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TECHNICAL NOTE

Experimental Crossflow Filtration of Pure Solvent in a Rectangular Slit with One Semipermeable Wall

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ABSTRACT

A filtration channel (rectangular slit) with one semipermeable wall can be easily used in the experimental verification of theoretical models of crossflow filtration. Experimental results with pure water coincide very well with predictions of analytical formulas, taking into account longitudinal variation of filtration flux.

INTRODUCTION

In the last decades continuous crossflow filtration has been widely used in the fields of biomedicine (1), biotechnology and wastewater treatment (2), and for the petroleum industry (3). The theoretical treatment of mass-transfer problems in crossflow filtration must take into account the specificity of the filtered solution and usually requires the application of numerical methods; see, e.g., Ref. 4. Approximate analytical solutions under several simplifying assumptions provide a description of useful limiting cases (4, 5).

A simple analytical equation, derived in Ref. 6 (cf. Ref. 4) for the filtration of pure solvent in a channel with one semipermeable wall is tested here experimentally. This filtration channel geometry* can be easily used

* Under different simplifying assumptions relevant for field-flow fractionation of proteins, crossflow filtration in the same geometry has been considered theoretically and tested experimentally in Ref. 11.

in the experimental verification of theoretical models (7, 8). Such analytical formulas for crossflow filtration of a one-component liquid can describe the case of vanishing concentration of a second rejected component, which any self-consistent theory should yield as a limiting case.

The scaled filtration flux is given by the following equation (6) [similar in form to respective equations for other relevant channel geometries (5)]:

$$\tilde{v}_w = \tilde{P}(\tilde{x})/\tilde{P}_0 = 1/2[(1 - 2\alpha)\exp(\alpha\tilde{x}) + (1 + 2\alpha)\exp(-\alpha\tilde{x})] \quad (1)$$

where

$$\alpha = (3/2\tilde{P}_0)^{1/2}$$

and

$$\tilde{x} = xv_{w,0}/u_0h, \qquad \tilde{P} = hv_{w,0}P/\mu_s u_0^2, \qquad \tilde{v}_w = \tilde{P}/\tilde{P}_0$$

where x = longitudinal coordinate, $v_{w,0}$ and P_0 denote, respectively, filtration flux and pressure at $x = 0$, μ_s is the Newtonian dynamic viscosity, and u_0 is the average entrance velocity (cm/s). With dimensional variables, Eq. (1) reads

$$P = P_0 \cosh(\lambda x) - 3\mu_s u_0 \sinh(\lambda x)/\lambda h^2 \quad (2)$$

where

$$\lambda = (3\mu_s/2R_m h^3)^{1/2}$$

$$u_0 = Q_{in}/2hW \quad (3)$$

and h is half of the height of the narrow slit $h \ll W$, W = width of the rectangular slit, and Q_{in} = total inlet flow rate.

$$Q_{in} = Q_x + Q_f \quad (4)$$

where Q_f (cm^3/s) is the filtration flow rate and Q_x is the tangential flow rate.

The fluid is considered to be pure incompressible solvent. Due to the filtration along the channel, the flow rate diminishes. The dimensional filtration flux is given by

$$v_w(x) = P(x)/R_m \quad (5)$$

where R_m denotes the membrane resistance and $P(x)$ is the transmembrane pressure.

$$Q_f = W\int_0^L v_w(x)dx$$
$$= W[P_0(e^{\lambda L} - e^{-\lambda L})/\lambda - 3\mu_s u_0(e^{\lambda L} + e^{-\lambda L} - 2)/\lambda^2 h^2]/2R_m \quad (6)$$

EXPERIMENTAL

Microfiltration membranes from Polyamide, 0.45 μm (SF "Spartack," Bourgas, Bulgaria), were used. The filtration resistance with respect to water, R_m, of each piece of membrane used was additionally established (in overall agreement with the catalog value—see below).

The filtration experiment was performed using prefiltered distilled water (Millipore disposable filter unit, 0.1 μm) with the addition of sodium azide (65 mg/L). The sodium azide protects water from the growth of microorganisms.

The experiments were performed in a small laboratory microfiltration setup similar to the one originally described in Ref. 9. It was additionally equipped with a computerized data acquisition system described in detail in Ref. 10. With the help of three pressure transducers the time traces of the three pressures with respect to atmospheric pressure (P_1 and P_2 are, respectively, at the tangential inlet and at the tangential outlet above the membrane filter foil, and P_3 is below the filter in the middle of the filtration path) and two flow rates (tangential and filtration) were registered.

The geometric parameters of the filtration channel were $h = 0.051$ cm, $W = 0.5$ cm, and $L = 6.2$ cm.

All experiments were performed at a constant hydraulic pressure of approximately 600 Pa, and P_1 and Q_{in} were changed by means of a clamp at the tangential outlet. A steady state with water is established within minutes.

With respect to P_3, the inlet pressure is $P_0 = P_1 - P_3$, and the pressure at the end of the filtration path ($x = L$) is $P_L = P_2 - P_3$. Experiment yields P_0, P_L, Q_x, and Q_f directly.

TABLE 1
PA Membrane with $R_m = 16 \times 10^6$ N·s/m^3

P_0, cm H_2O measured	P_L, cm H_2O measured	P_L, cm H_2O calculated	Q_f, mL/s measured	Q_f, mL/s calculated
5.1	1.9	2.0	0.0064	0.0059
5.3	2.1	2.5	0.0069	0.0066
6.8	4.4	4.3	0.0098	0.0094
9.0	6.9	7.0	0.013	0.0137
11.35	9.9	9.9	0.017	0.018
12.0	11.3	11.0	0.020	0.020
13.9	13.6	13.4	0.026	0.024
15.55	15.5	15.4	0.027	0.027

TABLE 2
PA Membrane with $R_m = 23 \times 10^6$ N·s/m^3

P_0, cm H_2O measured	P_L, cm H_2O measured	P_L, cm H_2O calculated	Q_f, mL/s measured	Q_f, mL/s calculated
6.2	3.0	3.2	0.0060	0.0065
8.2	5.4	5.7	0.0084	0.0090
9.6	7.3	7.5	0.010	0.010
11.3	9.7	9.8	0.012	0.013
14.05	13.2	13.3	0.015	0.017
14.86	14.7	14.7	0.018	0.018

COMPARISON OF CALCULATED AND EXPERIMENTAL RESULTS

The independently measured values of R_m are in the range 16–23 × 10^6 N·s/m^3.

The pressure P_L is calculated from Eq. (2) with measured values of u_0, h, R_m, and P_0. The values of Q_f are calculated from Eq. (6). The experimental results are compared with calculated values in Tables 1 and 2 for experimental runs with different membrane pieces. Calculated values of Q_f and P_L coincide very well with directly measured ones.

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