9.4 Fluidization

If a fluid is passed upwards in laminar flow through a packed bed of solid particles the superficial velocity u is related to the pressure drop ΔP by equation 9.33:

$$u = \left(\frac{\Delta P_f}{L}\right)\left(\frac{1}{K_c \mu}\right)\left[\frac{\varepsilon^3}{(1-\varepsilon)^2 S_o^2}\right] \tag{9.33}$$

As the fluid velocity is increased the drag on the particles increases and a point is reached where the pressure drop balances the effective weight of bed per unit cross-sectional area. At this point the fluid drag just supports the solid particles. A small increase in the flow rate causes a slight expansion of the bed from its static, packed state. Further increase in the flow rate allows the bed to expand more and the particles become free to move around and the bed is said to be fluidized. The state when the bed just becomes fluidized is known as incipient, or minimum, fluidization. The fluid velocity required to cause incipient fluidization is called the minimum fluidization velocity and is denoted by u_{mf}.

On increasing the velocity above u_{mf}, two types of fluidization may be observed. With most liquid–solid systems over the whole range of velocities and with gas–solid systems just above u_{mf}, the bed simply expands and remains fairly homogeneous: this is known as particulate fluidization. However, at higher velocities in gas–solid systems gas voids containing few particles form in the bed. This type of fluidization, in which the excess gas passes through the bed as 'bubbles' is known as aggregative fluidization or boiling fluidization. An air-fluidized bed of clear glass ballotini looks remarkably like vigorously boiling water. The bubbles carry particles in their wakes and help to provide the excellent mixing that occurs in fluidized beds. Aggregative fluidization can occur in liquid fluidization of very dense solids.

At higher gas velocities a turbulent bed is formed, in which the gas voids have irregular shapes and channelling may occur. This fluidization

regime may be compared with the churn-flow regime in gas–liquid two-phase flow (see Section 7.1).

In tall, narrow beds the gas voids may 'coalesce' producing a slugging bed. This condition is generally undesirable owing to its unsteady nature and the difficulty of scale-up.

At very high gas velocities the particles are carried out of the top of the bed. This is known as fast fluidization and is a type of pneumatic conveying. Fast fluidization has been used in catalytic crackers in order to circulate the catalyst particles; the gas velocity is also high enough to break down any agglomerates of solids thus improving performance.

In a similar way, a high liquid velocity will cause hydraulic conveying in a liquid–solid fluidized bed.

9.4.1 *Determination of the minimum fluidization velocity*

Neglecting the static head component of the pressure drop, a force balance at the point of incipient fluidization can be written as

$$(\Delta P)_{mf} = (1 - \varepsilon_{mf})(\rho_p - \rho)L_{mf}g \tag{9.34}$$

Combining equations 9.33 and 9.34, the minimum fluidization velocity u_{mf} is given by

$$u_{mf} = \left[\frac{(\rho_p - \rho)g}{K_c \mu}\right]\left[\frac{\varepsilon_{mf}^3}{(1 - \varepsilon_{mf})S_o^2}\right] \tag{9.35}$$

In equations 9.34 and 9.35 ε_{mf} is the value of the void fraction at minimum fluidization. It should be noted that ε_{mf} is not equal to the void fraction in the packed bed and in order to use equation 9.35 to calculate u_{mf} it is necessary to know the value of ε_{mf}.

The best method of determining the minimum fluidization velocity u_{mf} is experimentally, by measuring the pressure drop across the bed over a range of fluid velocities. The pressure drop increases linearly until fluidization occurs and then increases very slowly; indeed up to about twice the minimum fluidization velocity the pressure drop may appear to be constant within experimental error. When a bed is initially fluidized, there is a tendency for the pressure drop across the bed to be rather high and to go through a peak as incipient fluidization occurs. It is possible that this is caused by a need to 'unstick' the particles. If the fluid velocity of an already fluidized bed is reduced, the peak in the pressure drop is not observed and a much clearer transition to the linear pressure drop—flow