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투과성 입자로 이루어진 미세 칼럼의 유동 특성

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Flow Properties of Micro Column Packed with Perfusive Particles

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Key Words : Micro column(미세 칼럼), Flow resistance(유동 저항), Perfusive particle(투과성 입자)

ABSTRACT

In this work, perfusive particles are used to form a micro column in a microfluidic chip and flow properties of the micro column are investigated. The packing flow velocity and the column/particle size ratio are shown to be important parameters affecting the packing density of the micro column. Experimental results show that the effect of the column/particle size ratio on the flow resistance of the micro column is negligible. This contrasts with previous works on the effect of the column/particle size ratio on the total pressure drop across the column.

1. Introduction

Perfusive particles shown in Fig. 1 have recently attracted considerable attention due to advantage of intra-particle convection in adsorption chromatography that may lead to enhancement of chromatographic efficiency [1, 2]. However, to the authors' knowledge, the perfusive particles have not been applied to a microfluidic system yet. Therefore, in the present work, the perfusive particles are used to form a micro column in a microfluidic chip and flow properties of the micro column are investigated. Three different micro columns with a height ranging from 40㎛ to 250㎛ are packed with 20㎛ diameter particles. The packing flow velocity is varied from 0.01m/s to 0.04m/s. From the porosity measurement of the micro columns, the effect of the packing flow velocity and the column/particle size ratio on the packing density of the micro column is clarified. Some researchers pointed out that the total pressure drop across the column can be greatly influenced by the column/particle size ratio when the column size

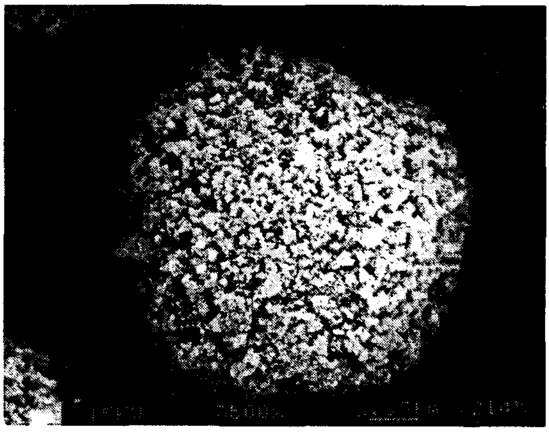

Fig. 1 SEM of perfusive particles [2]

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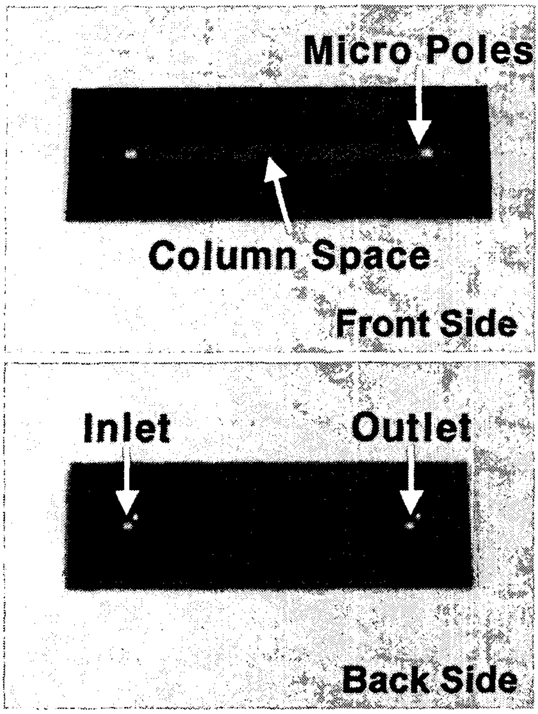

Fig. 2 Microfluidic chip

is comparable to the particle size [3, 4]. In the present work, if the column/particle size ratio affects the flow resistance of the micro column is checked.

2. Fabrication and Test

A microfluidic chip is fabricated using standard MEMS technology as shown in Fig. 2. On the front side, an empty space for a micro column and micro poles formed in a silicon substrate can be seen through a glass cover. On the back side, there are inlet and outlet holes for flow connection. The width and the length of the empty space in the chip are 1.5㎜ and 20㎜, respectively. The height of the space ranges from 40㎛ to 250㎛.

