일반강연 II-10

A Study on Cake Resistance and Microfiltraion Performance of Rotating Membrane Filters

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회전막 정밀여과기에서 케이크 저항과 여과성능에 대한 연구

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1. Introduction

In microfiltration the transport, deposition and removal of particles control cake formation on a filter. In this connection a new model on cake formation, based on the wall shear stress, was tested here in comparison with experiments of fine particle slurry under Taylor-vortex flow. The model expresses the deposition process for particles as two first-order steps in series of mass transfer and adhesion, and their removal process as a linear relation to the wall shear stress. This embraces characteristics of both dead-end and crossflow filtration. The correlation resulting from fitting to experimental data represented the experimental data reasonably well. This study will be helpful in analyzing fouling in heat exchangers.

2. Theory

Since cake formation is a transient process, its rate is commonly expressed as a balance between deposition and removal processes:

$$\frac{dM_c}{dt} = \dot{M}_{cd} - \dot{M}_{cr} \qquad \cdots(2.1)$$

where $\dot{M}_{cd}$ is deposition rate and $\dot{M}_{cr}$ the removal rate. M_c represents the mass of the cake layer per unit filter surface area and is given as follows,

$$M_c = \rho_c x_c = \gamma R_c \qquad \cdots(2.2)$$

where ρ_c is the cake density, x_c the cake thickness, and γ the proportionality coefficient including the effect of the particle size and porosity. Here R_c

denotes the cake resistance and it is the measure of operation. In the present dynamic separation using a rotating filter as is shown in Fig. 1, the driving force of gravity is reduced owing to centrifugal forces and Taylor vortices [1].

The particle transport is followed by the surface adhesion and in the present microfiltration system it is assumed that the adhesion rate of particles will be the same as the deposition rate.

$$\dot{M}_{cd} = C_o \left(\frac{1}{J_m + k_m} + \frac{1}{k_a} \right)^{-1} \qquad \cdots(2.3)$$

Removal of particles from the cake surface occurs due to the force exerted by the fluid, adversely to their deposition. The removal rate has been known to be proportional to the cake thickness x_c and also to the wall shear stress:

$$\dot{M}_{cd} = k_r x_c \tau_{\omega i} \qquad \cdots(2.4)$$

where k_r is the removal coefficient.

The process of deposition and removal is represented in terms of $\tau_{\omega i}$ from the above equations by

$$\frac{dR_c}{dt} = C_o \left(\frac{1}{k_1 J + k_2 \tau_{\omega i}^{0.5}} + \frac{1}{k_3 / \tau_{\omega i}} \right)^{-1} - k_4 \tau_{\omega i} R_c \qquad \cdots(2.5)$$

where $k_i (i=1 \sim 4)$ is the empirical coefficient In the present study, equation (2.5) was compared with the following model of Kern and Seaton [2]:

$$R_c = R_{cs}(1 - e^{-Kt}) \qquad \cdots(2.6)$$

where R_{cs} denotes the asymptotic value at the pseudosteady state and 1/K is a kind of time constant. The above equation corresponds to

$$\frac{dR_c}{dt} = K(R_{cs} - R_c) = K R_{cs} \exp(-Kt) \qquad \cdots(2.7)$$

From the above equation and equation (2.5) the following relations are obtained:

$$\frac{dR_c}{dt} = K_d R_{cs} \quad \text{for } t \to 0 \qquad \cdots(2.8)$$

$$K_r = K_4 \tau_{\omega i} \qquad \cdots(2.9)$$

here K_d and K_r represent the overall deposition and removal coefficients.

The K-value in equation (2.7) becomes K_d or K_r, depending on the mechanism. Melo and Pinheiro [3] used K_d while Kruase [4] recommended K_r in place of K in equation (2.6). Therefore this simple model means that the initial deposition rate is $\gamma K_d R_{cs}$ and the value of R_{cs} is the measure of the deposition rate.

3. Experiments

By using fine fine particles (average size=5, 12, 20, 50 ㎛) suspended in water microfiltration experiments were conducted under the Couette-Taylor flow. The inner rotating filter contained MF-cellulose ester membrane having average pore size of 1.2㎛. The inner filter rotated with a fixed angular velocity and the outer cylinder was motionless. The slurry level inside the annular gap (*h*) was 50 cm and the resulting hydrostatic pressure was the main driving force in filtration.

4. Results and discussion

In the present microfiltration system under the Couette-Taylor flow the $\tau_{\omega i}$-value ranged in 0~10 Pa. Equation (2.5) fitted to the experimental R_c-values for each experimental run represents the present system very well as shown in Fig. 2. Since the K_i-values fitted to each set of experimental results are almost constant for the present system, their average were used in equation (2.5).

