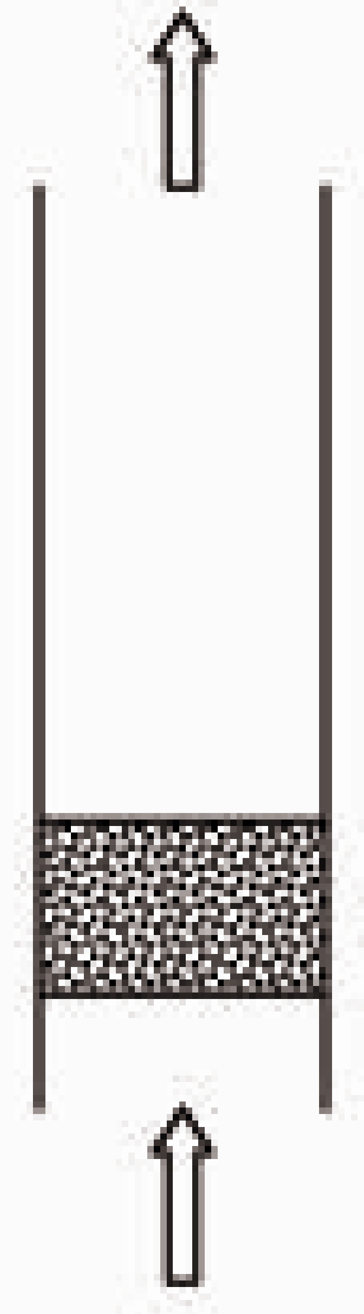
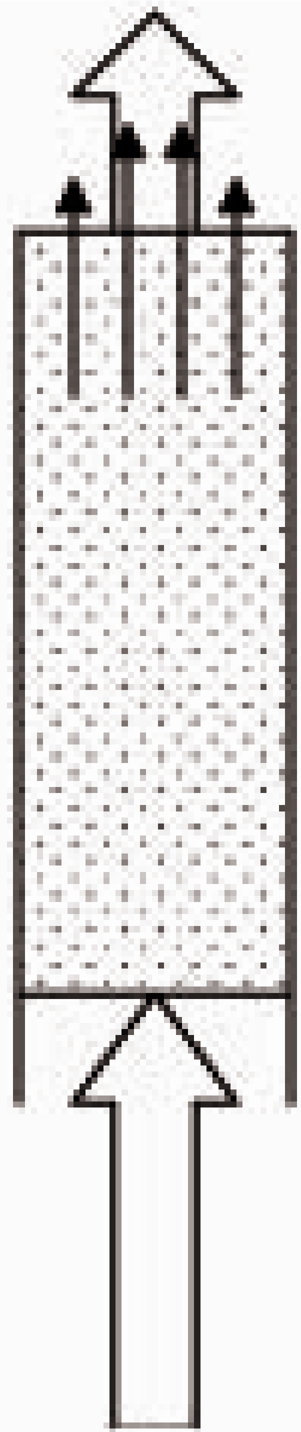
FLUIDIZATION

PRINCIPLES

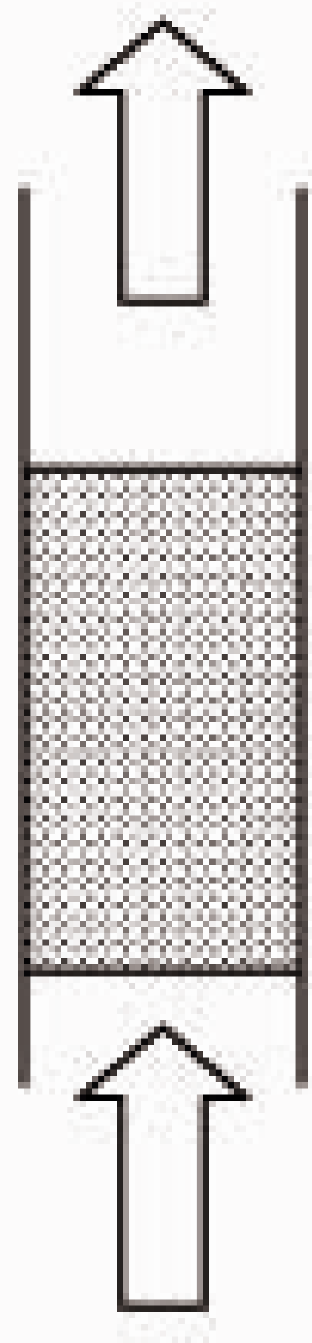
When a fluid is pumped upward through a bed of fine solids particles at a very low flow rate, the fluid percolates through the void spaces (pores) without disturbing the bed. This is a fixed bed process. Particles are in direct contact with each other.



If the upward flow is very large, the bed mobilizes pneumatically and may be swept out of the process vessel. This is pneumatic transportation.



At an intermediate flow rate, the bed expands and is what we call an expanded state. In this state, the particles have a free distance between them. They are supported by the drag force of the fluid.



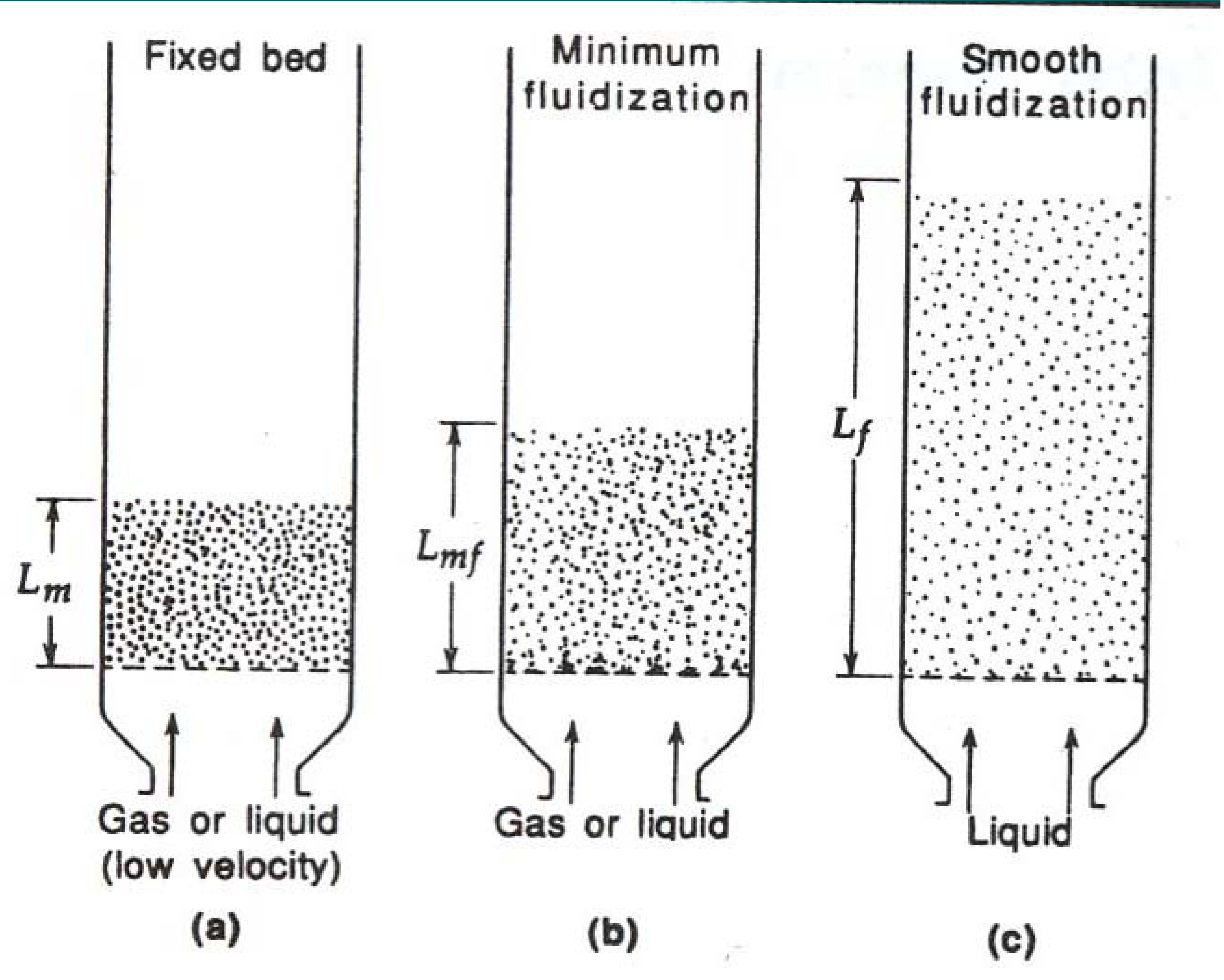
Fluidization velocity

- It is the fluid volumetric flow rate in the vessel divided by the cross sectional area of the bed.

