Powder flow

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Powder flow

Powders are generally considered to be composed of solid particles of the same or different chemical compositions having equivalent diameters less than 1000 µm.

Importance of free powder flow

A. Reproducible and uniform filling of tablet dies and capsules, which is necessary for weight uniformity of these dosage forms, requires free flowing of the powder from the feeder.

B. Uneven powder flow can result in excess entrapped air within powders, which may promote problems (capping and lamination).

C. Many industrial processes that require powder movement from one location to another (such as mixing, feeding, transfer, and fluidization) are affected by powder flow properties.

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Particle properties

Adhesion and cohesion

- Cohesive and adhesive forces are composed mainly from:
  - Short range non specific van der Waals forces:
    - Increase as particle size decreases and is affected by relative humidity
  - Surface tensional forces arising from adsorbed layer of liquid
  - Electrostatic forces arising from contact or frictional charging

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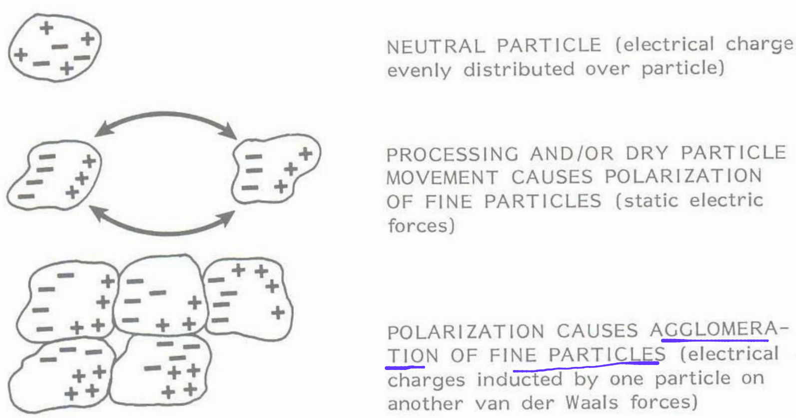

Figure 22 Effect of electrical forces on fine particles.

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Powder properties affecting bulk flow

Particle size

- Fine particles have high surface to mass ratios and are more cohesive (bad flowability).

Particle shape

- Spherical particles have minimum interparticle contact and therefore optimal flow properties.

Particle density (True density)

- Dense particles are generally less cohesive than less dense particles of the same size and shape.

Powder properties affecting bulk flow

Surface roughness of particles

- Rough surface of particles lead to bad flowability of powders.

Moisture content

- High moisture content causes increase surface-tensional cohesive forces and reduced flowability.

Electrostatic charge

- Electrostatic charge increases cohesion and adhesion and reduces flowability.

Mass-Volume relationship for powders

- A powder bed is composed of particles and voids.
- Voids are:
  - – Interparticulate voids: The air space between individual particles
  - – Intraparticulate voids: Those within a single particle
    - Open to the external environment
    - Closed to the external environment

FIG. 4-4. *Diagram of various intraparticulate and interparticulate air spaces in a bed of powder.*

Mass-Volume relationship for powders

Three interpretation of powder volume may be proposed:

- The true volume (V_t): The total volume of the solid particles, which excludes all space greater than molecular dimension.
- The granular volume (particle volume) (V_g): The volume occupied by particles and all **intraparticular** voids.
- The bulk volume (V_b): The total volume occupied by the entire powder mass (i.e. particles and intraparticulate and **interparticulate** voids)

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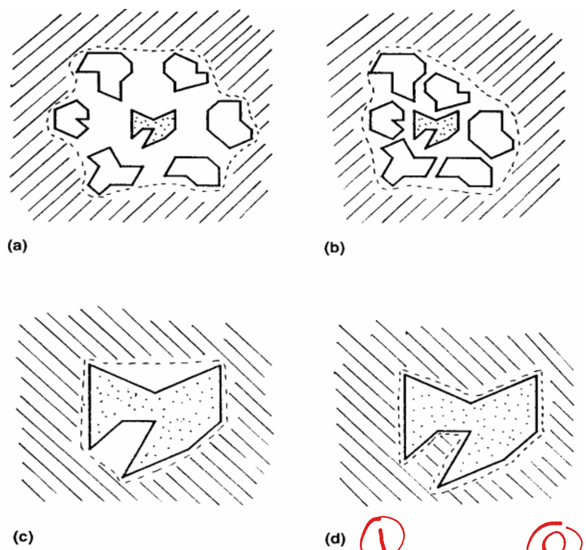

The different types of densities a) bulk density b) tapped density c) particle density d) true density

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Mass-Volume relationship for powders

- True density = mass / true volume
- Granular density = mass / granular volume
- Bulk density = mass / bulk volume

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Packing geometry

- The apparent volume (or density) of a powder can be changed by rearrangement of the packing geometry of particles (by vibration for example).

