CRITICAL AERATION RATE IN DISCHARGING AERATED SOLIDS THROUGH A VERTICAL STANDPIPE

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Introduction

In recent years, industrial processes in which granular materials are handled have changed batch to continuous operations. Attention is thus increasingly focused on recycling systems. In these systems, such as the catalyst circulation of catalytic crackers[6], standpipes are used to convey particulate solids with the aid of gravity and aeration against an adverse gas pressure gradient.[1,2,4]

In a previous paper[7], a method was proposed to predict effectively the particle flow rate through an orifice attached to a standpipe below a certain critical aeration rate.

As the aeration rate increases beyond a critical value, particle flow becomes unstable and control of the particle flow rate becomes difficult. How to estimate this critical aeration rate has been left unexamined.[5] In this study, the critical aeration rate was experimentally determined and an estimating equation was presented.

1. Experimental

The experimental apparatus is schematically shown in **Fig. 1.** It consists of a feed hopper, a standpipe (length 2 m and inner diameter 20 mm) and an orifice. After filling the hopper and the standpipe with glass bends, particle flow was initiated by pulling a slide plate below the orifice. Air was then injected into the standpipe through four aeration holes, each 2 mm in diameter, which were drilled circumferentially at even intervals in the standpipe. The mass flow rate of particles, W_s, was measured. The experimental conditions are given in **Table 1**.

2. Results and Discussion

Figures 2 and 3 show the relationships between the aeration rate Q_{in} and the particle flow rate W_s, in which L_a is the distance from the orifice to the aeration point. At a certain critical aeration rate, Q_c, air bubbles begin to arise from the injection port and the particle flow becomes unstable. Q_c in each experiment is shown by an arrow in these figures. The superficial velocity, u_c $(=Q_c/S : S$ is the sectional area of standpipe) is plotted against L_a in **Fig. 4.** It is observed that u_c is hardly affected by the orifice diameter D_o. In general, the total air pressure drop below the aeration point

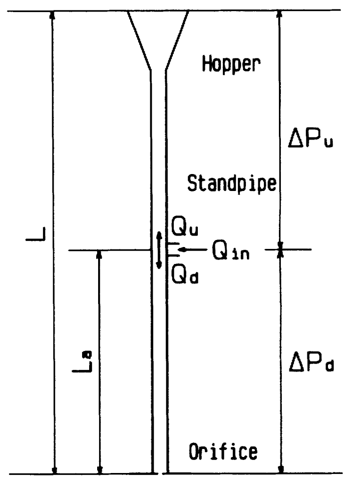

Fig. 1. Outline of experimental apparatus

Table 1. Experimental conditions

Orifice diameter	D_o [mm]	6, 8, 10, 12
Aeration position	L_a [m]	0.1, 0.7, 1.3, 1.9
Particle diameter	d_p [μm]	51, 85, 168, 508

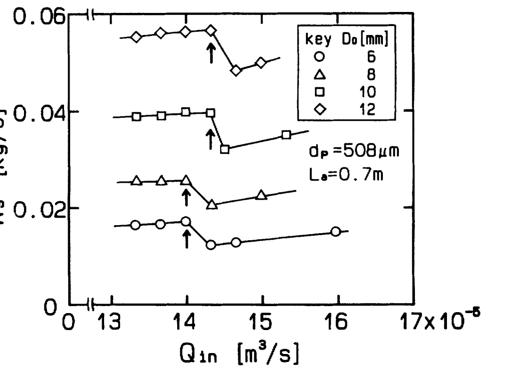

Fig. 2. Relationship between particle flow rate and aeration rate ($L_a = 0.7$ m)

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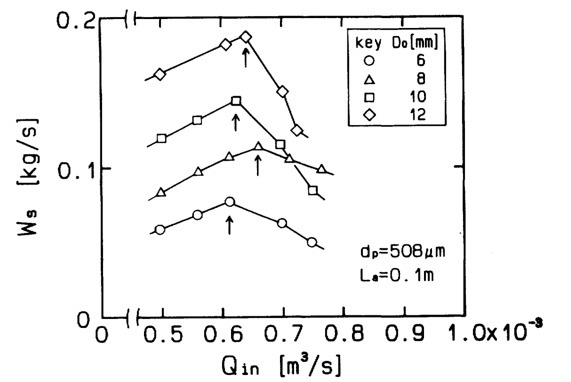

Fig. 3. Relationship between particle flow rate and aeration rate ($L_a = 0.1$ m)

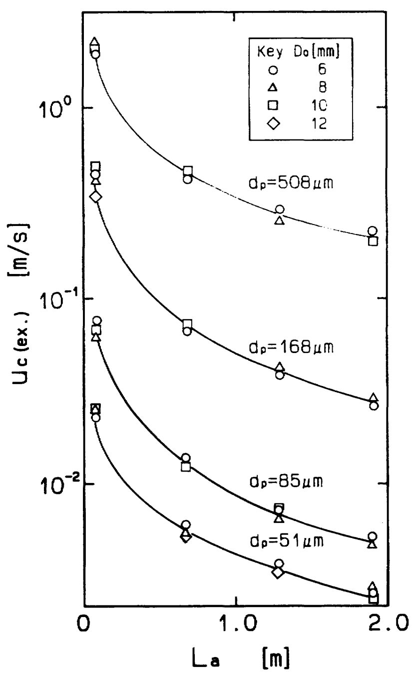

Fig. 4. Effect of aeration point on superficial critical velocity of aeration

is the sum of the pressure drop across the moving particle bed, the pipe friction and the pressure drop at the orifice. The superficial critical velocity was hardly affected by the orifice diameter, suggesting that the pressure drop at the orifice is significantly smaller than the others. Further, it was experimentally found that the pipe friction loss was much smaller than the air pressure drop across the moving bed. Thus, the total air pressure drop can be attributed mainly to the air pressure drop across the moving bed, which is presented by Ergun's relation for the particle bed; the air pressure drops above and below the aeration point, ΔP_u and ΔP_d respectively, are given as