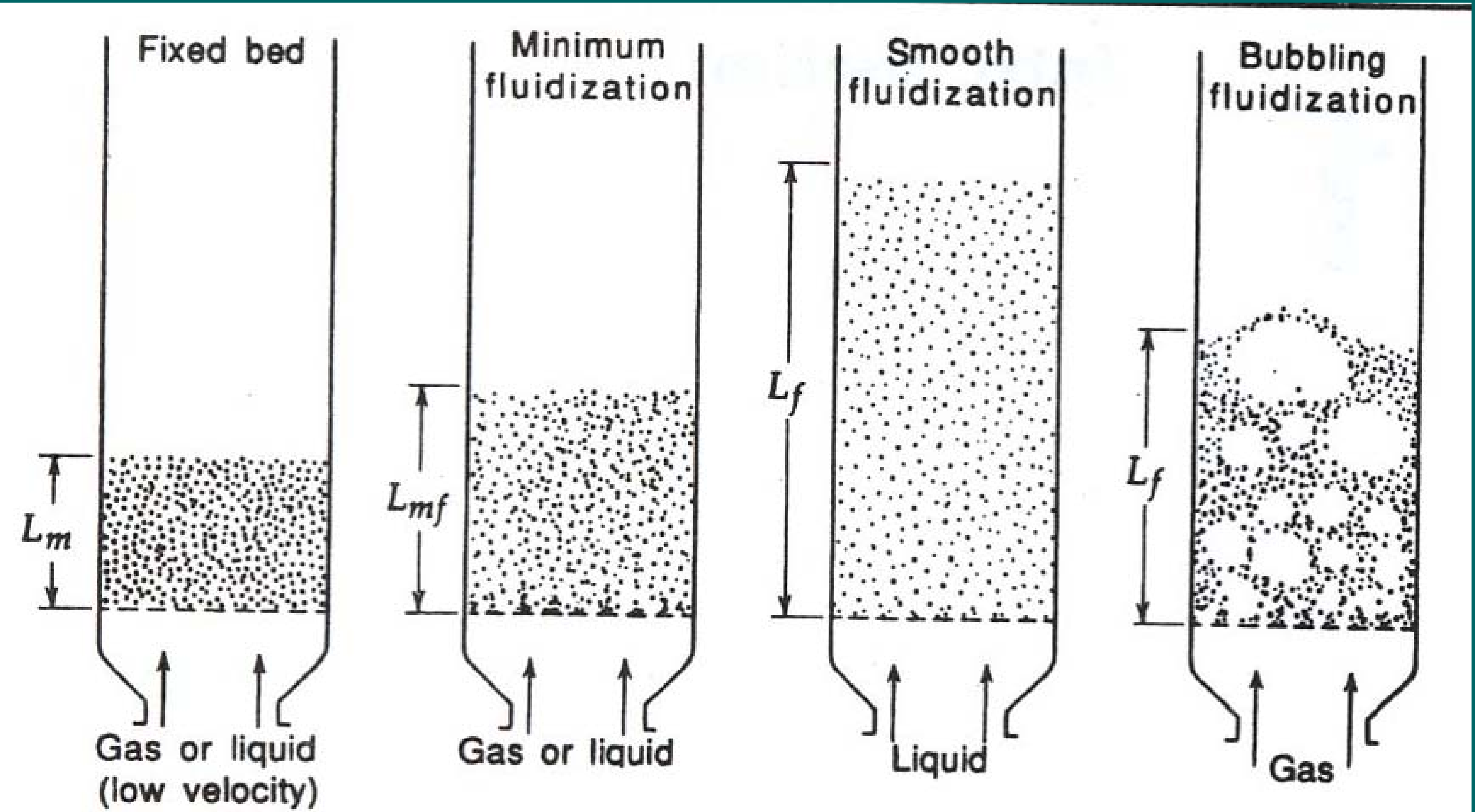
- V_o = Q in m^3 /s @ operating temp / Area
- $V_m < V_o < V_t$
- V_m - minimum fluidization velocity
- V_o – operating velocity
- V_t – Terminal velocity / transport velocity

Bed expansion Versus velocity

In a liquid – solid system increase in fluidization velocity results in a smooth progressive expansion- it is homogeneous fluidization.

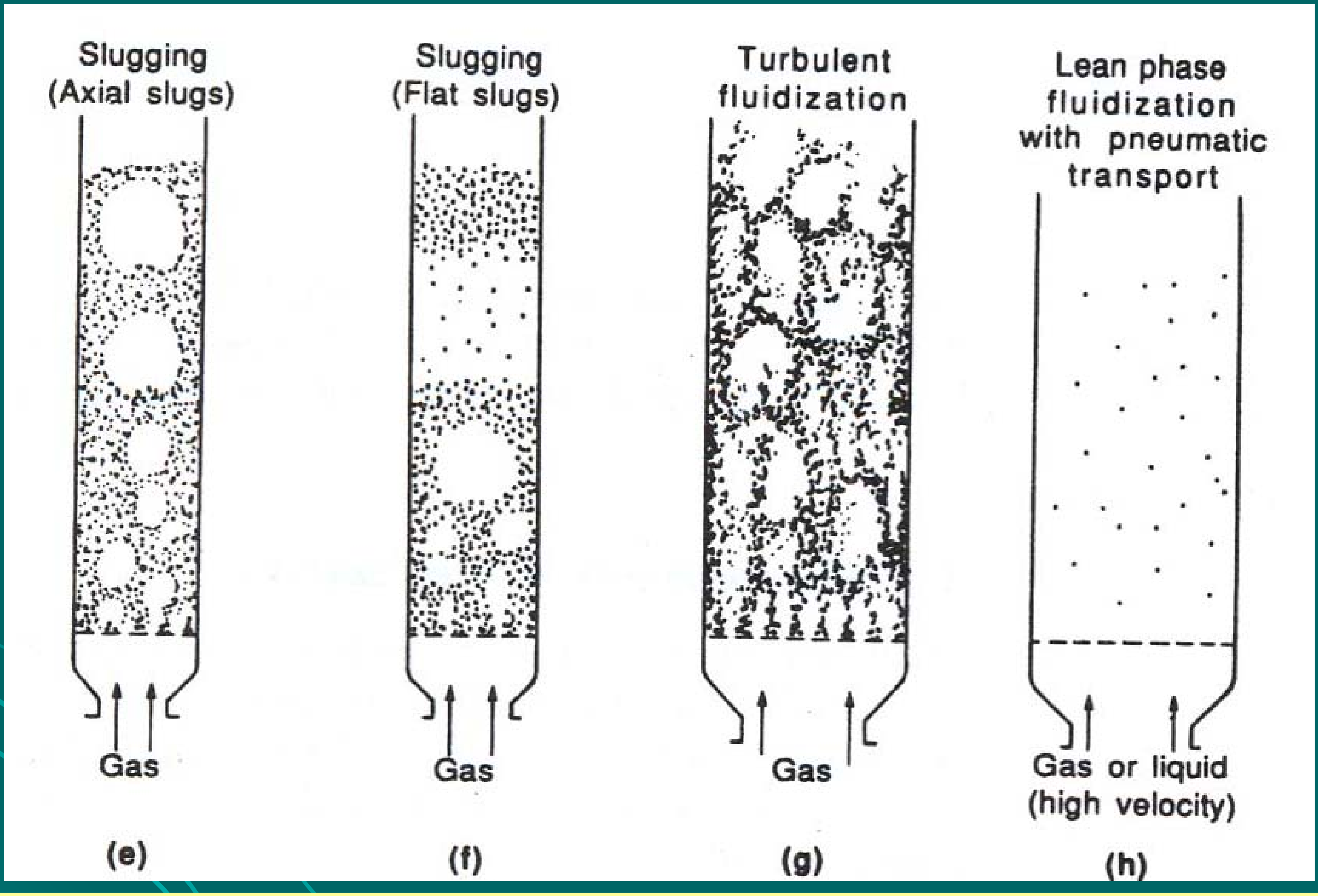


Fluidization velocity & densities of fluid and solids



- When there is large difference between the fluid density and solid particle density, the increase in fluidization velocity typically causes large bubbles or other such instabilities.

