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Filtration Resistance in Crossflow Microfiltration for Microbial Cell Suspension

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Experiments were performed to clarify the characteristics of filtration resistance in crossflow microfiltration for two kinds of baker's yeast cell suspensions as a model sample of microbial cells. From the data for filtration flux at steady state, the filtration resistances were calculated. The filtration resistance at steady state was found to be a function of only filtration pressure for two kinds of baker's yeast cell suspensions. As a result, two correlation equations for filtration resistance at steady state were obtained.

Introduction

Crossflow microfiltration is considered a promising technology to solve many separation problems, especially in food and beverage industries. This is due to the simplicity and the gentle nature of the process, that is, high temperature and phase change are usually not required. The low energy requirements and the often-low capital and operating costs are also advantageous. However, it is difficult to evaluate the filtration flux, which is most important in practical processes, because many microbial cells form a dense cake layer which cannot be easily removed by the shear stress action of fluid on the membrane surface, and the filtration flux is consequently decreased (Belfort *et al.*, 1994; Kroner *et al.*, 1984; Defrise and Gekas, 1988). The permeation behavior in crossflow microfiltration of suspensions of spherical, monodisperse and incompressible particles, such as latex, has not been well elucidated (Belfort *et al.*, 1994; Kimura, 1992). The behavior would be more complicated in crossflow microfiltration of microbial cell suspensions since microorganisms are not always spherical and the cake of microbial cells is usually compressible.

In this study, the filtration characteristics in crossflow microfiltration for two kinds of baker's yeast cell suspensions as model samples of microbial cells are investigated. The filtration fluxes at steady state obtained from the data of flux decline are considered using Darcy's law, and the filtration resistance in crossflow microfiltration at steady state is found to be a function of only filtration pressure. As a result, two correlation equations for the filtration resistance at steady state are obtained for two tested samples.

1. Experimental

A schematic diagram of the crossflow microfiltration system is shown in **Fig. 1**. It is composed of a feed circulation system, a crossflow filtration module and a computer system to measure the filtrate. **Figure 2** shows the assembly of the module. The module was constructed with three assemblies (A, B and C). The feed solution was pumped into the flow channel through the A and B

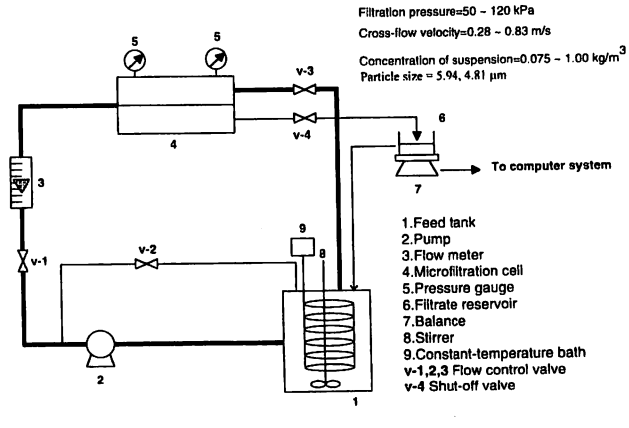

Fig. 1 Schematic diagram of experimental apparatus

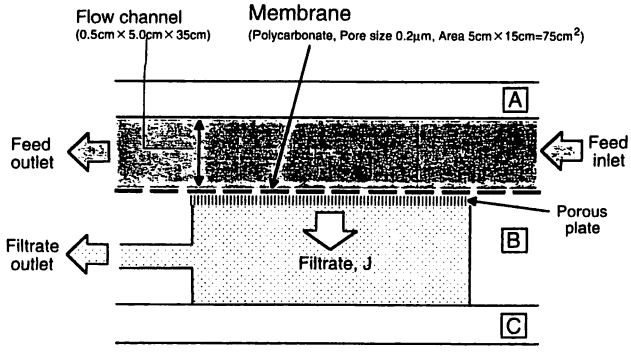

Fig. 2 Crossflow microfiltration module

assemblies. The dimensions of the flow channel were: depth 5 mm, width 5 cm and length 35 cm. A nuclepore membrane with a pore size of 0.2 μm (Polycarbonate, Nomura Micro Science Co., Ltd.) was set on the bronze support of a porous plate. The effective membrane area for the filtrate was 75 cm^2. The cross flow velocity, u, was varied from 0.28 to 0.83 m/s. The filtration pressure, ΔP, was varied in the range of 50 – 120 kPa. The concentration of the suspensions, C, ranged from 0.075 to 1.0 kg/m^3. Two kinds of baker's yeast cells (wet and dry) were used as shown in **Table 1**. The particle size in Table 1 was evaluated using photographs by an optical microscope.

