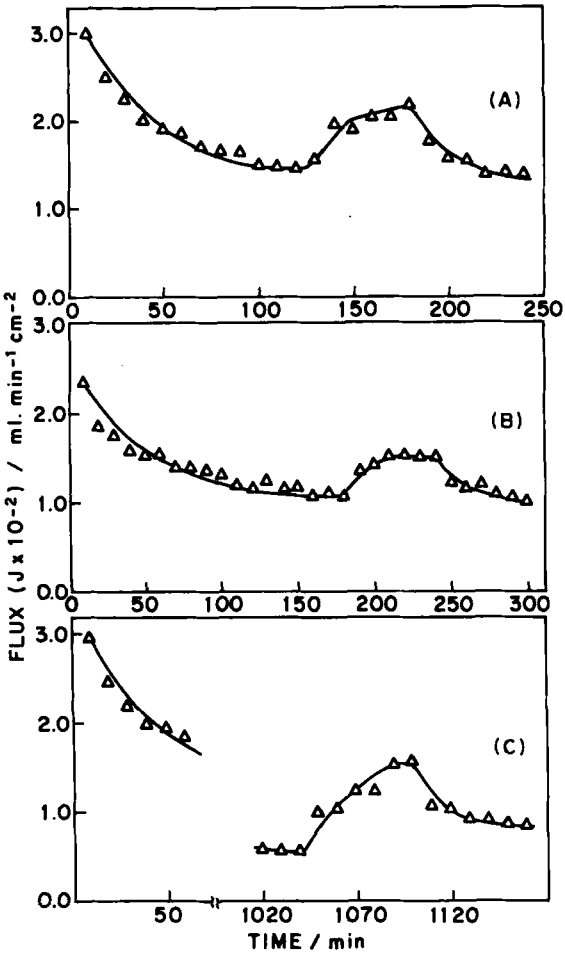


FIG. 8. Flux restoration by electrical field applied after different filtration running times (in hours): (A) 2, (B) 3, (C) 17.

The results show that permeate flux can be restored up to the initial value, depending on geometry and voltage. The flux restoration rate also depends on the same parameters. The results in Table 1 indicate that when circular geometry is used, membrane fouling is counteracted more efficiently; permeate flux returns to the initial value and the flux restoration rate is higher than when using the other geometry. Two membrane pictures are shown in Fig. 4: one was obtained after carbon UF and the other is from a membrane utilized in a circular geometry cell after performing UF

TABLE 1
Flux Restoration Rate and Restoration Factor $R = J_m/J_f$ (J_m is the maximum flux as restored by electrical field coupling and J_f is the flux just before turning on the electric field)

Voltage (V)	Geometry	Previous running time (h)	$V = J/t$ (mL·min^{-2}·cm^{-2}) × 10^4	R
60	A	1	3.2	1.94
100	B	1	2.8	1.31
150	B	1	4.8	1.50
100	B	2	2.5	1.34
100	B	3	1.8	1.32
100	B	17	1.7	2.63

assisted by a parallel electric field. These photos indicate that besides the electrical potential used, the force field configuration is also important. Figure 4(b) shows that the cleanest region over the membrane does not correspond to the regions of higher fields (compare the electrode position with Fig. 2A).

We first assumed that flux restoration occurs by particle electrophoresis parallel to the membrane surface. Thus, at each voltage pulse a portion of the membrane surface is freed of particles. Assuming that particle mobilities are between 4 and 7 × 10^{-4} cm^2·s^{-1}·V^{-1} and the average electric field is 50 V·cm^{-1}, we obtained stationary electrophoretic velocities between 0.20 and 0.035 cm·s^{-1}. On the other hand, particle migration velocities due to vertical flux (which is in the range of 0.015 and 0.040 mL·min^{-1}·cm^{-2}) are between 0.9 and 2.4 cm·s^{-1}. Therefore, particle deposition velocities will always be greater than the electrophoretic tangential velocity. Thus, factors other than particle electrophoresis are responsible for membrane defouling. Some of them are: 1) electroosmotic fluid movement in the neighborhood of the membrane surface, throughout the polarization layer, 2) turbulence in the fluid due to electric field gradients, and 3) particle drag due to "slip-spin" forces (*12*) that act upon particles flowing in a shear field.

In this work we utilized long pulses and low voltages. Recently Bowen et al. (*10*) examined another electrical technique for membrane cleaning during microfiltration. They made use of brief and intermittent field pulses of high current, and they concluded that this can be economically viable. This aspect of the technique described in this paper, as well as the question of the actual mechanism of depolarization, will be the subject of future work.

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