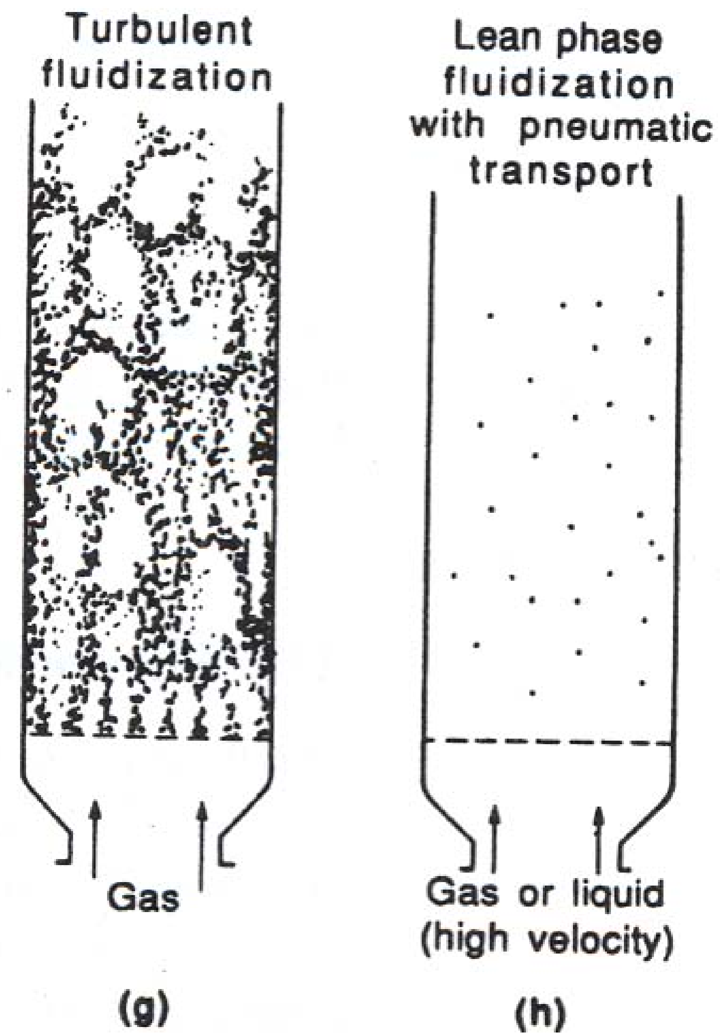
Fluidization velocity & densities of fluid and solids



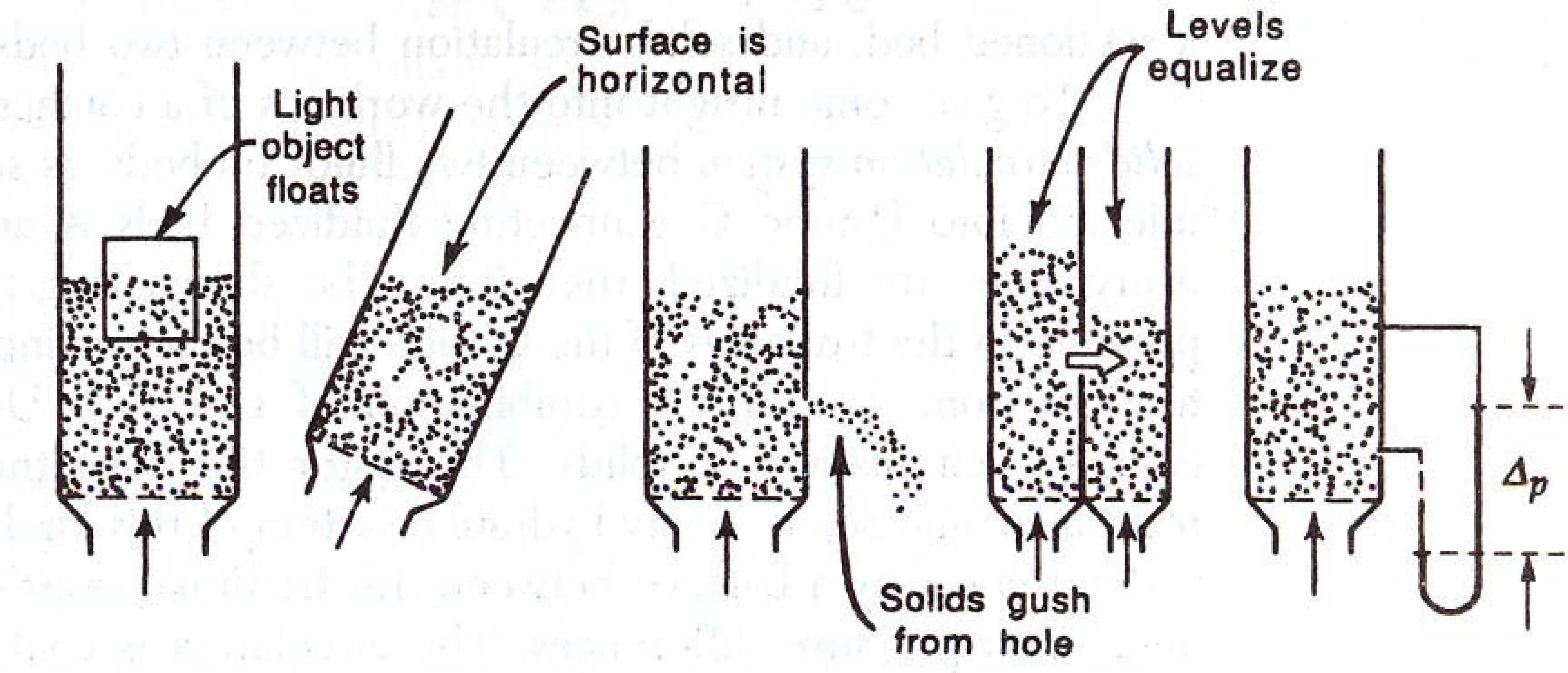
- When there is large difference between the fluid density and solid particle density, the increase in fluidization velocity typically causes large bubbles or other such instabilities.

Fluidization velocity & densities of fluid and solids

- In turbulent / pneumatically mobilised bed a significant part of solids will be thrown out of bed. For steady state operation the particles need to be recovered and returned to bed for proper operation.



Fluid-like behaviour of fluidized bed



- Lighter objects float on top of bed.
- Surface stays horizontal even in tilted beds.
- Solids can flow through an opening.
- Levels equalise when two fluid beds are connected.
- Bed has a static pressure head given by "***ρ*g*h*** "

Advantages of fluidized bed operations

- Liquid like behaviour, easy to control and automate.
- Rapid mixing and thus uniform temperature and concentrations.
- Resists rapid temperature changes. Responds slowly to changes in operating conditions.
- Good for small as well as large operations.
- Heat and mass transfer rates are high.

Uses of fluidization

- Reactors – cracking of hydrocarbons, coal gasification, carbonization, calcinations.
- Heat exchange.
- Drying operations.
- Coatings such as metal with polymers.
- Solidification / Granulation.
- Adsorption process.