- Packing geometry can be characterized by:

Bulk density

- It is the mass of powder occupying a known volume.
- A powder can have many different bulk densities depending on the way in which the particles are packed.
- However, a high bulk density value does not necessarily imply a close-packed low-porosity bed, as bulk density is directly proportional to true density.

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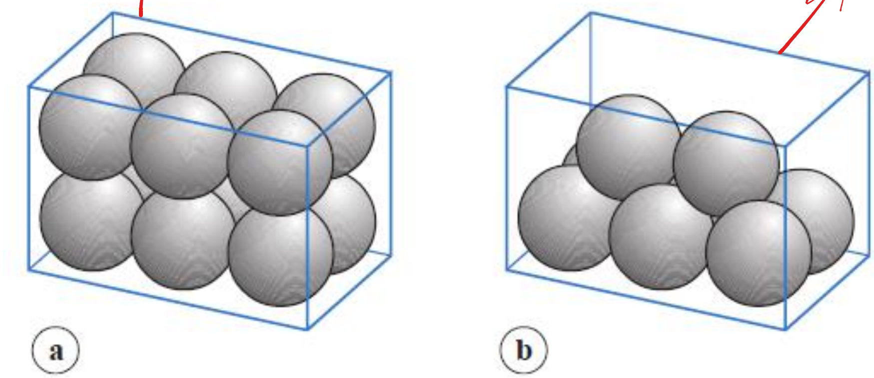

(a) Cubic packing.

(b) Rhombohedral packing.

Different geometric packings of spherical particles

Packing geometry

Packing fraction (Fractional solid content, k)

- It is the bulk density divided by true density of the solid.

$$K = \frac{\text{True volume}}{\text{Bulk volume}} = \frac{\text{Bulk density}}{\text{True density}}$$

Porosity (Fractional void content, e)

Porosity (e) = 1 - K

- Porosity represents the fractional void content of a powder bed.

Factors affecting packing geometry

1) Particle size and size distribution

- Void spaces between coarse particles may be filled with **fine** particles in a powder with a wide size range, resulting in closer packing.

2) Particle shape and textures

- Arches within the powder bed will be formed more readily through the interlocking of non-isometric, highly textured particles

3) Surface properties

- The presence of electrostatic forces can promote closer particle packing

4) Handling and processing conditions

- The way in which a powder has been handled prior to flow or packing affects the type of packing geometry

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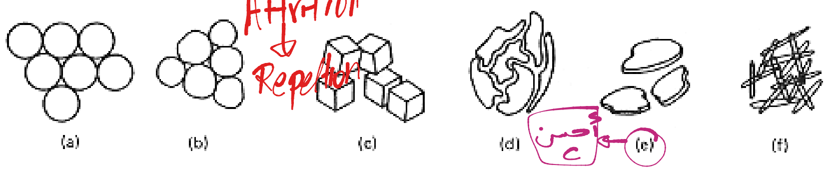

General particle shapes and their effect on power flow.

(a) Spherical particles normally flows easily,
(b) oblong shapes with smooth edges normally flows easily
,(c) equidimensionally shaped sharp edges such as cubes does not flow as readily as (a) or (b),
(d) Irregularly shaped interlocking particles normally shows poor flow and easily bridges,
(e) irregularly shaped two-dimensional particles such as flakes normally shows fair flow and may cause bridges,
(f) Fibrous particles very poor flow, and bridges easily. Bridging refers to the stoppage of powder flow as a result of particles which have formed a semirigid or rigid structure within the powder bulk.

