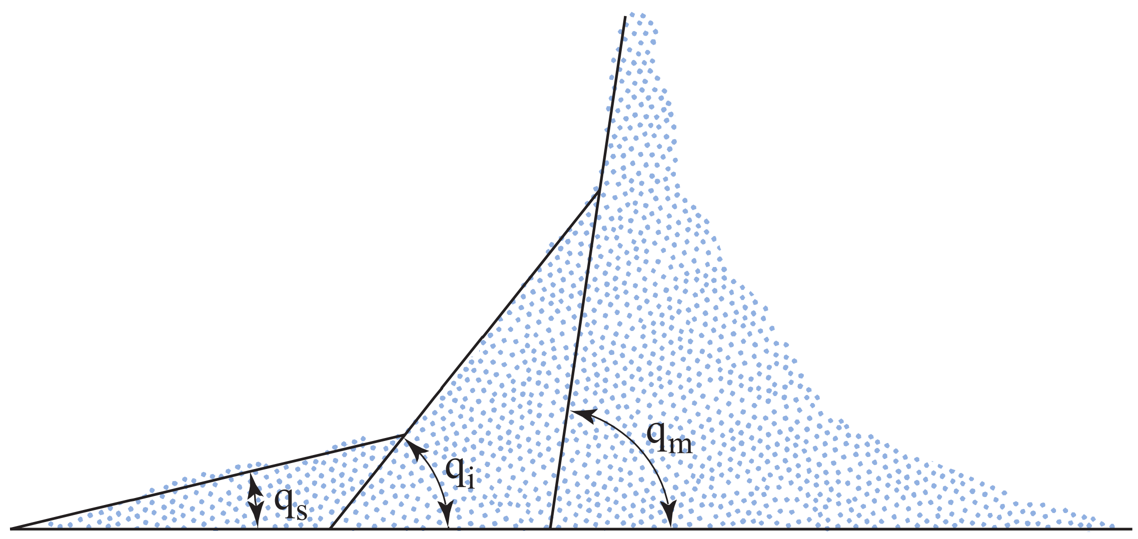

Fig. 12.1 • Cohesive powder poured in a heap and showing different angles of repose: θ_m maximum angle formed by cohesive particles θ_s shallowest angle formed by collapse of cohesive particle heap, resulting in flooding. In some cases, a third angle. θ_i is identifiable as an intermediate slope produced by cohesive particles stacking on flooded powder.

mobile. The resulting heap has two angles of repose: a large angle remaining from the initial heap and a shallower angle formed by the powder flooding from the initial heap (Fig. 12.1).

Particle properties and bulk flow

In the discussion concerning adhesion/cohesion it is clear that an equilibrium exists between forces responsible for promoting powder flow and those preventing powder flow, i.e. at equilibrium:

$$\Sigma f(\text{driving forces}) = \Sigma f(\text{drag forces}) \tag{12.1}$$

that is:

$$\Sigma f(\text{gravitational force, particle mass, angle of inclination of powder bed, static head of powder, mechanical force} \ldots) = \Sigma f(\text{adhesive forces, cohesive forces, other surface forces, mechanical interlocking} \ldots) \tag{12.2}$$

Some of these forces are modified or controlled by external factors related to particle properties, such as size, shape and density.

Particle.size.effects

Because adhesion and cohesion are phenomena that occur at surfaces, particle size will influence the flowability of a powder. In general, fine particles with very high surface-to-mass ratios are more adhesive/cohesive than coarser particles which are influenced more by gravitational forces. Particles larger than 250 μm are usually relatively free flowing but as the size falls below 100 μm, powders become more adhesive/cohesive and flow problems are likely to occur. Powders having a particle size less than 10 μm are usually extremely adhesive/cohesive and resist flow under gravity. An important exception to this reduction in flowability is when the very small particles become adhered/cohered to larger ones and the flowability of the powder as a whole then become controlled by the larger particles. This phenomenon is important in the concept of ordered mixing (Chapter 11) and formulation of dry powder inhalers (Chapter 37).

Particle.shape

Powders with similar particle sizes but dissimilar shapes can have markedly different flow properties owing to differences in interparticulate contact areas. For example, a group of spheres has minimum interparticulate contact and generally optimal flow properties, whereas a group of particle flakes or dendritic particles has a very high surface-to-volume ratio and poorer flow properties. Irregular shaped particles may experience mechanical interlocking in addition to adhesional and cohesional forces.

Particle.density.(true.density)

Because powders normally flow under the influence of gravity, higher density particles are generally less adhesive/cohesive than less dense particles of the same size and shape.

Packing geometry

A set of particles can be filled into a volume of space to produce a powder bed which is in static equilibrium owing to the interaction of gravitational and adhesive/cohesive forces. By slight vibration of the bed, particles can be mobilized so that if the vibration is stopped, the bed is once more in static equilibrium but occupies a different spatial volume than before. The change in bulk volume has been produced by rearrangement of the packing geometry of the particles. In general, such geometric rearrangements result in a transition from loosely packed particles to more tightly packed ones, so that the