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RESEARCH NOTES

Study on the Axial Dispersion of Liquid in Column Flotation*

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Abstract An experimental study on the axial dispersion of liquid was carried out in a 0.382-m-ID flotation column packed with different structured packings or free of packings. The correlations of axial Peclet numbers with the liquid and gas superficial Reynolds numbers were developed for various packings. Among the packings tested, it is found that in the column packed with 250Y or 350Y packings the axial dispersion is the lowest. The addition of frother can decrease the axial dispersion. By the simulation analysis of the one-dimension dispersion model of packed flotation column, it is found that small axial dispersion, high collection rate constant and low axial liquid velocity can increase the collection zone recovery.
Keywords packed flotation column, flotation column, numerical analysis, mineral processing

1 INTRODUCTION

Column flotation is one of the most important unit operations in mineral processing. Packed flotation columns developed by Yang[1] have been widely applied to mineral processing and many other fields like waste water treatment[2].

Packed flotation column is similar to bubble packed column in which liquid and gas phases mutually contact. Many researchers[3–6] have studied the axial dispersion characteristics of bubble column packed with various packings, but little work has been done on packed flotation columns. Ding *et al.*[7] studied the dispersion properties of the flotation column packed with structured packings. Their results are different from others[6]. This inspired us to make further research effort on the dispersion properties of packed flotation columns.

The objective of this work is to study the dispersion characteristics of the collection zone of flotation columns packed with various structured packings and the effect of axial dispersion on collection zone recovery.

2 EXPERIMENTAL

2.1 Experimental method

The point source pulse injection technique and the online analysis of conductance were used to measure residence time distribution (RTD) data[8]. The one-dimension dispersion model given by Danckwerts[9] was used to process the experimental data. Fig. 1 shows the measured RTD curve and the calculated values.

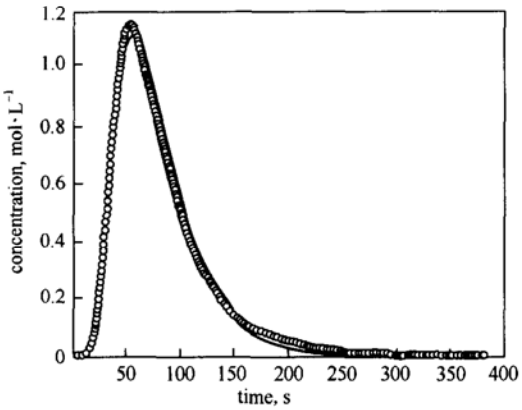

Figure 1 Experimental RTD curve and the calculated results
○ experimental values; — calculated values

2.2 Determination of the dispersion coefficient and correlations

The dispersion coefficients were obtained by minimizing the objective function [Eq. (1)] with the least square method in time domain.

$$\min F(D_z, \overline{u}_l) = \sum_{i=1}^{n} (c_{i,\text{mea}} - c_{i,\text{cal}})^2 \tag{1}$$

$$Pe_z = kRe_L^a 10^{bRe_G} \tag{2}$$

Table 1 Parameters in correlations of Pe_z

packings	k	a	b
open	0.016898	0.38053	−1.85368E-05
250X	0.00211	0.69454	−0.01427
250Y	0.003838	0.70947	−0.01149
350Y	0.001826	0.66218	0.00203

Note: For details of all packings[14].

By using the common empirical Eq. (2), axial dispersion correlations were obtained and shown in Table 1. The deviations of experimental values from calculated values by Eq. (2) are all within 25%.

2.3 Experimental results and discussion

From correlation Eq. (2) and Table 1 it is obvious that with the increase of axial liquid velocity the axial Peclet number increases or the axial dispersion decreases.

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In Eq. (2), the b values for open flotation column and column packed with 350Y packings are very small, which indicates that the influence of gas velocity on the axial dispersion can be neglected. However, for 250X and 250Y packings, the axial dispersion increases with increasing gas velocity.