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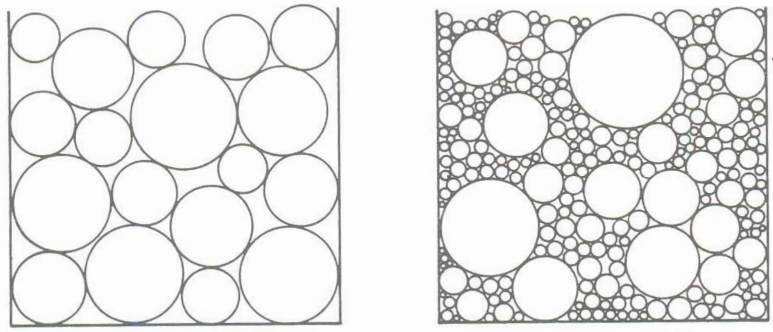
size of distribution — packing طريقة



VOLUME = 1 cm^3
WEIGHT = 2 grams

BULK DENSITY = $\frac{2 \text{ grams}}{1 \text{ cm}^3} = 2.0$

VOLUME = 1 cm^3
WEIGHT = 2.7 grams

BULK DENSITY = $\frac{2.7 \text{ grams}}{1 \text{ cm}^3} = 2.7$

dense

Figure 24 Effects of particle size distribution on the bulk density of a powder.

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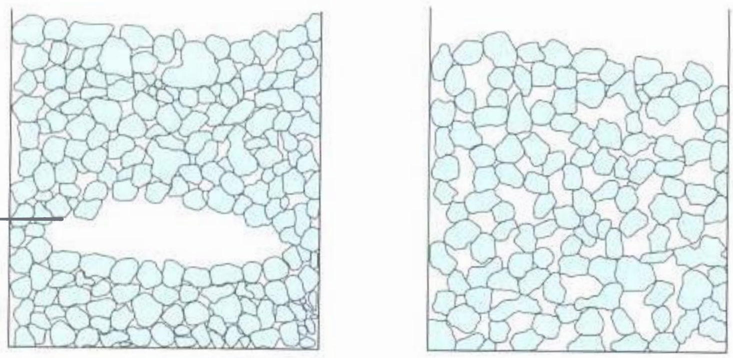
↓ flow



Active formula

Fig. 13.6 Two equidimensional powders having the same porosity but different packing geometries.

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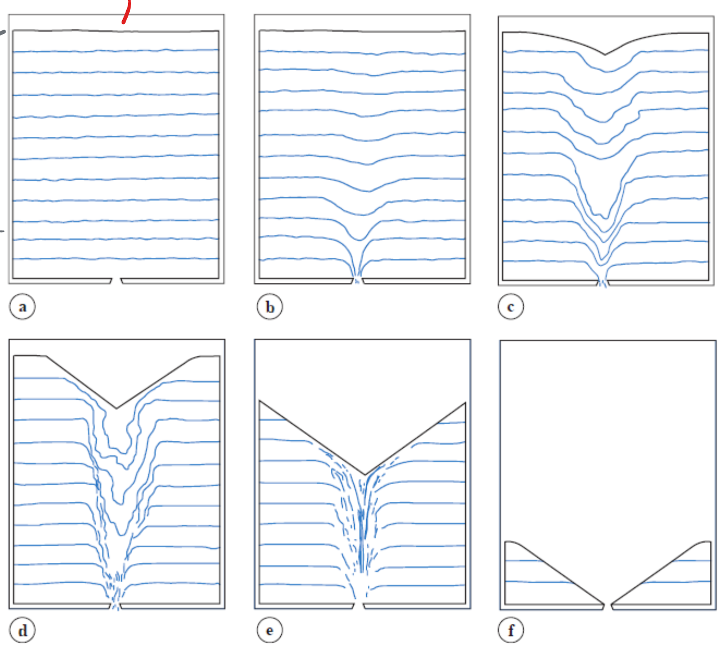
Flow rate through an orifice

- There are many manufacturing processes of pharmaceutical solid dosage forms that require the powder flow through the opening in a hopper or bin used to feed powder to tableting machine, capsule- filling machine, sachet-filling machines …



Development of flow through an orifice

Flow rate through an orifice

- This flow through orifices is affected by:

1. Orifice diameter

- Flow rate is proportional to orifice diameter

2. Hopper width

3. Adhesion to the walls of hopper

4. Head size

- This is the height of powder bed above the orifice

5. Hopper wall angle

- As the angle decreases, flow rate increases

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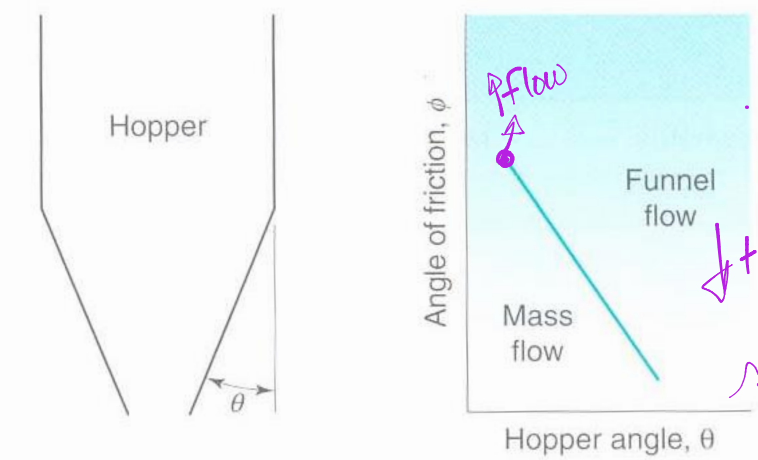

Fig. 13.11 Influence of hopper wall angle and particle–wall friction on powder flow.

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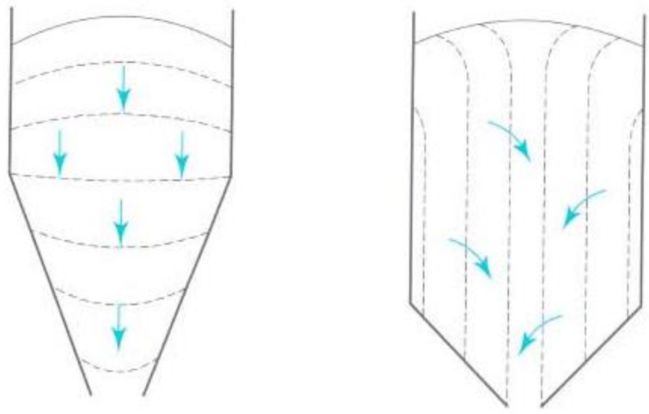

(a) (b)

Fig. 13.12 (a) Mass flow hopper. (b) Funnel flow hopper.

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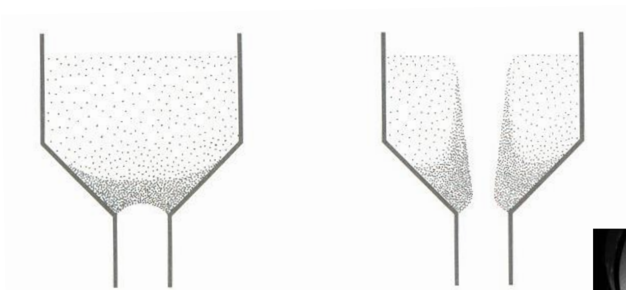
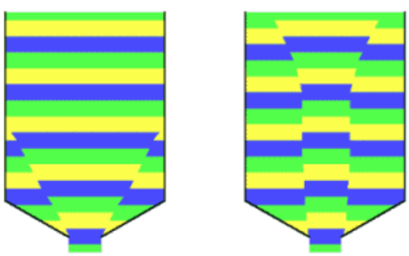


FIG. 11-12. *Bridging (left); rat-holing (right).*



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Characterization of powder flow

Indirect methods (Measurement of adhesive/cohesive properties)

1) Angle of repose

- It represents the balance between frictional/cohesive forces and gravitational force
- Therefore, it describes interparticle cohesion and it is an indirect method for estimating powder flowability.
- There are different methods for determination of angle of repose which may produce different values.
- The high values indicate bad flow properties.