Pressure Drop across fluidized bed

Ergun (Packed Bed):

$$\frac{(\Delta P)}{L} = \frac{150\mu V(1-\varepsilon)^2}{D_p^2\varepsilon^3} + \frac{1.75V^2\rho_f(1-\varepsilon)}{D_p\varepsilon^3}$$

Pressure Drop Across a Fluidized Bed :

$$\Delta P = M(\rho_p S_p)(\rho_p - \rho_f)g$$

Where:

ΔP = pressure drop across the bed

L= Length of the bed

D_p= Equivalent particle diameter (V_p/S_p)

V_p = Volume of particle

S_p = Surface area of particle

ρ_p = Density of the particle

ρ_f = Density of the fluid

M = Mass of the particles

V = Superficial velocity

ε = Void fraction

Minimum Fluidization velocity for small particle system

$$V_m \approx \frac{g(\rho_p - \rho)}{150\mu} \cdot \frac{\varepsilon_M^3}{1-\varepsilon_M} \Phi_s^2 D_p^2$$

$$when, \frac{D_p V_m \rho_g}{\mu} \lhd 20$$

Where:

V_{om} = Minimum fluidization velocity

g = acceleration

μ = viscosity

ε_m = Void fraction

ρ_p = density of particles

ρ = density of air

D_p = Diameter of the particle

Φ = Sphericity

Φ = **Sphericity** = $\dfrac{\textbf{Surface of sphere}}{\textbf{Surface of particle}}$ (of same volume)

Type of particle	Sphericity
Sphere	1
Cube	0.81
Disk, h = d/3 h = d/6 h = d/10	0.76 0.60 0.47
Coal bituminous	0.63
Sand (round)	0.86
Sand (sharp)	0.53

Sphericity versus voidage

- Uniform particles help in stacking properly and thus have less voidage. More the voidage the fluidization velocity has to be higher.

Minimum Fluidization velocity

$$V_{\min} \approx \frac{g(\rho_p - \rho)}{150\mu} \cdot \frac{\varepsilon_m^3}{1-\varepsilon_m} \Phi_s^2 D_p^2$$

ρ_p –particle density increases – difficult to fluidize

D_p –particle diameter increases – difficult to fluidize

Φ –Sphericity increases – difficult to fluidize

ϵ_m – Voidage is more – difficult to fluidize

Minimum Fluidization velocity for coarser particle system

$$\frac{1.75}{\varepsilon_m^3 \phi_s}\left(\frac{D_p V_m \rho_g}{\mu}\right)^2 + \frac{150(1-\varepsilon_m)}{\varepsilon_m^3 \phi_s^2}\left(\frac{D_p V_m \rho_g}{\mu}\right) = \frac{D_p^3 \rho_g (\rho_s - \rho_g) g}{\mu^2}$$

$$when, \frac{D_p V_m \rho_g}{\mu} \triangleright 20$$

Where:

V_m = Minimum fluidization velocity

g = acceleration

μ = viscosity

ε_m = Void fraction

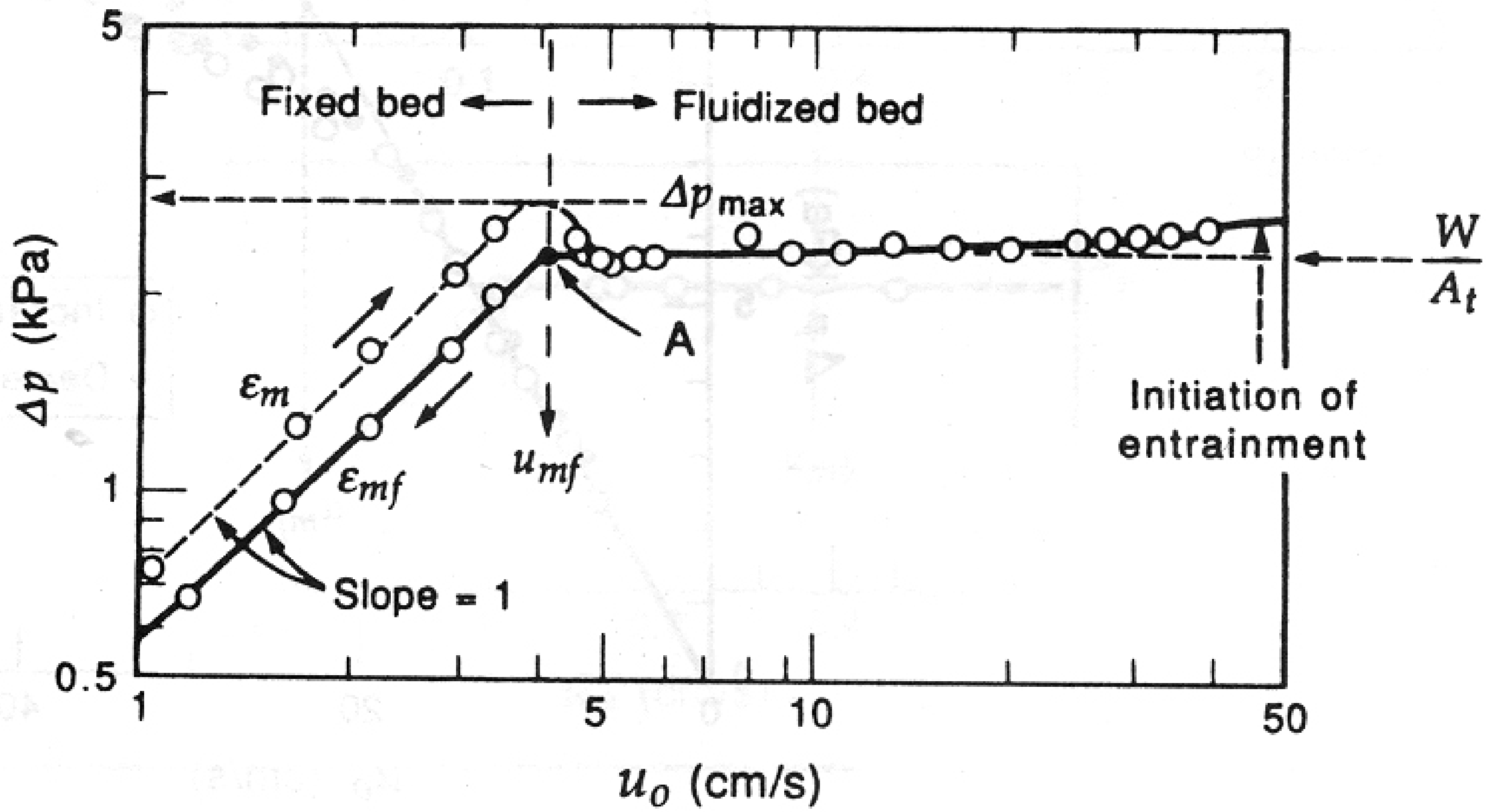
ρ_p = density of particles

ρ = density of air

D_p = Diameter of the particle

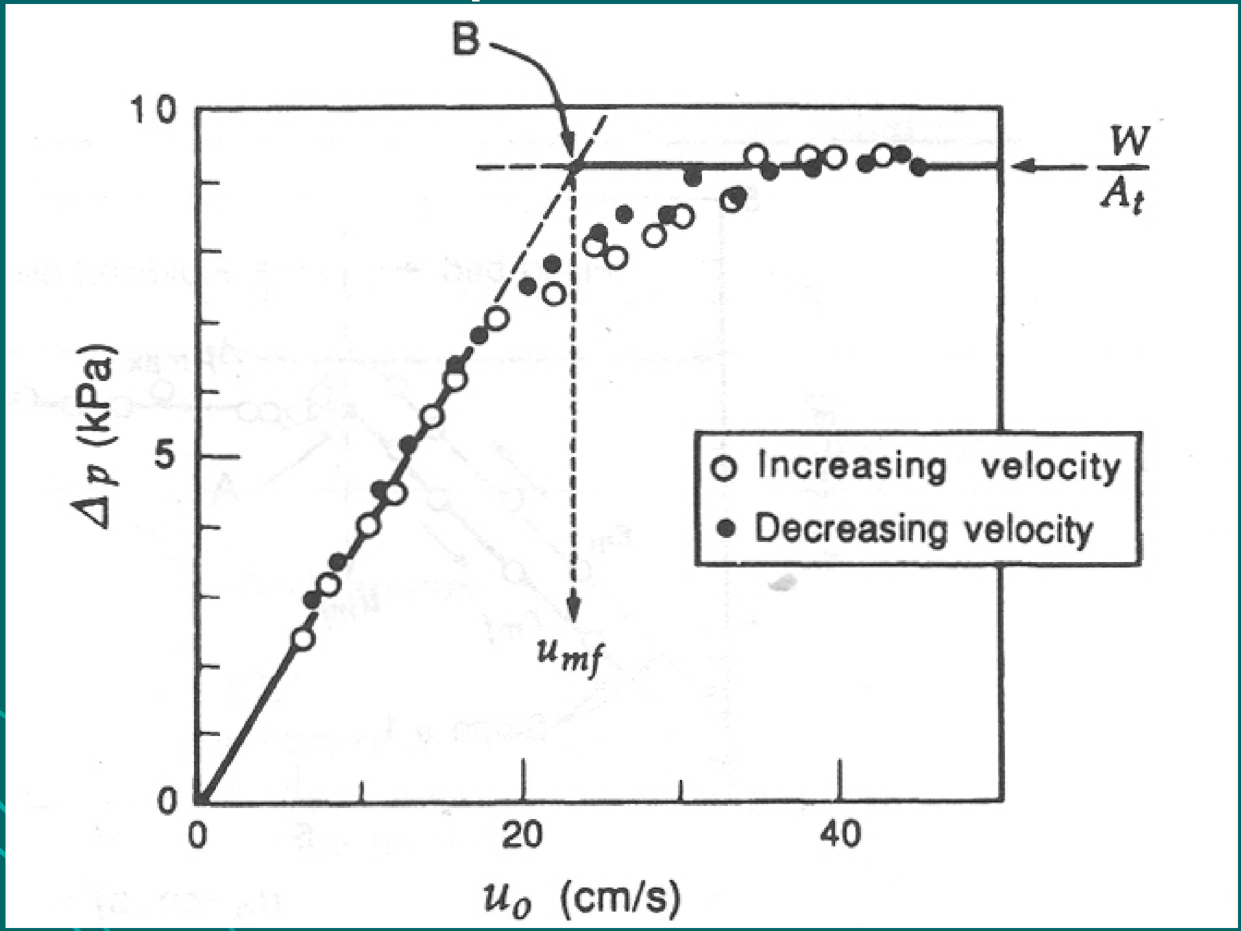
Φ = Sphericity

Onset of fluidization- for not too small uniformly sized particles



The fluidization goes with a clearly defined fluidization

Onset of fluidization- for wide distribution of particles



The fluidization goes gradual – not clearly defined

Typical Minimum / mixing fluidization velocity

- For an average particle size of 1.8 mm, the minimum fluidization velocity is around 0.7 m/s.
- As the bed ash becomes coarser such as 0.85 to 2.3 mm, the minimum mixing velocity is considered as 0.9 m/s.
- The bed needs to be disturbed during start up at least for some time to bring the coarser lot to fluidization regime. The Distributor plate drop has to be of the order of 500 mmWC.

Heat transfer to heating surface in fluidized bed

- Heat transfer between bed and immersed surfaces (vertical bed walls or tubes) is made up of three components which are approximately additive (Botterill, 1975):

  $h = h_{pc} + h_{gc} + h_r$
- h_{pc} -particle convective heat transfer coefficient due to heat transfer due to the motion of packets of particles carrying heat to the surface.
- h_{gc} -gas convective heat transfer coefficient from gas.
- h_r is the radiant heat transfer coefficient.

$$h_c \approx \frac{k(1-\varepsilon)}{D_p} \cdot \left[\frac{3600 \rho_s C_p D_p V}{K_g} C_5 + C_6 \right]$$

Heat transfer coefficient for particle & gas convection

Where:

h_c = heat transfer coefficient

K,C_5,C_6 = empirical constants

D_p= particle size

ε = Void fraction at fluidization condn

ρ_s =particle density

C_p=particle specific heat

V=Fluidization velocity

$$h_r \approx \frac{\sigma(T_b^4 - T_w^4)}{\left[(1/e_p + 1/e_s - 1)(T_b - T_w)\right]}$$

Heat transfer coefficient for gas radiation from bed

Where:

h_r = heat transfer coefficient

σ = radiation constant

T_b= bed temperature

T_w = metal temperature

e_p=emissivity of particle

e_s=emissivity of metal

$$h_c \approx \frac{k(1-\varepsilon)}{D_p} \cdot \left[\frac{3600 \rho_s C_p D_p V}{K_g} C_5 + C_6 \right]$$

Heat transfer coefficient for particle & gas convection

- As particle size increases heat transfer comes down.
- As fluidization velocity increases heat transfer improves.

$$h_r \approx \frac{\sigma(T_b^4 - T_w^4)}{\left[(1/e_p + 1/e_p - 1)(T_b - T_w)\right]}$$

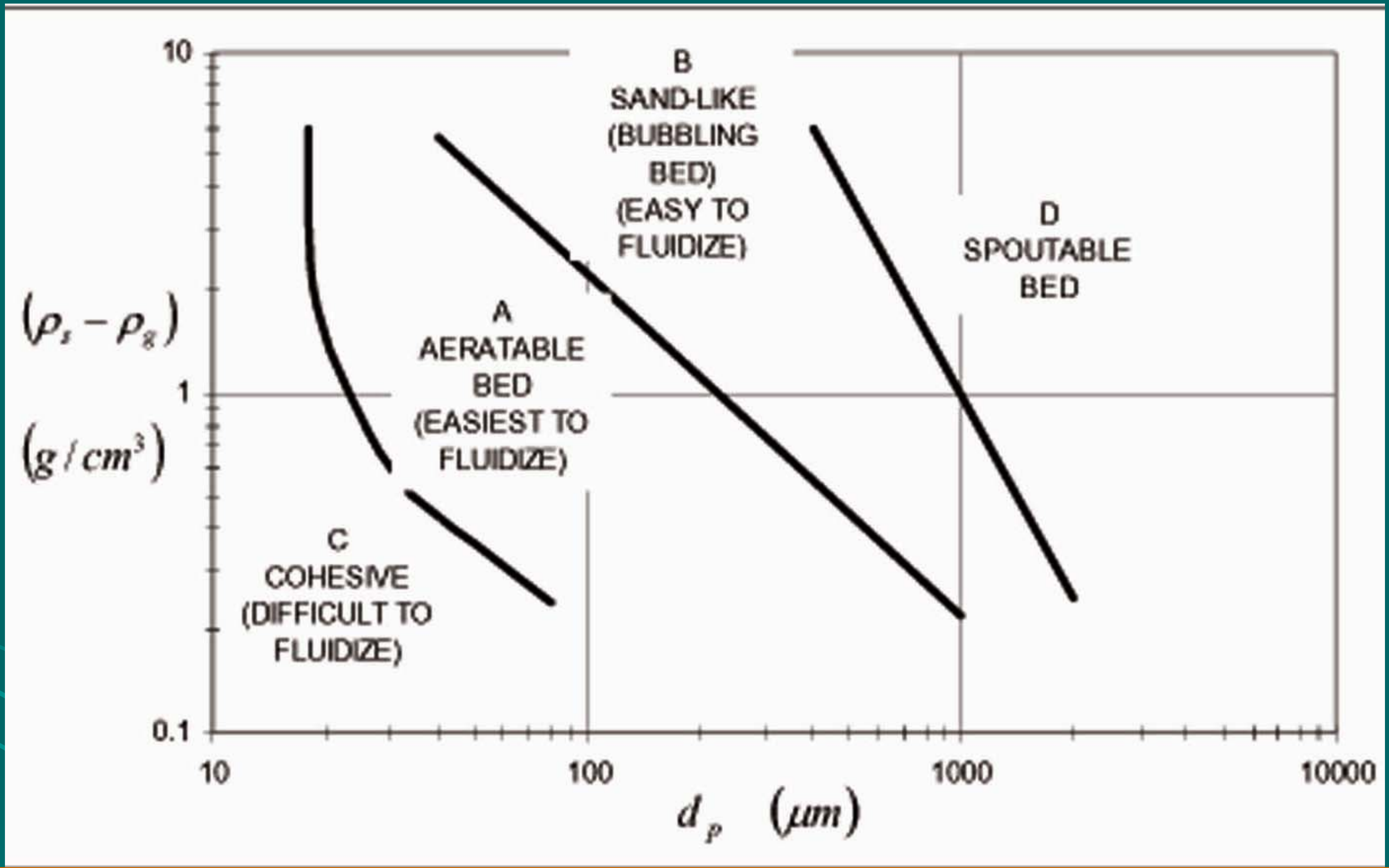
Heat transfer coefficient for gas radiation from bed

- As bed temperature increases heat transfer improves.

