into granules and individual larger particles which may have overall dimensions greater than 1000 μm (Chapter 28). As far as powder flow is concerned, these will be discussed together and the word 'powder' is used here to describe either system.

The largest pharmaceutical use of powders is to produce tablets and capsules. Together with mixing and compaction properties, the flowability of a powder is of critical importance in the production of pharmaceutical dosage forms. Some of the reasons for producing free-flowing pharmaceutical powders include:

- uniform flow from bulk storage containers or hoppers into the feed mechanisms of tableting or capsule-filling equipment, allowing uniform particle packing and a constant volume-to-mass ratio in order to maintain tablet weight uniformity
- reproducible filling of tablet dies and capsule dosators to improve weight uniformity and allow tablets to be produced with more consistent physicomechanical properties
- uneven powder flow can result in excess entrapped air within powders, which in some high-speed tableting conditions may promote capping or lamination
- uneven powder flow can result from excess fine particles in a powder, which increases particle–die-wall friction, causing lubrication problems, and increased dust contamination risks during powder transfer.

There are many industrial processes that require powders to be moved from one location to another and this is achieved by many different methods, such as gravity feeding, mechanically assisted feeding, pneumatic transfer, fluidization in gases and liquids and hydraulic transfer. In each of these examples, powders are required to flow and, as with other operations described earlier, the efficiency with which they do so is dependent on both process design and particle properties.

Particle properties

Adhesion and cohesion

The presence of molecular forces produces a tendency for solid particles to stick to themselves and to other surfaces. Adhesion and cohesion can be considered as two aspects of the same phenomenon. Cohesion occurs between like surfaces, such as the same component particles in a bulk solid, whereas adhesion occurs between two different objects, for example between two different particles, or between a particle and, say, a hopper wall.

Adhesive and cohesive forces acting between particles in a powder bed are composed mainly from short-range non-specific van der Waals forces which increase as particle size decreases and vary with changes in relative humidity. Other attractive forces contributing to interparticulate adhesion and cohesion may be produced by surface tensional forces between adsorbed liquid layers at the particle surfaces and by electrostatic forces arising from contact or frictional charging. These may have short duration but increase adhesion and cohesion through improving interparticulate contacts and hence increasing the quantity of van der Waals interactions. Cohesion provides a useful method of characterizing the drag or frictional forces acting within a powder bed to prevent powder flow.

Angle of repose

Angle of repose is a simple measure of powder flow but it is based on scientific principles. An object, such as a particle, will begin to slide when the angle of inclination is large enough to overcome frictional forces. Conversely, an object in motion will stop sliding when the angle of inclination is below that required to overcome adhesion/cohesion. This balance of forces causes a powder poured from a container on to a horizontal surface to form a heap. Initially the particles stack until the approach angle for subsequent particles joining the stack is large enough to overcome friction. They then slip and roll over each other until the gravitational forces balance the interparticulate forces. The sides of the heap formed in this way make an angle with the horizontal which is called the angle of repose and is a characteristic of the internal friction or cohesion of the particles.

The value of the angle of repose will be high if a powder is cohesive and low if a powder is non-cohesive. If the powder is very cohesive, the heap may be characterized by more than one angle of repose. Initially, the interparticulate cohesion causes a very steep cone to form but, on the addition of further powder, this tall stack may suddenly collapse, causing air to be entrained between particles and partially fluidizing the bed, thus making it more