In the present system R_{cs} was obtained by letting $dR_c/dt=0$ in equation (2.5) and using the K_i values. The resulting overall correlation was derived as

$$R_{cs} = 2.51 \times 10^{10}\ \tau_{\omega i}^{-0.898} \quad \cdots(4.1)$$

By comparison of equation (2.5) with equation (2.8) at t=0, the following relationship is obtained:

$$K_d = \frac{C_o}{R_{cs}} \left(\frac{1}{k_1 J_{mo} + k_2 \tau_{\omega i}^{0.5}} + \frac{1}{k_3 / \tau_{\omega i}} \right)^{-1} \quad \cdots(4.2)$$

For $\tau_{\omega i} \rightarrow \infty$, equation (4.2) reduces to

$$K_d = C_o K_3 / (R_{cs}\ \tau_{\omega i}) \quad \cdots(4.3)$$

The K_r-relation and the K_d-values obtained from each experimental run are plotted as a function of $\tau_{\omega i}$ in Fig. 3. For the test of equation (2.6) the case of $d/r_i=0.44$ with K=Kd of Kr is compared in Fig. 4.

5. Conclusion

In the present study a new model introduced to predict the cake resistance expresses the deposition and removal rates of particles as a function of the wall shear stress. The correlation fitted to the experimental data of slurry under the Couette-Taylor flow represented the present system reasonably well.

References

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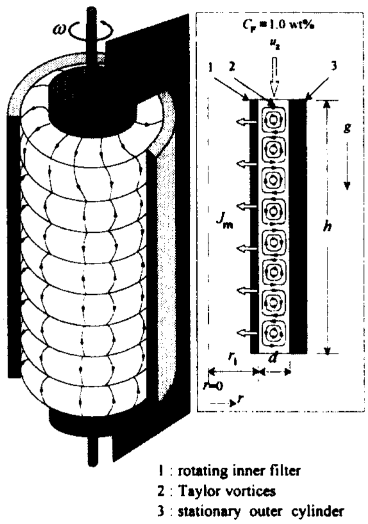

Fig. 1. Schematic of the present system under the Couette-Taylor flow.

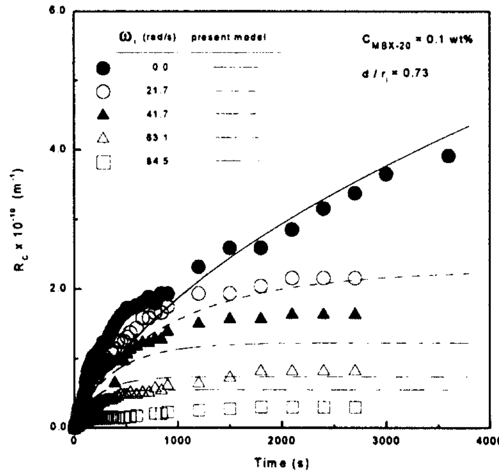

Fig. 2. Comparison of experimental and predicted cake resistances R_c using equation (5) for d/r_i=0.73.

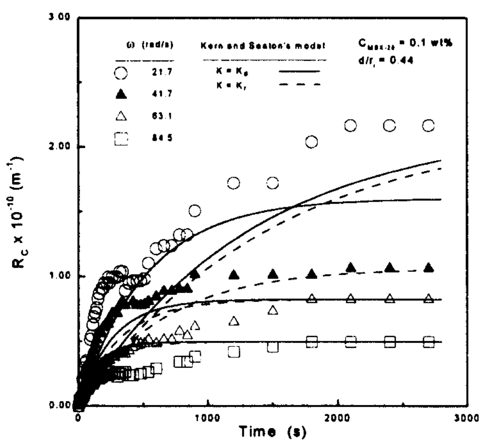

Fig. 3. The deposition coefficient Kd and the removal coefficient Kr as a function of the wall shear stress $\tau_{\omega i}$.

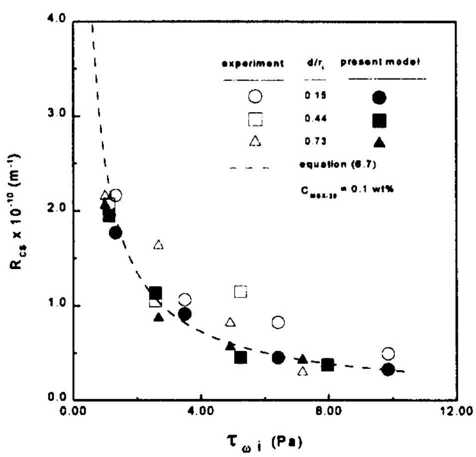

Fig. 4. Prediction of the cake resistance R_c using equation (6) for d/r_i=0.44.