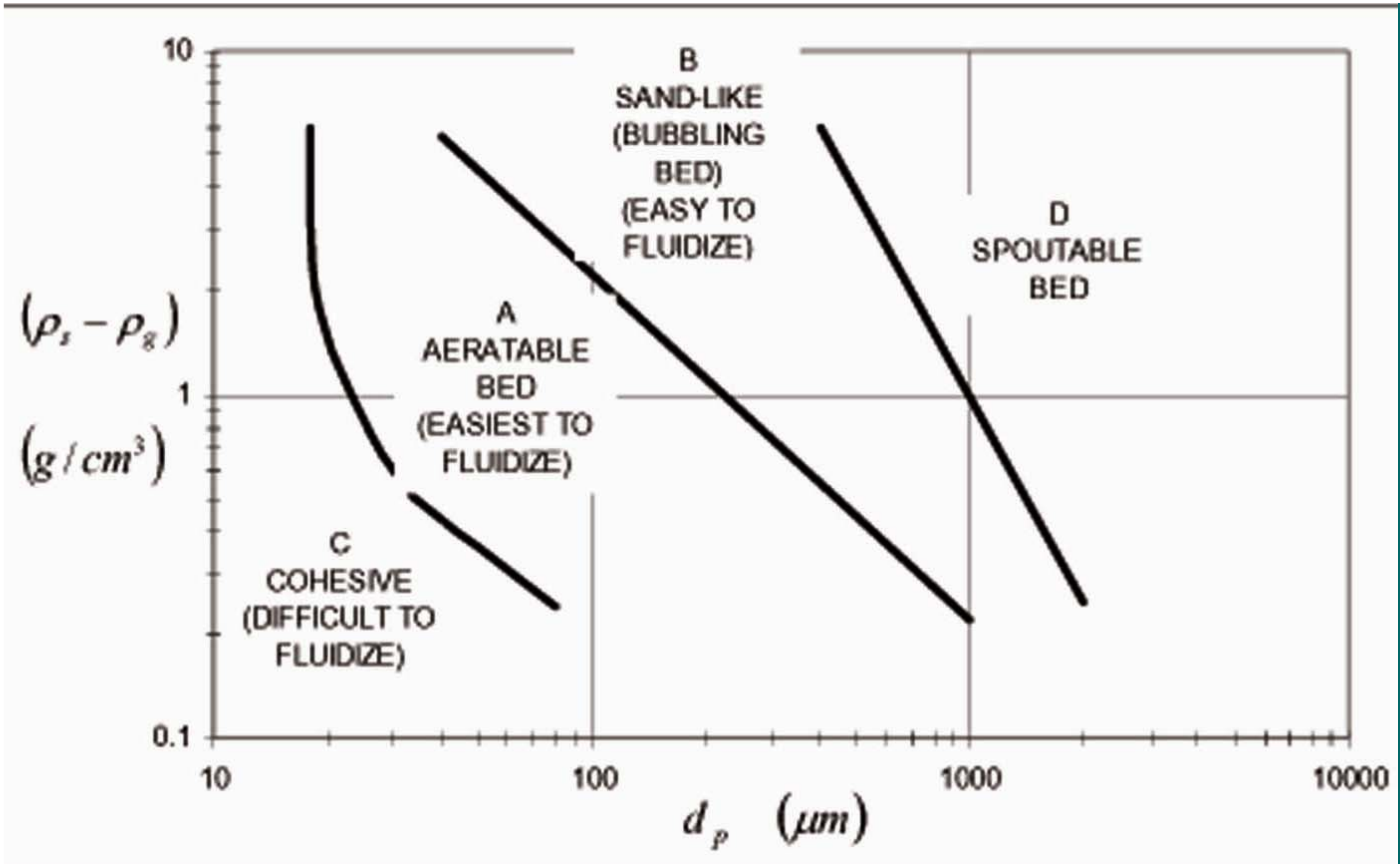
Fluidization quality

- A good fluidized bed should be able to keep all the particles in motion.
- When coarser particles drop out of motion, localized defluidisation occurs.
- Localized bed particle mounts lead to reduction of heat transfer & haphazard erosion.
- Particle size plays an important role in keeping up good fluidization.

Geldart classification of particles for fluidized bed

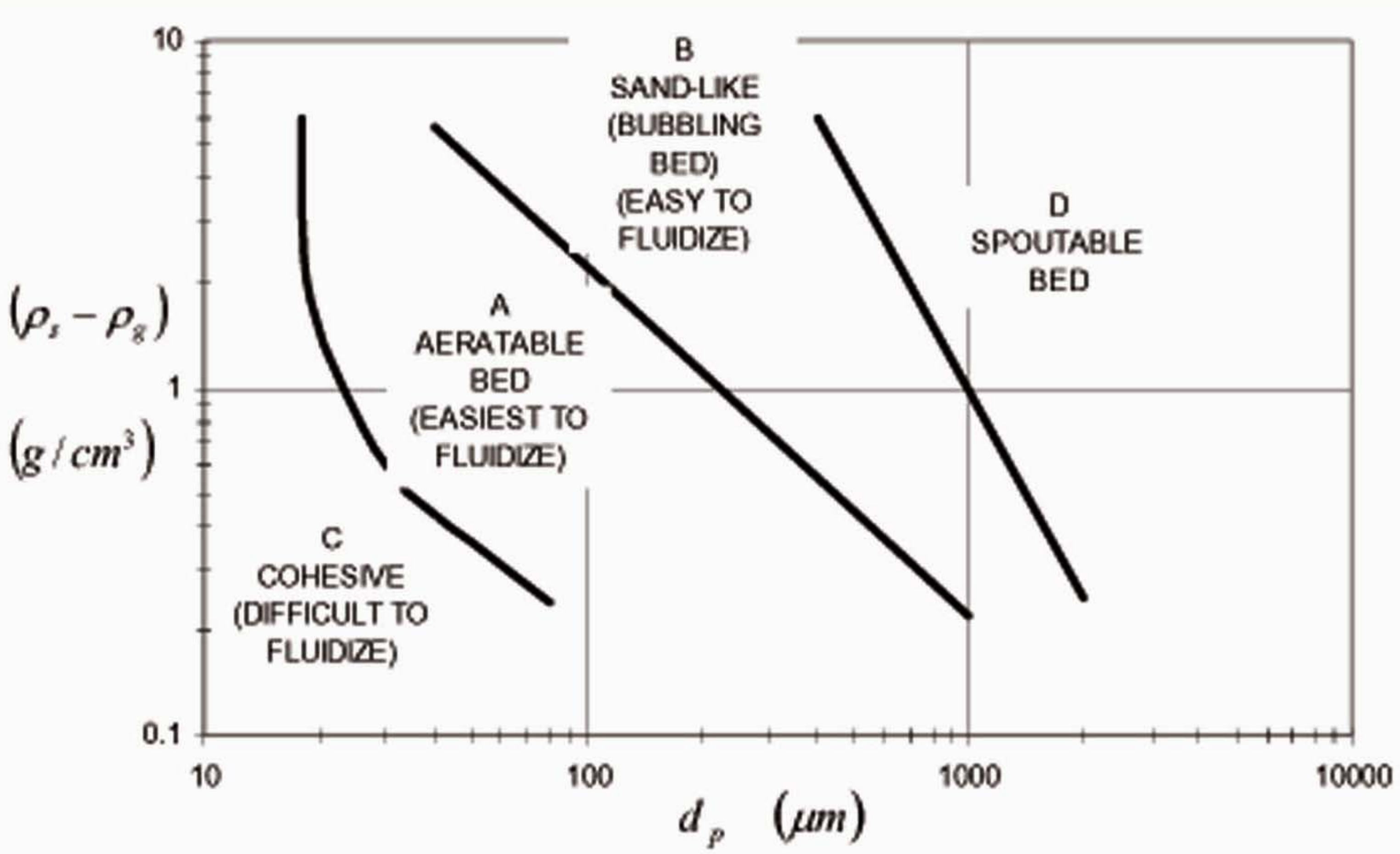


He categorized his observations on fluidization of different solid particle size versus the relative density difference between fluid phase & the solid particles. He identified four regions in which the fluidization character can be distinctly defined.