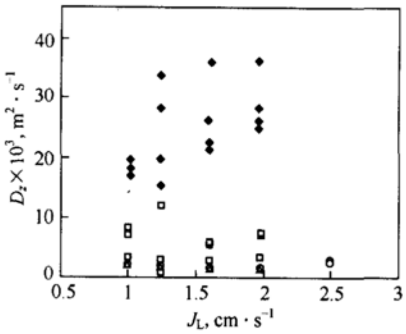

Figure 2 Comparison of axial dispersion coefficients among different packings
◆ open; □ 240X; △ 250Y; ○ 350Y

Figure 2 shows the axial dispersion coefficients of different packings and open column. Obviously, the axial dispersion of open column is the highest, while 350Y and 250Y packings are the lowest. The explanations are: (1) structured packings split the column into many small flow channels whose length to diameter ratio is much higher than those of open column, so the liquid flow in packed column is close to plug flow[10], which means that the axial dispersion of packed column is less than that of open column; (2) the inclination angle of the flow channels in 250X packings with the vertical is less than those in 250Y and 350Y packings, which results in short channels and small channel length to diameter ratio. Therefore the axial dispersion of 250X packings is higher than that of 250Y and 350Y packings.

The study on the effect of frother on axial dispersion for different packings indicates that the addition of frother can increase Pe_z or decrease the axial dispersion. The more frother is added, the less axial dispersion. The reason is that frother can reduce the diameter of bubbles[11], which may decrease the bubble velocity. So the intensity of turbulence due to high flow rate is reduced and the axial dispersion decreases.

3 SIMULATION AND DISCUSSION

3.1 Mathematical model

Dispersion highly influences transfer processes. According to the above experimental results, the dispersion in flotation columns packed with different packing is very different. But few works have been done to analyze the effect of dispersion on column flotation. It is very useful and helpful to discuss how the dispersion affects flotation process by simulation.

By mass balance on an elementary body and neglecting the gas dispersion, the one-dimension dispersion model for the collection zone of flotation column can be obtained[8]

$$\begin{cases} \overline{u}_l \dfrac{\partial c}{\partial z} - D_z \dfrac{\partial^2 c}{\partial z^2} + \overline{u}_g m c = 0 \\ \dfrac{\partial c_g}{\partial z} = -mc \end{cases} \tag{3}$$

Boundary conditions are

$$\begin{cases} c(z)|_{z=0} = c_0 \\ \left.\dfrac{\partial x(z)}{\partial z}\right|_{z=H} = 0 \\ c_g(z)|_{z=H} = 0 \end{cases}$$

where $m = \dfrac{1.5E_k}{d_b}$.

The solution of Eq. (3) is[12]

$$R = 1 - \frac{4a\exp\left(\dfrac{Pe'_z}{2}\right)}{(1+a)^2\exp\left(\dfrac{aPe'_z}{2}\right) - (1-a)^2\exp\left(\dfrac{-aPe'_z}{2}\right)} \tag{4}$$

where $a = (1 + 4m\overline{u}_g\tau_k/Pe'_z)^{1/2}$, $\tau_k = \dfrac{H}{\overline{u}_l}$, R is the ratio of the captured quantily by gas at the top of the column to the feed quantily.

3.2 Calculated results and discussion

If defining the collection rate constant as $k_c = \dfrac{1.5E_k\overline{u}_g}{d_b}$, the collection zone recovery R is a function of axial liquid velocity $\overline{u}_l$, axial dispersion coefficient D_z, and collection rate constant k_c. Their relationships[8] are given in Figs. 3 to 6.

Figure 3 demonstrates that the collection zone recovery decreases with the increase of axial dispersion coefficient, and the extent of decrease becomes slow with increasing axial liquid velocity. Therefore, the collection zone recovery is high under low liquid velocity but suffers more unfavorable effect with increase of axial dispersion coefficient. According to Fig. 2, it can be concluded that 250Y and 350Y packings are the most beneficial to collection zone recovery because of the lowest dispersion coefficients, while open flotation column is on the contrary.