In the fabricated chip, perfusive particles whose nominal diameter is 20㎛ are packed. Moderate amount of particles are suspended in a 33% ethanol of 50μℓ. The slurry is infused into the chip by a syringe pump and held in place using a row of

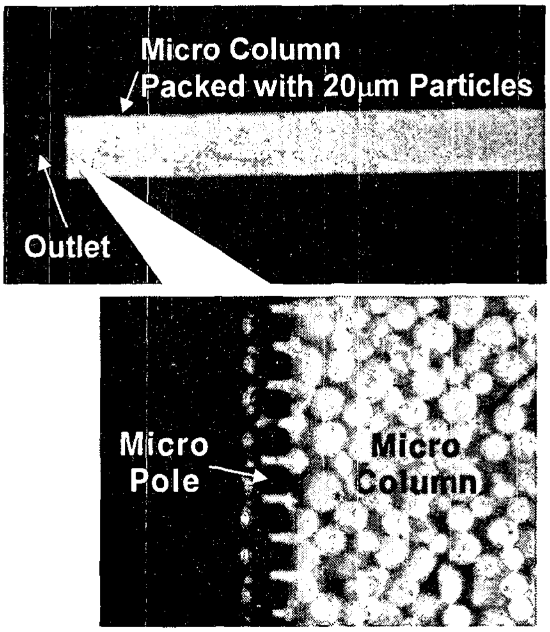

Fig. 3 Micro column

Table 1 Porosity and related properties of micro columns

Sample	Column Height (㎛)	Packing Flow Velocity (m/s)	m (μg)	V (μℓ)	ε
1	40	0.04	80.8	0.3378	0.4159
2	100	0.04	192.5	0.771	0.3903
3	250	0.01	1440.8	6.195	0.4321
4	250	0.02	744	3.1613	0.4252
5	250	0.04	483	1.905	0.3808

micro poles whose spacing is about 10㎛. During the slurry infusion, the chip is vibrated by a shaker to enhance the packing density. After the infusion, 5% ethanol of 3㎖ is infused into the chip to stabilize the micro column. The micro column formed in the chip is shown in Fig. 3.

To predict the flow resistance of the micro column, the porosity of the column should be known in advance. In spite of difficulty in the porosity measurement of microscale beds, the porosity is successfully determined by its definition as follows:

$$\epsilon = 1 - \frac{m}{(1-\epsilon_p)\rho_p V} \qquad (1)$$

where ε, m, ε_p, ρ_p and V are the porosity of the micro column, total mass of particles, the porosity of particles, the density of particles and the volume of the micro column, respectively. m is carefully measured using a micro balance. ε_p and ρ_p are reported to be 0.61 and 1.05g/mℓ, respectively [2]. V is determined from the area occupied by particles. Parameters for porosity determination and the resultant porosity are summarized in Table 1. Together with the porosity, the flow resistance of the micro column is measured in the present work. 5% ethanol is infused into the chip by a syringe pump. The pressure drop across and the flow rate through the micro column are measured by a pressure transducer and a mass flow meter, respectively.

3. Results and Discussion: Packing Density

During the packing process, the inertia force and the viscous force exerted on particles affect the packing behavior of particles. If the inertia force is predominant, particles tend to fill up voids of the micro column yielding close packing. On the other hand, if the viscous force is predominant, particles tend to stick to neighbor particles yielding loose packing. Therefore, the packing density of the micro column can be controlled by varying the ratio of the inertia force to the viscous force. Fig. 4 and 5 show that the porosity of the micro column decreases as any one of the packing flow velocity and the column/particle size ratio increases. As the packing flow velocity increases, the inertia force increases and the resultant porosity of the column decreases as shown in Fig. 4. As the column/particle size ratio increases, the viscous force due to the bounding wall decreases and the porosity decreases as shown in Fig. 5.

4. Results and Discussion: Flow Resistance

Some researchers pointed out that the total

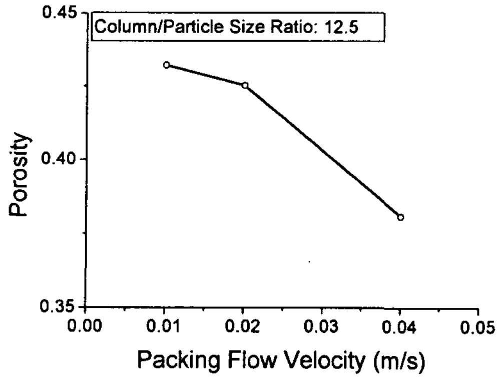

Fig. 4 Effect of packing flow velocity on column porosity

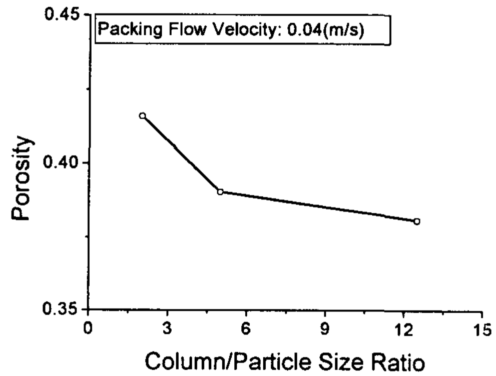

Fig. 5 Effect of column/particle size ratio on column porosity

pressure drop across the column can be greatly influenced by the column/particle size ratio when the column size is comparable to the particle size [3, 4]. To check the effect of the column/particle size ratio on the flow resistance of the micro column, three different micro columns with the column/particle size ratio ranging from 2 to 12.5 are tested and the experimental data on the flow resistance are compared with predictions from three correlations summarized as follows:

Ergun[5]

$$\frac{\Delta P}{L} = \frac{150\mu u(1-\epsilon)^2}{d_p^2\epsilon^2} + \frac{1.75\rho u^2(1-\epsilon)}{d_p\epsilon^3} \quad (2)$$

Foumeny et al.[3]

$$\frac{\Delta P}{L} = \frac{130\mu u(1-\epsilon)^2}{d_p^2\epsilon^2} + \frac{Sr}{0.335Sr+2.28}\frac{\rho u^2(1-\epsilon)}{d_p\epsilon^3} \tag{3}$$

Felice and Gibilaro[4]

$$\frac{\Delta P}{L} = \frac{150\mu(1-\epsilon)^2}{d_p^2\epsilon^2}\frac{u}{2.06-1.06\left(\frac{Sr-1}{Sr}\right)^2} + \frac{1.75\rho(1-\epsilon)}{d_p\epsilon^3}\left(\frac{u}{2.06-1.06\left(\frac{Sr-1}{Sr}\right)^2}\right)^2 \tag{4}$$

where ΔP, L, μ, u, d_p, ρ and Sr represent the pressure drop across the micro column, the length of the column, the viscosity of the passing liquid, the area-averaged velocity, the particle diameter, the liquid density and the column/particle size ratio, respectively. Fig. 6 shows that Ergun's correlation which does not consider the effect of the column/particle size ratio predicts the experimental data better than modified correlations which depend on the column/particle size ratio. Therefore, it can be concluded that the effect of the column/particle size ratio on the total pressure drop across the micro column is negligible. It is worth mentioning that the correspondence between the experimental data and predictions based on the assumption of impermeable particles shows negligible intra-particle flow rate.

5. Conclusions

In this paper, perfusive particles are used to form a micro column in a microfluidic chip and flow properties of the micro column are investigated. It is shown that the porosity of the micro column decreases as any one of the packing flow velocity and the column/particle size ratio increases. Experimental results show that the effect of the column/particle size ratio on the flow resistance of the micro column is negligible. This contrasts with previous works on the effect of the column/particle

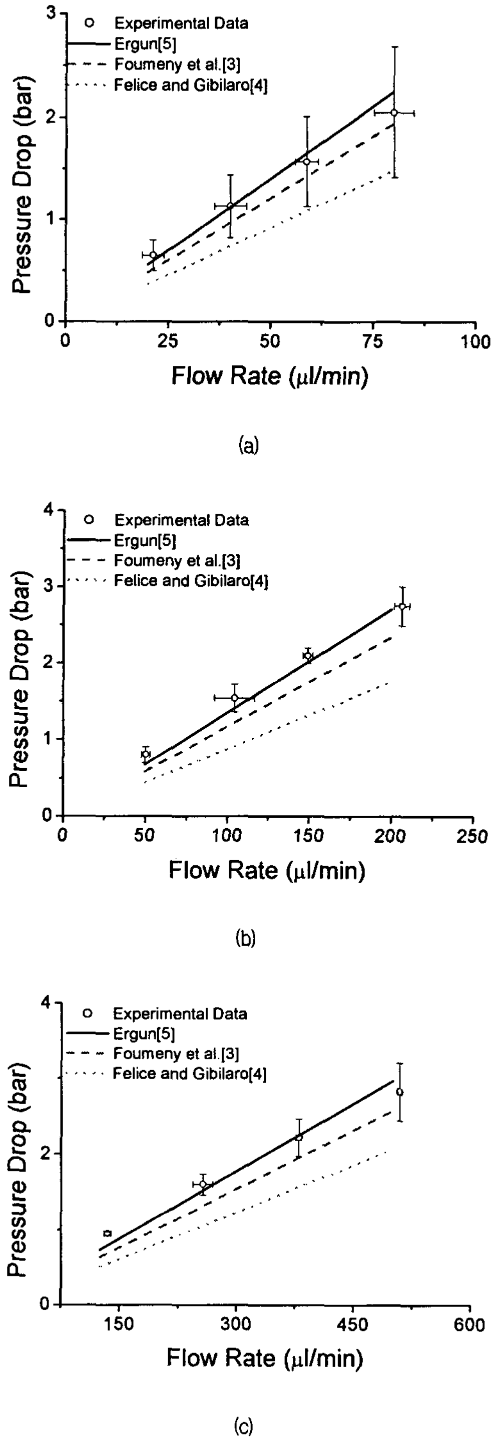

Fig. 6 Flow resistance of micro columns: (a)Sr=2; (b)Sr=5; (c)Sr=12.5

size ratio on the total pressure drop across the column.

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