$$\frac{\Delta P_u}{L-L_a} = k_1 V_u + k_2 V_u^2 \qquad (1)$$

$$\frac{\Delta P_d}{L_a} = k_1 V_d + k_2 V_d^2 \qquad (2)$$

where

$$k_1 = \frac{150\,\mu(1-\varepsilon)^2}{d_p^2 \varepsilon^2} \quad \text{and} \quad k_2 = \frac{1.75\,\rho(1-\varepsilon)}{d_p \varepsilon} \qquad (3)$$

L is the height of particle bed, and V_u and V_d are the slip velocity above and below the aeration point respectively.

As shown in Fig. 4, the superficial critical velocity of aeration, u_c, increases as the distance, L_a, from the orifice to the aeration point decreases and the particle diameter, d_p, increases. The relation among L_a, d_p and u_c is derived as follows.

At minimum fluidizing condition for the moving bed above the aeration point, the upward critical slip velocity V_{uc} is given as

$$V_{uc} = u_{mf}/\varepsilon \qquad (4)$$

where ε is the void fraction of the moving bed flowing down, and u_{mf} is the minimum fluidization velocity and is obtained by the velocity equation at minimum fluidizing condition.[3)]

As the orifice at the bottom of the standpipe and the upper surface of the hopper are both open to the atmosphere, $\Delta P_u = \Delta P_d$. Thus, substituting V_{uc} in Eq. (4) for V_u in Eq. (1), we have

$$\left\{k_1 \frac{u_{mf}}{\varepsilon} + k_2 \left(\frac{u_{mf}}{\varepsilon}\right)^2\right\}(L-L_a) = (k_1 V_d + k_2 V_d^2) \times L_a \qquad (5)$$

By using the material balance for the injected air, Eq. (5) can be reduced to a quadratic equation with respect to u_c. Then the superficial critical velocity of aeration u_c, is given as

$$u_c = \frac{A}{2}\left\{\left[1 - \frac{8u_{mf}^2}{A} + \frac{4(K\varepsilon u_{mf} + u_{mf}^2)}{A}\cdot\frac{L}{L_a}\right]^{0.5} - 1\right\} \qquad (6)$$

where $A = K\varepsilon - 2u_{mf}$ and $K = 150\,\mu(1-\varepsilon)/(1.75\,\rho d_p \varepsilon)$. Eq. (6) elucidates the experimental fact that u_c increases as L_a decreases.

The critical aeration velocity u_c can be calculated from Eq. (6) with experimentally determined u_{mf} and ε values[7)]. It is considered that the void fraction of the particle bed above the aeration point is different from that below the aeration point because air bubbles begin to rise in the moving bed above the aeration point at the critical condition. However, the measurement or prediction of void fraction at the critical condition is difficult. The average void fraction as calculated from the air pressure in the moving bed before the critical condition is reached was used as the void fraction ε is Eq. (6). As shown in **Fig. 5**, the critical aeration velocity $u_{c(cal.)}$ is estimated within a

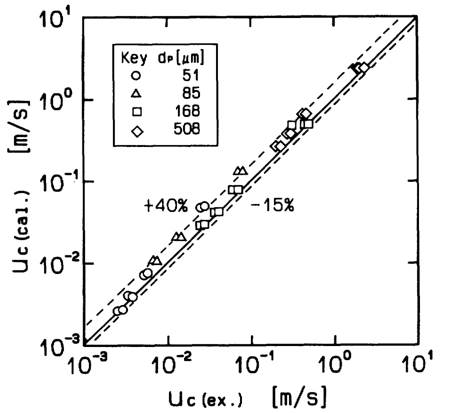

Fig. 5. Comparison of experimental and calculated values of superficial critical velocity of aeration

maximum error of about 40% compared to the experimental value $u_{c(ex.)}$. It is considered that the overprediction of the critical aeration velocity is mainly due to the aeration method of the present study. As air was injected into the standpipe through four small holes drilled along the circumferential direction of the standpipe wall, air was not uniformly injected into the falling solid layer at the aeration port. Then the air velocity at the aeration holes, which is higher than the average velocity over the cross section, might cause local bubbling.

In the discharge of aerated solids through the orifice attached to the standpipe, the critical superficial velocity of aeration increased with closeness of the aeration point to the orifice and with increase in particle diameter. But it was hardly affected by the orifice diameter. A calculating equation for the critical superfical velocity of aeration was presented.

Nomenclature

L	= length of particle bed	[m]
L_a	= distance from aeration point to orifice	[m]
Q_c	= critical aeration rate	[m³/s]
Q_{in}	= aeration rate	[m³/s]
S	= sectional area of pipe	[m²]
u_c	= superfical critical velocity of aeration	[m/s]
u_{mf}	= velocity at minimum fluidization	[m/s]
V_d	= slip velocity below aeration point	[m/s]
V_u	= slip velocity above aeration point	[m/s]
V_{uc}	= critical slip velocity above aeration point	[m/s]
W_s	= mass flow rate of particles	[kg/s]
ε	= void fraction	[—]
ΔP_d	= air pressure drop across particle bed below aeration point	[Pa]
ΔP_u	= air pressure drop across particle bed above aeration point	[Pa]
μ	= air viscosity	[Pa·s]
ρ	= air density	[kg/m³]

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