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Letter

Experimental Study of Transitional Packed Bed Flow in a Standpipe

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In any fluid–solid system, the flow regimes which may occur can be broadly categorized as either fluidized or non-fluidized. In fluidized flow, the particles are held in suspension as a result of fluid drag and there is significant independent motion of the solid particles. It is well established that the voidage in the suspension expands with increasing slip velocity between the two phases. In non-fluidized flow, variation of voidage with increasing fluid drag is largely ignored in the literature because the particles move collectively with little relative motion between them. However, this study provides further evidence that non-fluidized flow voidage does increase with increasing fluid drag as suggested by some previous workers [1, 2]. Taking account of this voidage variation achieves a significant improvement in the calculated pressure gradients.

For non-fluidized flow, the following two sub-divisions were proposed by Kojabashian [3] and adopted by Leung and Jones [4]:

(i) PACFLO
i.e., packed bed flow, where

$$v_{sl} \leqslant 0 \tag{1}$$

$$\epsilon = \epsilon_c \tag{2}$$

and

(ii) TRANPACFLO
i.e., transitional packed bed flow, where

$$0 < v_{sl} < \frac{U_{mf}}{\epsilon_{mf}} \tag{3}$$

$$\epsilon_c < \epsilon < \epsilon_{mf} \tag{4}$$

$$\epsilon = \epsilon(v_{sl}) \tag{5}$$

In PACFLO, the fluid moves downwards faster than the solids, thus creating a negative slip velocity. The solids are compacted by fluid drag and tend to arrange themselves to the voidage of a vibrated packed bed.

For TRANPACFLO, the solids are partially supported by fluid drag. Knowlton *et al.* [1] suggested for this flow regime the use of a linear relationship between voidage and slip velocity as follows:

$$\epsilon = \epsilon_c + (\epsilon_{mf} - \epsilon_c)\,\frac{v_{sl}}{(U_{mf}/\epsilon_{mf})} \tag{6}$$

where

$$v_{sl} = \frac{U_s}{1-\epsilon} - \frac{U_g}{\epsilon} \tag{7}$$

The pressure gradient in non-fluidized flow is described by the modified Ergun equation [5],

$$-\frac{dp}{dz} = K_1 v_{sl} + K_2 v_{sl}|v_{sl}| \tag{8}$$

where

$$K_1 = \frac{150\mu_g(1-\epsilon)^2}{(\phi_s d_p)^2\epsilon^2} \tag{9}$$

and

$$K_2 = \frac{1.75\rho_g(1-\epsilon)}{\phi_s d_p \epsilon} \tag{10}$$

It is important to realize the sensitivity of the modified Ergun equation to the value of the voidage used. To demonstrate this, pressure gradients were measured in a 1.5-m tall, 19.5-mm diameter overflow standpipe operating in the TRANPACFLO mode (see Fig. 1). Geldart Class B particles flowed countercurrently through air injected 100 mm above the bottom orifice. Figure 2 compares the experimental pressure gradients with those predicted by the modified Ergun equation. It is clear that the TRANPACFLO voidage should not be assumed to be either ϵ_c or ϵ_{mf}. The voidage should be calculated by solving eqns. (6) and (7) simultaneously. This greatly improves the accuracy of the predicted pressure gradients.

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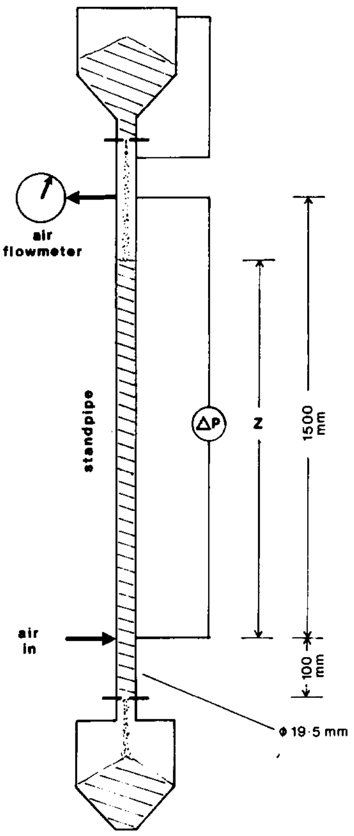

Fig. 1. Experimental apparatus.

List of symbols

d_p	particle diameter
K_1, K_2	constants defined in eqns. (9) and (10)
p	pressure
U_g	superficial gas velocity (positive downwards
U_{mf}	minimum fluidization velocity
U_s	superficial solids velocity (positive downwards)
v_{sl}	actual slip velocity (positive upwards)
Z	height of solids

Greek symbols

ϵ	voidage
ϵ_c	vibrated packed bed voidage
ϵ_{mf}	minimum fluidization voidage
μ_g	gas viscosity
ρ_g	gas density
ϕ_s	shape factor

References

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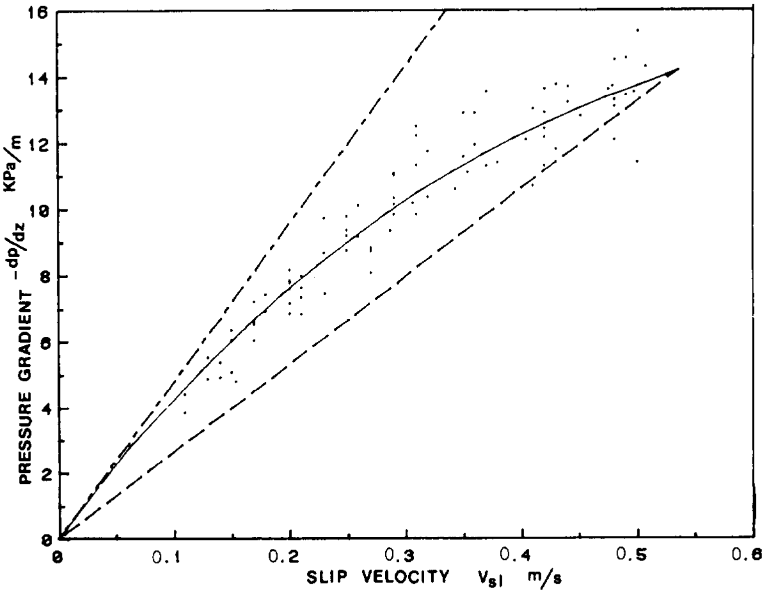

Fig. 2. Transitional packed bed flow pressure gradient in a 19.5-mm diameter standpipe: air-glass ballotini, d_p = 510 μm, $\phi_s = 0.866$, $\rho_s = 2480$ kg/m^3, $\epsilon_c = 0.36$, $\epsilon_{mf} = 0.43$, $U_{mf} = 0.23$ m/s; ——, eqn. (8) with ϵ given by eqn. (6); — · —, eqn. (8) with $\epsilon = \epsilon_c$; — — —, eqn. (8) with $\epsilon = \epsilon_{mf}$.