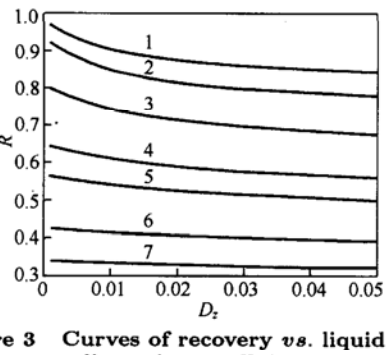

Figure 3 Curves of recovery *vs*. liquid axial dispersion coefficient
u_l: 1—0.02; 2—0.03; 3—0.05; 4—0.08; 5—0.1; 6—0.15; 7—0.20

Figure 4 reveals the relationship between the collection zone recovery and the collection rate constant. Obviously, the collection zone recovery increases with the rising of the collection rate constant. The change of recovery becomes flat with the increase of collection rate.

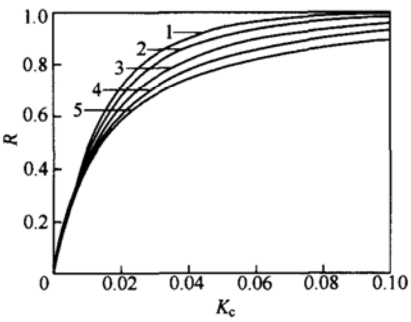

Figure 4 Curves of recovery *vs.* collection rate constant
D_z: 1—0.001; 2—0.003; 3—0.008; 4—0.02; 5—0.08

Figure 5 shows that the collection zone recovery increases with increase of Pe'_z or decreases with axial dispersion. Moreover, the influence of axial dispersion on the collection zone recovery is remarkable when axial dispersion is large (Pe'_z less than 50). For Pe'_z higher than 50, the axial dispersion has less influence on the collection zone recovery. In our experiment, most axial Peclet numbers are less than 100, therefore small difference of Pe'_z between various packings will result in large difference of collection zone recovery.

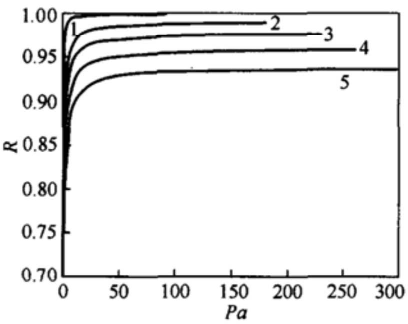

Figure 5 Curves of recovery *vs.* axial peclet number
u_l: 1—0.01; 2—0.018; 3—0.022; 4—0.26; 5—0.03

It also can be seen that the collection zone recovery decreases with increasing axial liquid velocity. This is because the increase of liquid velocity reduces the residence times of particles, which results in the decrease of the number of attached particles.

From the above analysis, it can be concluded that the decreasing of axial liquid velocity or axial dispersion coefficient, or the increasing of collection rate constant or Pe'_z can improve the collection zone recovery. In addition, because the collection rate constant has a peak value at a certain gas rate[13] the collection zone recovery reaches a maximum value at the optimal gas rate.

NOMENCLATURE

c	concentration, mol·L^{-1}
c_g	concentration in gas phase, mol·m^{-3}
$c_{i,cal}$	calculated concentration, mol·m^{-3}
$c_{i,mea}$	measured concentration, mol·m^{-3}
c_0	initial concentration, mol·m^{-3}
D_z	liquid axial dispersion coefficient, m^2·s^{-1}
d_b	bubble diameter, mm
d_{eq}	equivalent diameter of packings, m
E_k	collection efficiency
H	collection zone height, m
J_L	superficial liquid velocity, m·s^{-1}
Pe_z	axial Peclet number, $= \overline{u}_l d_{eq}/D_z$
Pe'_z	axial Peclet number, $= u_l H/D_z$
R	collection zone recovery, %
Re_L	superficial Reynolds number of liquid, $= \overline{u}_l d_{eq}\rho_l/u_l$
Re_G	superficial Reynolds number of gas, $= \overline{u}_g d_{eq}\rho_g/u_g$
$\overline{u}_g$	axial gas velocity, m·s^{-1}
$\overline{u}_l$	axial liquid velocity, m·s^{-1}
V_g	volume flowrate of gas, m^3·h^{-1}
z	axial position, m
μ_g	gas viscosity, Pa·s
μ_l	liquid viscosity, Pa·s
ρ_g	gas density, kg·m^3
ρ_l	liquid density, kg·m^3

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