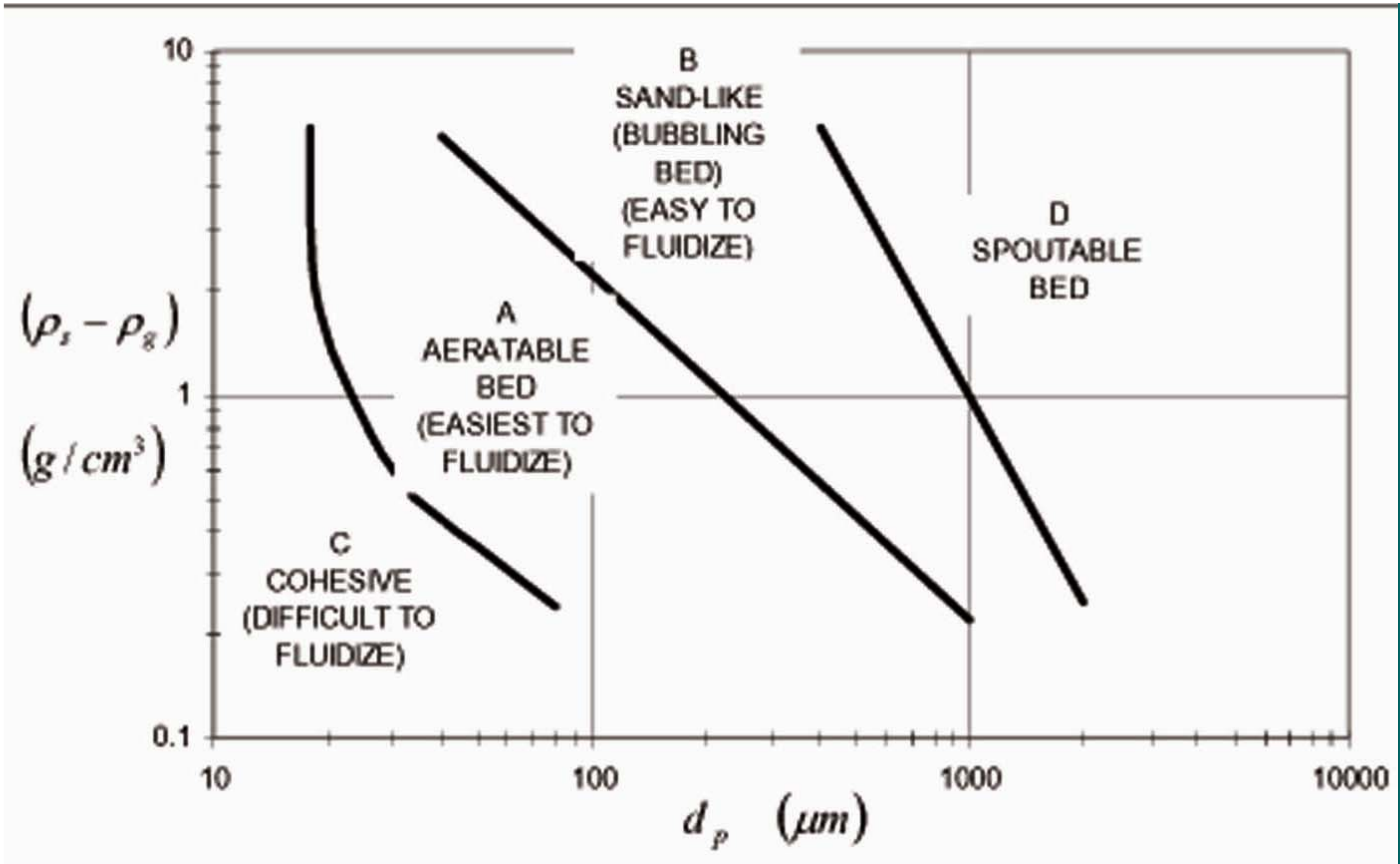
Group A particles

- Good bubbling bed fluidization.
- Good solid mixing occurs.
- Bed expands considerably.
- The maximum bubble size is 100 mm.
- Bubbles split & coalesce frequently through the bed.



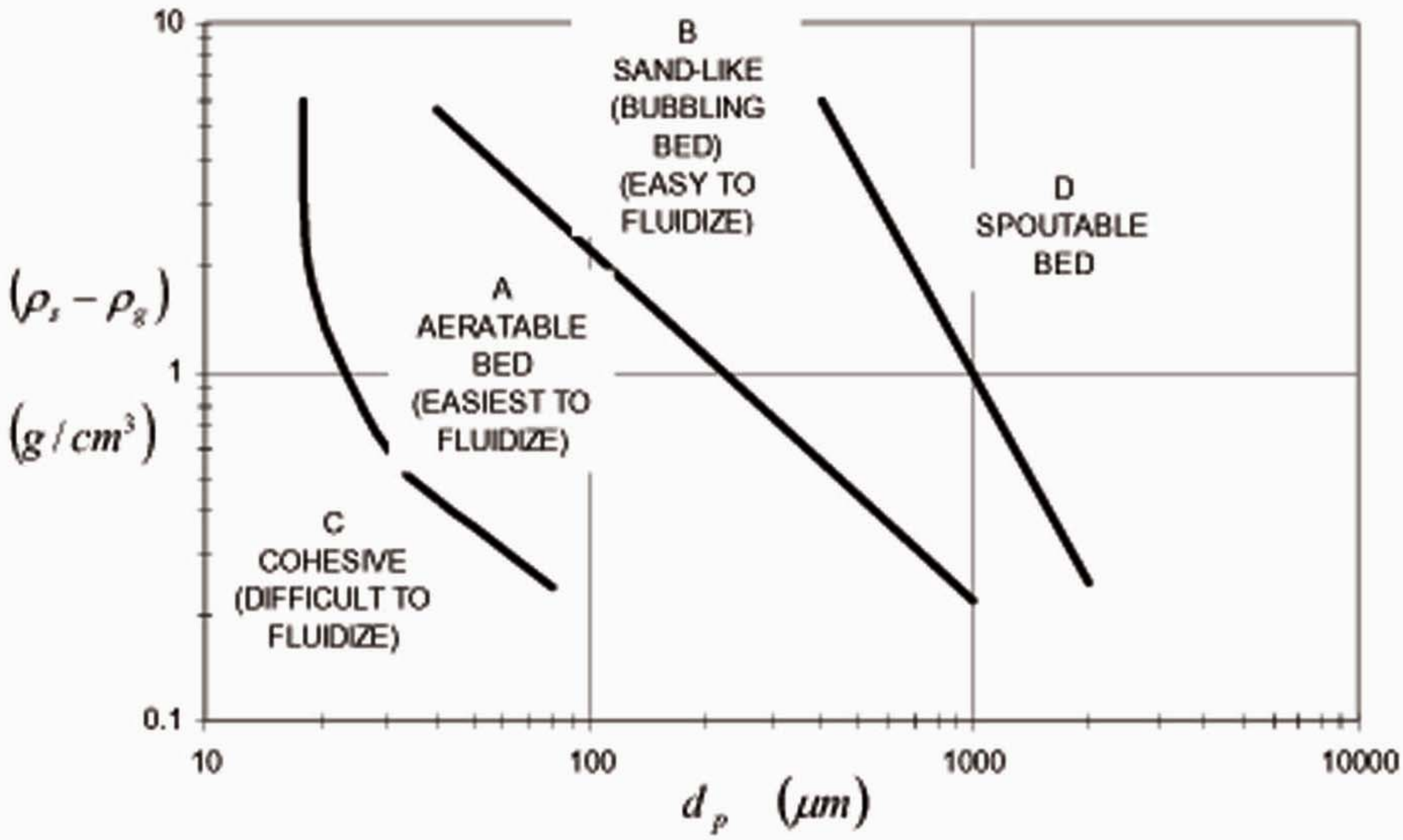
Group B particles

- Made of coarser particles than group A & denser as well.
- Form bubbles soon as gas velocity >min fluidization velocity.
- Bubble grows from small to big as it travels upwards.
- Bubble sizes are independent of particle sizes.
- Gross circulation / mixing is experienced.



Group C particles

- Are difficult to fluidize and tend to rise as slug of solids.
- Flow channels at some places in large beds with no fluidization.
- Tends to be cohesive.