Table 1 Characteristics of particles employed

Particle	Volumetric mean diameter [μm]	Remarks
Baker's yeast	5.94	Wet
Baker's yeast	4.81	Dry

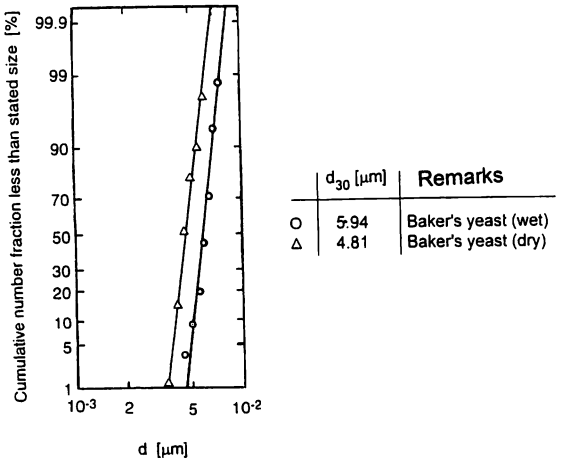

Fig. 3 Particle size distribution

Figure 3 shows the particle size distribution on log-normal probability distribution plots. As shown in this figure, for two kinds of baker's yeast cell particles, the linearity suggests that the log-normal probability function provides a satisfactory representation of the measured distribution. Therefore, the particle size distribution data roughly fit a log-normal probability distribution. The number distribution function in this case is given as

$$\frac{dR}{d\{\ln(d_p/d_{pG})\}} = \frac{1}{\sqrt{2\pi}\ln s_G}\exp\left[-\frac{\{\ln(d_p/d_{pG})\}^2}{2(\ln s_G)^2}\right] \quad (1)$$

Two parameters are required to determine the mean particle size, that is, d_{pG} and s_G. They can be obtained from the data as

$$d_{pG} = (d_{p1}\cdot d_{p2}\cdots d_{pn})^{1/n} \quad (2)$$

and

$$s_G = \exp\left[\sum\{\ln(d_p/d_{pG})\}^2/n\right]^{1/2} \quad (3)$$

Where d_{pG} is the geometric mean diameter and s_G is the geometric standard deviation. The relationship between d_{ji} and d_{pG} of a log-normal probability distribution is (Mugele and Evance, 1959)

$$d_{ji} = d_{pG}\exp\{(j+i)(\ln s_G)^2/2\} \quad (4)$$

The volumetric mean diameter of each particle employed, d_{30}, can be calculated using Eqs. (2), (3) and (4). The results are also shown in Table 1. Pure water obtained by a reverse osmosis instrument (Elix 10, Japan Millipore Co., Ltd.) was used to suspend these particles.

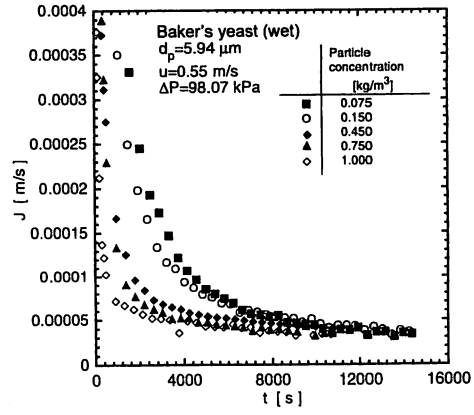

Fig. 4 Effect of particle concentration on time course of filtration flux

2. Results and Discussion

2.1 Time course of filtration flux

Figure 4 shows the data for the time course of filtration flux under several particle concentrations. A steady state was reached when the filtration flux remained constant. As shown in this figure, the steady state for each particle concentration condition is reached within around 3 hours (10800 seconds). This figure also shows the effect of particle concentration, C, on filtration flux, J. At the beginning of filtration period, J increases with decreasing C. However, as filtration progresses the difference of filtration flux for each concentration is not markedly affected.