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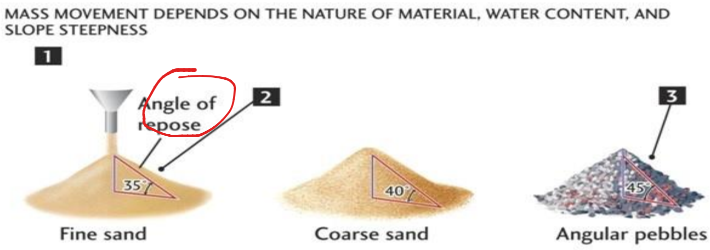
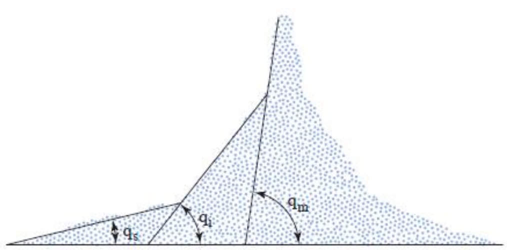
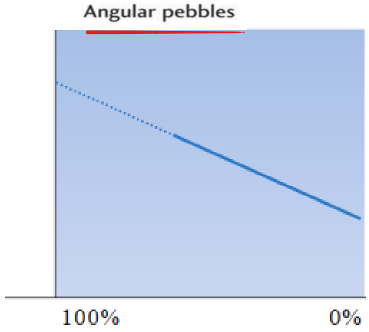




Cohesive powder poured in a heap



Determination of angle of repose for very cohesive powders.

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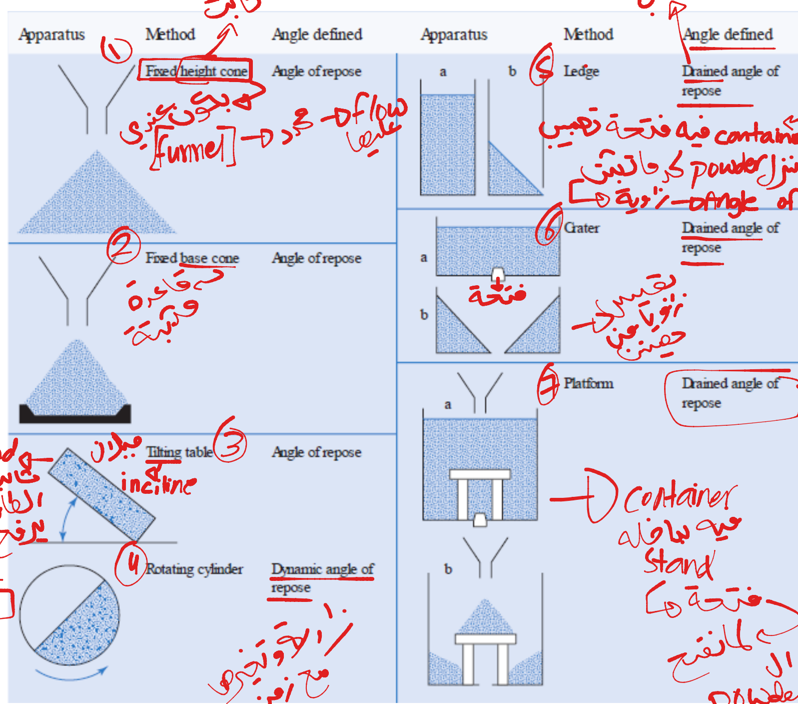
- Balance → frictional forces + Gravity forces



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Angle of repose (degrees)	Type of flow
25–30	Excellent
31–35	Good
36–40	Fair (flow aid not needed)
41–45	Passable (may hang up, flow aid might be needed)
46–55	Poor (agitation or vibration needed)
56–65	Very poor

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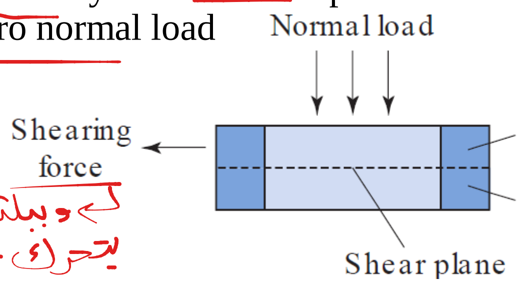
Characterization of powder flow

Indirect methods (Measurement of adhesive/cohesive properties)

2) Shear strength determination

- Cohesion can be defined as stress (force per unit area) necessary to shear the powder bed under conditions of zero normal load



Diagrammatic representation of Jenike shear cell.

