In powders where the particle shape or cohesiveness promotes arch or bridge formation, two equilibrium states could have similar porosities but widely different packing geometries. In such conditions, interparticulate pore size distributions can be useful for comparing packing geometry.

For example, Figure 12.3a shows a group of particles in which arching has occurred and Figure 12.3b shows a similar group of particles in which arch formation is absent. The total porosity of the two systems can be seen to be similar but the pore size distributions (Fig. 12.4) reveal that the powder in which arch formation has occurred is generally more tightly packed than that in which arching is absent.

The measurement of packing geometry by an assessment of percentage compressibility and changes in bulk density have proved to be useful indirect methods to estimate powder flow in an industrial manufacturing process (see later in this chapter).

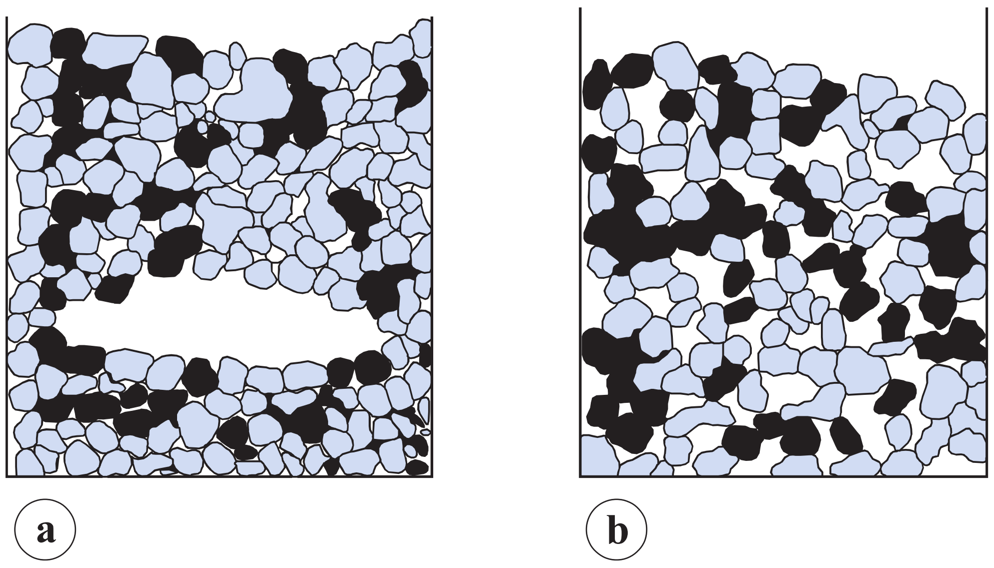

Fig. 12.3 • Two equidimensional powders having the same porosity but different packing geometries.

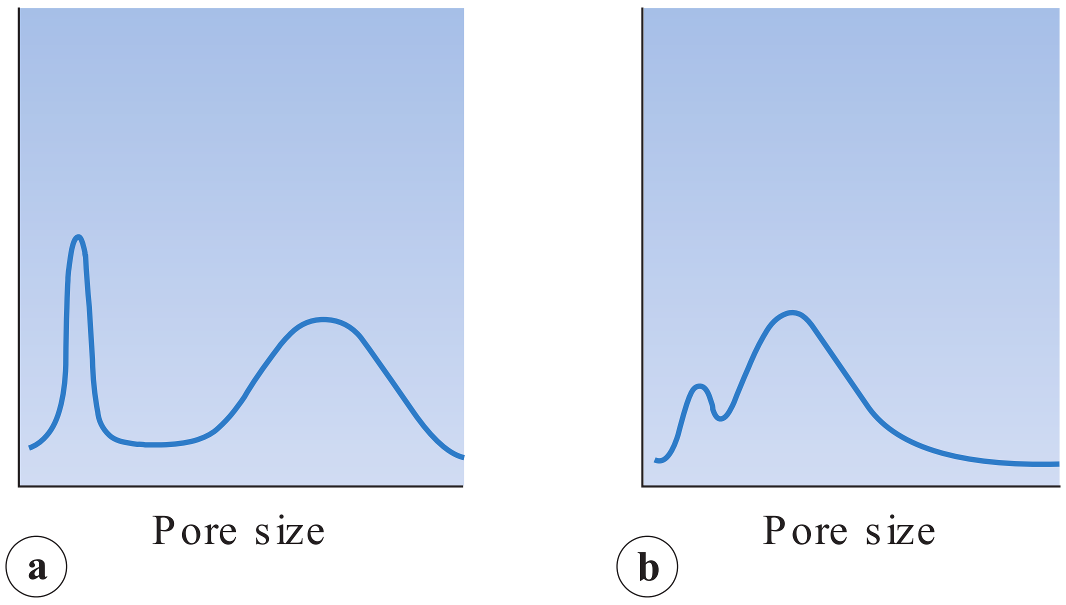

Fig. 12.4 • **(a)** Interparticulate pore size distribution corresponding to close-packed bed containing a powder arch. **(b)** Interparticulate pore size distribution corresponding to loosely packed bed.

Process conditions: hopper design

Flow through an orifice

There are many examples of this type of flow to be found in the manufacture of pharmaceutical solid dosage forms, for example when granules or powders flow through the opening in a hopper or bin used to feed powder to tableting machines, capsule-filling machines or sachet-filling machines. Because of the importance of such flow in producing unit doses containing the same or very similar powder masses, and the importance of flow behaviour in other industries, the behaviour of particles being fed through orifices has been extensively studied. This has led to the design of hopper now used in most industrial pharmaceutical powder applications.

A hopper or bin can be modelled as a tall cylindrical container having a closed orifice in the base and initially full of a free-flowing powder which has a horizontal upper surface (Fig. 12.5a). When the orifice at the base of the container is opened, flow patterns develop as the powder discharges (Fig. 12.5a–f).

The observed sequence is as follows:

1. On opening the orifice, there is no instantaneous movement at the surface but particles just above the orifice fall freely through it (Fig. 12.5b).
2. A depression forms at the upper surface and spreads outwards to the sides of the hopper (Fig. 12.5c, d).
3. Provided that the container is tall and not too narrow, the flow pattern illustrated in Figure 12.5e and shown schematically in Figure 12.6 is rapidly established. Particles in zone A move rapidly over the slower moving particles in zone B, whereas those in zone E remain stationary. The particles in zone A feed into zone C, where they move quickly downwards and out through the orifice. The more slowly moving particles in zone B do not enter zone C.
4. Both powder streams in zones B and C converge to a ‘tongue’ just above the orifice, where the movement is most rapid and the particle packing is least dense. In a zone just above the orifice, the particles are in free flight.

Important practical consequences of this flow pattern are that if a square-bottomed hopper or bin