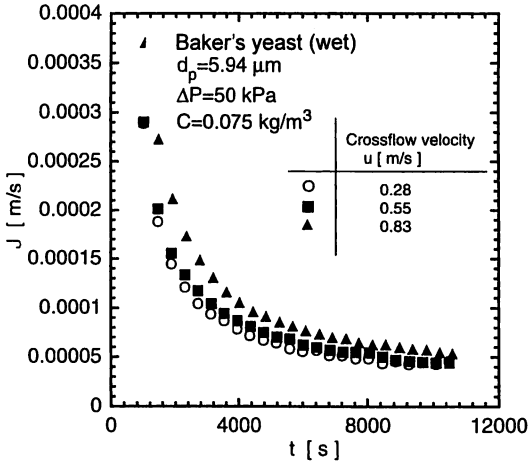

Fig. 5 Effect of crossflow velocity on filtration flux

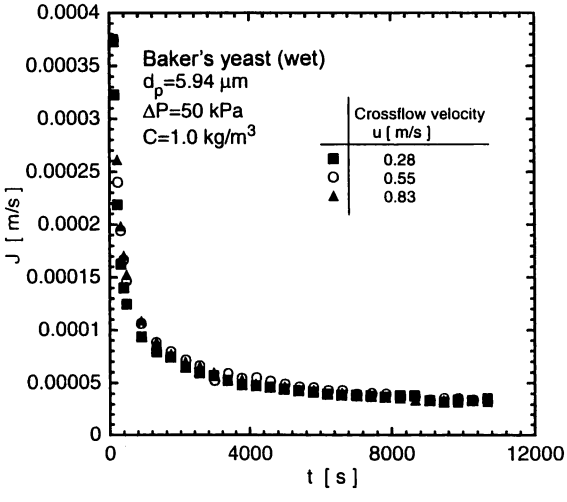

Fig. 6 Effect of crossflow velocity on filtration flux

The effects of cross flow velocity on filtration flux are shown in **Fig. 5** (for C=0.075 kg/m^3) and **Fig. 6** (for C=1.0 kg/m^3). As shown in these figures, increasing the cross flow velocity enhances the filtration flux at relatively low particle concentration, while at high particle concentration the effect of cross flow velocity is not noticed. This indicates that the cake layer of baker's yeast cells is hard to remove by shear force induced by cross flow probably due to the adhesion of yeast cells on the membrane at high particle concentration.

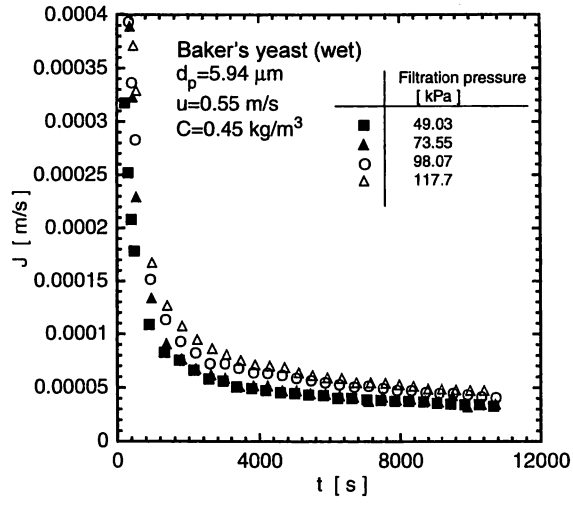

Fig. 7 Effect of filtration pressure on filtration flux

The effect of filtration pressure, ΔP, on filtration flux is shown in **Fig. 7**. From this figure, it is found that increasing the filtration pressure enhances the filtration flux. The results mentioned above are for baker's yeast (wet).

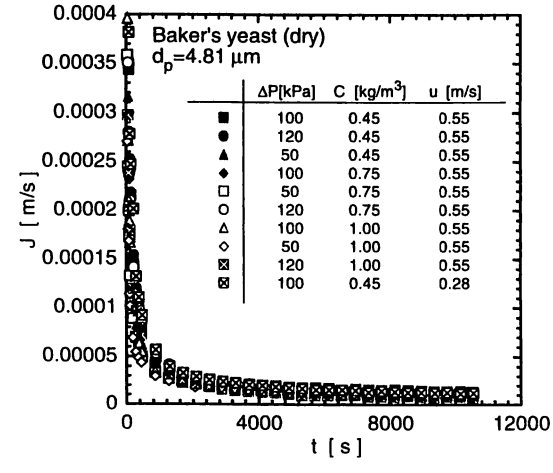

Fig. 8 Time course of filtration flux under all conditions for baker's yeast (dry)

Figure 8 shows the data for the time course of filtration flux under all conditions for baker's yeast (dry). As shown in this figure, none of the effects of any operating conditions employed in this study on filtration flux over time are observed. This is probably due to the compressible characteristic of microbial cells. However, the reason is not clear.

2.2 Filtration resistance at steady state

In practice, a filtration flux decline from the initial value to a steady value is observed over time. Filtration flux with the cake and membrane resistances being time dependent may be written as (Murkes, 1990; Song, 1998)

$$J = \frac{\Delta P}{\mu(R_m + R_c)} \tag{5}$$

where μ is the viscosity of liquid, J the filtration flux, ΔP the filtration pressure, and R_m and R_c are the membrane resistance and the resistance of the cake layer, respectively. As reported earlier by the authors (Miyahara *et al.*, 2000), the resistance of the cake layer is very large compared with that of the membrane. Thus, the crossflow microfiltration resistance controls the filtration resistance of the cake layer. Therefore, Eq. (5) can be rewritten as follows:

$$J = \frac{\Delta P}{\mu \cdot R_c} \tag{6}$$

At steady state,

$$J_s = \frac{\Delta P}{\mu \cdot R_{cs}} \tag{7}$$

As mentioned above, the crossflow microfiltration in this study controls the filtration resistance of the cake layer. Thus, we obtained R_{cs} using Eq. (7) and the filtration flux at steady state. **Figure 9** shows the correlation of resistance of the cake layer for baker's yeast (wet). From this figure, it is found that R_{cs} is a function of only filtration pressure. Furthermore, from **Fig. 10**, R_{cs} for baker's yeast (dry) also becomes a function of only filtration pressure. From these figures, we obtained the following correlations for R_{cs} for each baker's yeast cell suspension, respectively.

$$R_{cs} = 2.53 \times 10^7 \Delta P \tag{8}$$

for baker's yeast (wet) and

$$R_{cs} = 5.35 \times 10^6 \Delta P^{1.25} \tag{9}$$

for baker's yeast (dry)

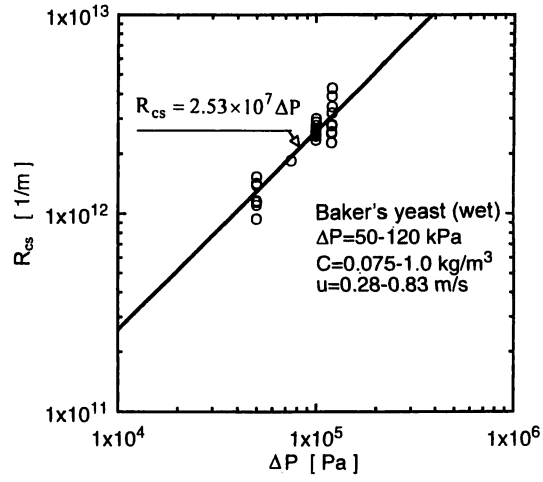

Fig. 9 Correlation of resistance of the cake layer for baker's yeast (wet)

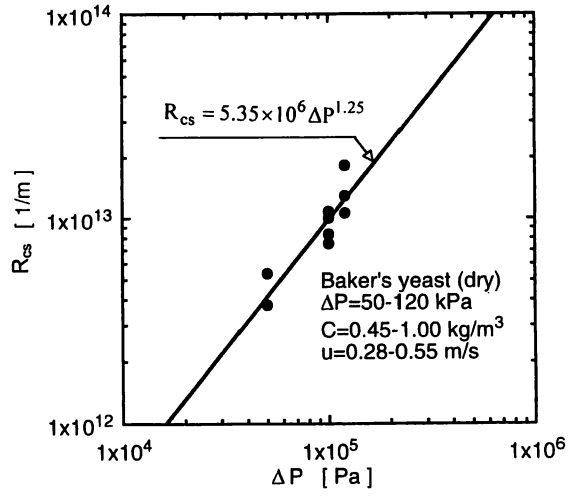

Fig. 10 Correlation of resistance of the cake layer for baker's yeast (dry)

Concluding Remarks

To clarify the filtration characteristics in crossflow microfiltration for microbial cell suspension, experiments were conducted using two kinds of baker's yeast cell (wet and dry) suspensions as model samples. As a result, the following conclusions were drawn:

1) For baker's yeast (wet), the filtration flux increases with decreasing suspension concentration at the beginning of filtration period, while no marked difference in filtration flux for with suspension concentration is noticed as the

filtration progresses. However, these findings are not noticed for baker's yeast (dry).

2) For baker's yeast (wet), increasing the cross flow velocity enhances the filtration flux at relatively low suspension concentrations, while at high concentrations the effect of cross flow velocity is not noticed. However, these findings are not found for baker's yeast (dry).
3) For baker's yeast (wet), increasing the filtration pressure enhances the filtration flux, while for baker's yeast (dry) no effect of filtration pressure is noticed.
4) The resistance of the cake layer at steady state for each baker's yeast is a function of only filtration pressure. Therefore, two empirical correlation equations are obtained.

Nomenclature

C = concentration of suspension, kg/m^3
d_p = particle diameter, m
d_{ji} = general mean particle diameter, m
d_{pG} = geometric mean particle diameter, m
d_{30} = volumetric mean particle diameter, m
J = filtration flux, m/s
J_s = filtration flux at steady state, 1/m
ΔP = filtration pressure, Pa
R_c = filtration resistance of the cake layer, 1/m
R_{cs} = filtration resistance of the cake layer at steady state, 1/m
R_m = filtration resistance of the membrane, 1/m
s_G = geometric standard deviation
t = time, s
u = cross flow velocity, m/s
μ = viscosity of liquid, Pa.s

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