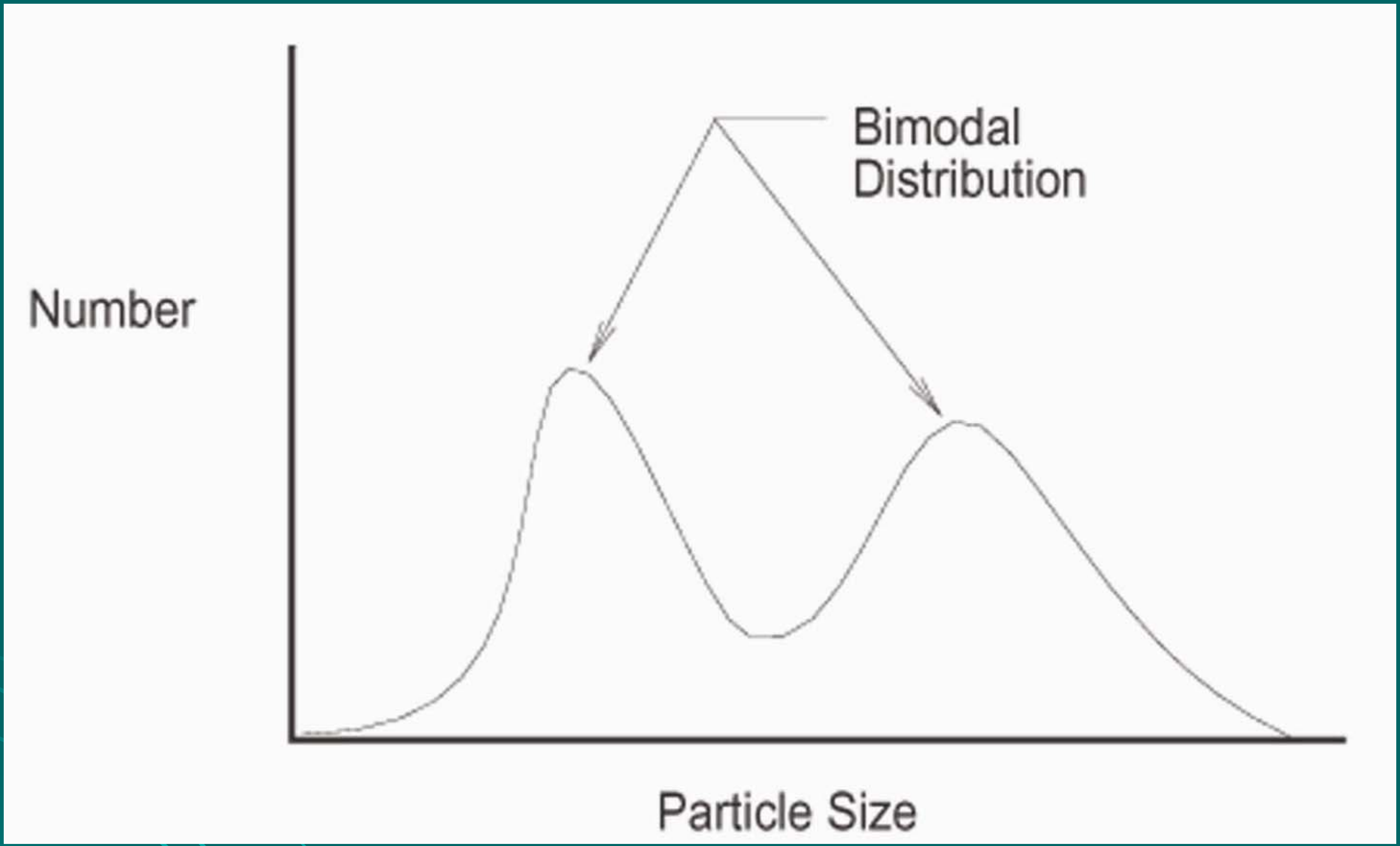


Group D particles

- Very large, dense particles.
- Bubbles grow very big.
- Material is thrown vigorously (spouts) at top of the bed.

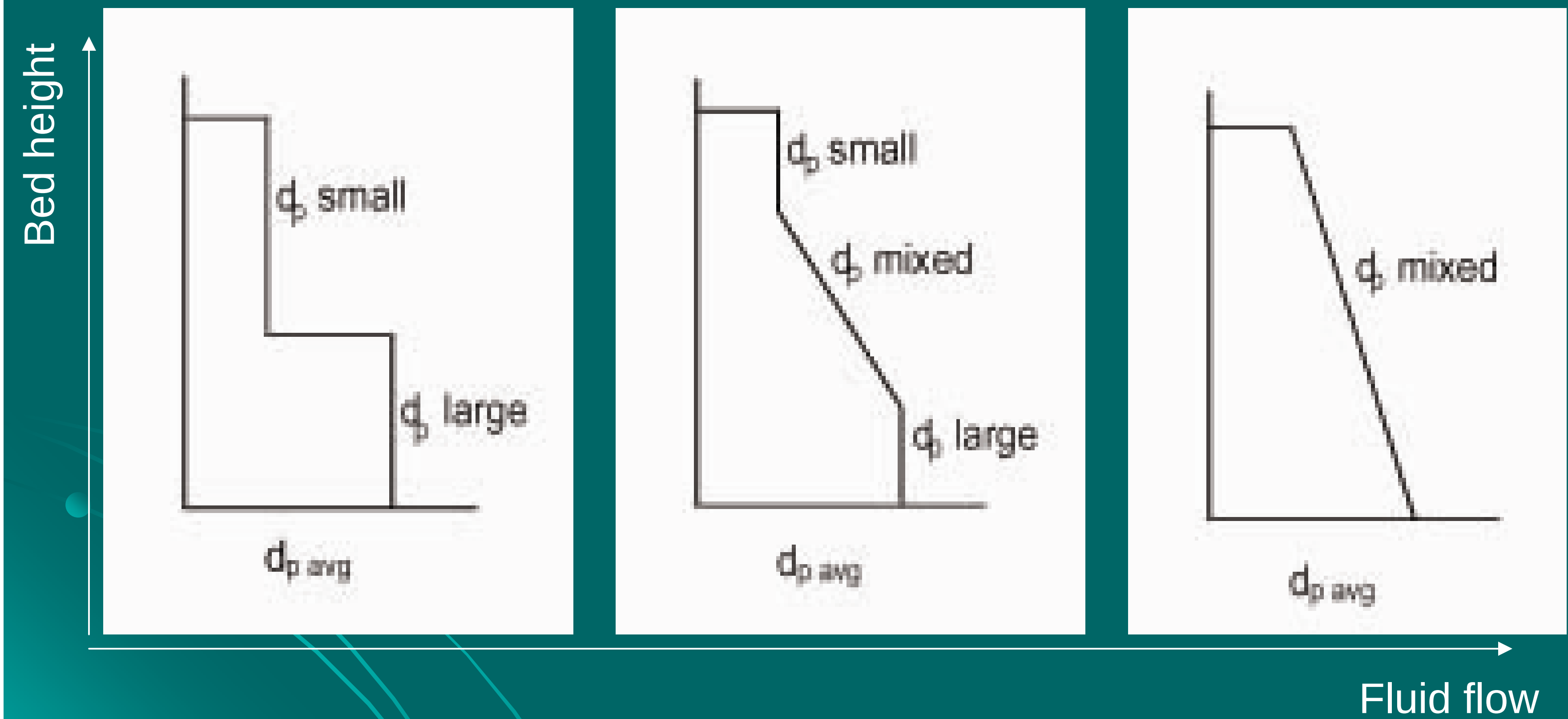
Wide size distribution of particles

- There will be two fluidization velocities when a large range of particles are present.
- The smaller particles will find a path to travel through the voids and fluidize on the surface.
- The larger particles may fluidize only at higher air flow. At this time, the fines elutriation will be more. The fluidization can be best achieved by adding more fines and removing the coarse lot from the bed.



Bimodal distribution of particles leads to two different fluidization velocities. Poor performance is often the result of this situation.

Fluidized bed with bimodal particle distribution



Particle segregate across the bed height as function of fluidizing gas flow rate.

Real life problems in AFBC

- Sub-bituminous coal with high ash may add more coarser particles to bed and try to shift the average particles to a higher size.
- High volatile coal ash / Lignite ash would be ideal in maintaining a lower & consistent average particle size since the start up.

Real life problems in AFBC

- Boilers with rice husk firing tend to produce more unburnt when the stones begin to accumulate.
- Depending upon the crushing & screening system, the average particle size could drift to higher size and pose combustion and erosion problems.