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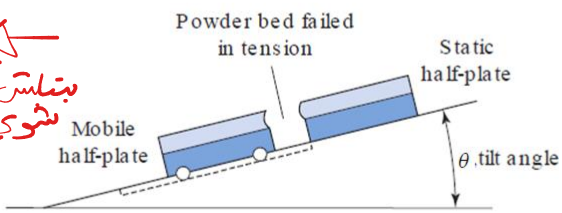
Characterization of powder flow

Indirect methods (Measurement of adhesive/cohesive properties)

3) Tensile strength determination

- The powder bed is caused to fail in tension by splitting.



Diagrammatic representation of tilting table method.

$$\sigma_t = \frac{Mg\sin\theta}{A}$$

Equation for calculation of tensile strength

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Characterization of powder flow

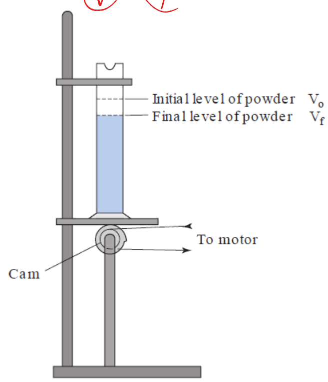
Indirect methods

4) Bulk density measurement (% compressibility and Hausner's ratio)

$$\% \text{ compressibility} = \frac{D_f - D_0}{D_f} \times 100 = \frac{V_0 - V_f}{V_0} \times 100$$

$$\text{Hausner's ratio} = \frac{D_f}{D_0} = \frac{V_0}{V_f}$$

D_f = Final bulk density (tapped density)
D_o = initial bulk density
V_f = Final bulk volume (tapped volume)
V_o = initial bulk volume



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Mechanical tapping device

Compressibility index (%) (Carr's index)	Type of flow	Hausner ratio
1–10	Excellent	1.00–1.11
11–15	Good	1.12–1.18
16–20	Fair	1.19–1.25
21–25	Passable	1.26–1.34
26–31	Poor	1.35–1.45
32–37	Very poor	1.46–1.59
>38	Very, very poor	>1.60

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Characterization of powder flow

Indirect methods

5) Critical orifice diameter

- Critical orifice diameter is a measure of powder cohesion and arch strength.
- The smallest orifice diameter through which powder can flow

Characterization of powder flow

Direct methods

1) Hopper flow rate

- Simple and direct
- The mass of a powder discharged from a hopper is divided by the time taken for the powder to discharge.

2) Recording flowmeter

- The powder is allowed to discharge onto a balance and the increase of powder mass with time is recorded.

Approaches for improvement of powder flow

Alteration of particle size and size distribution

- Coarse particles are less cohesive and therefore are flowing better than fine particles.

Alteration of particle shape or texture

- Spherical particles have better flowability than irregular particles.
- Particles with smooth surface have better flowability than particles with rough surface.
- Particles with suitable shape can be obtained by spray drying or by controlling crystallization process.

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Approaches for improvement of powder flow

Alteration of surface forces

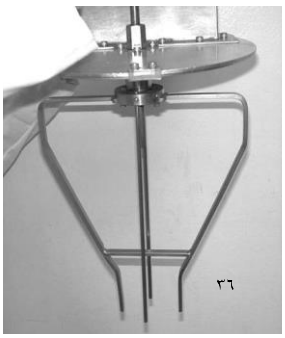
- Electrostatic charges and high moisture content decrease the flowability.

Formulation additives (flow promoters)

- Glidants decrease cohesive and adhesive forces.

Alteration of process conditions

- Use of vibration-assisted or agitated hoppers
- Use of force feeders



Internal agitator

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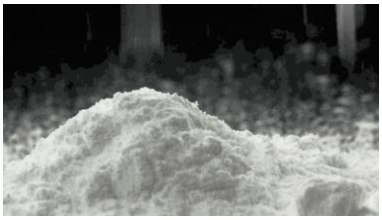
Flow activators

- Flow activators (enhancers, promoters) improve the flowability of powders by reducing adhesion and cohesion.
- They are referred to as glidants.
- Some of them have anti-adherent and lubricant properties.
- Commonly used glidants include talc, maize starch, colloidal silicon dioxide and magnesium stearate.



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Mechanisms of action of flow activators

Glidants improve flowability by one or more of the following mechanisms:

1. They make the surface of the particles more smooth.
2. They reduce electrostatic charges.
3. They interfere with the cohesion or adhesion due to adsorbed moisture layer

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