FLUIDIZATION

So a solid particle bed now behaves like liquid. This method of contacting of this two phase mixture have some unusual characteristics that are widely used in many fields of chemical industry. Simplified diagram showing the idea of fluidization is presented in Figure below Gas is delivered from the bottom of the reactor, goes through a gas distributor to provide inform distribution through whole profile of bed and flows through packed bed of solids.

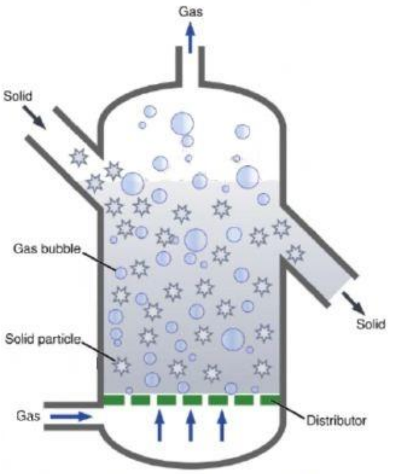
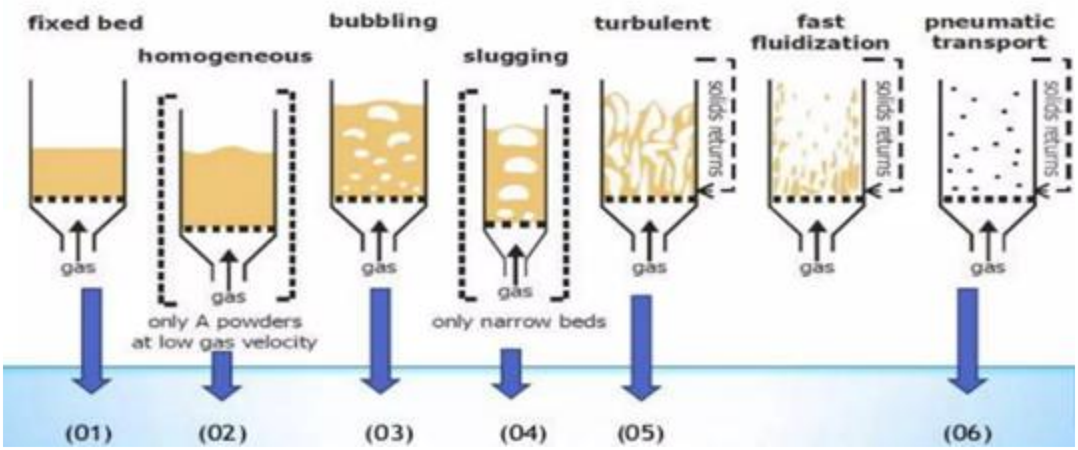


Figure 1: Schematic diagram of fluidization

At low gas velocities the drag force is to small to lift the bed, which remains fixed. Increasing gas velocity causes solids to move upward and create fluid bed. Depending on the velocity of gas we can distinguish different modes of fluidization (Fig..2) from bubbling fluidization, through turbulent and fast fluidization modes up to pneumatic transport of solids.



Figure(2): Fluidization type depending on gas velocity.

Another important issue concerning the fluidization process is pressure drop through a fixed bed. Figure (3) presents changes in pressure drop with changing gas velocity. The velocity at which the pressure is stabilized is called ***minimum fludization velocity*(u_{mf}).**

If the particles are spherical the bed can be described by means of their diameter distribution, but in real application most particles are nonspherical which yields a question about the way to describe this kind of beds. However, the most wildly used is the one called **sphericity** (*φs*) defined as the ratio of the surface of sphere to the surface of particle with the same volume. For spherical particles *φs* = 1 and for other shapes 0 ≤ *φs* ≤ 1.

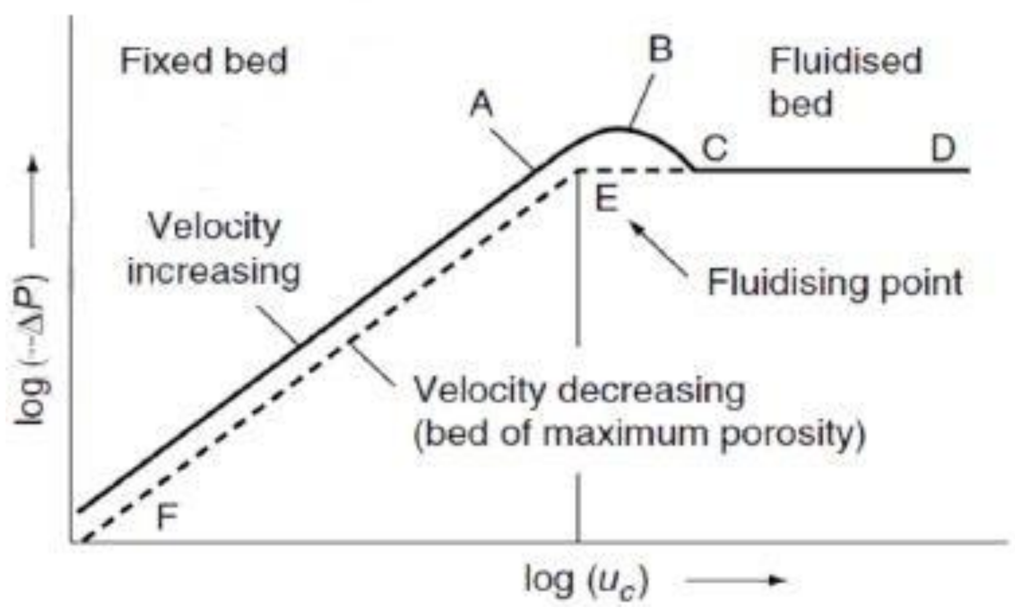


Figure (3): Pressure drop over fixed and fluidized beds.

In a fluidized bed, the total frictional force on the particles must equal the effective weight of the bed. Thus, in a bed of unit cross-sectional area, depth *l*, and porosity *e*, the additional pressure drop across the bed attributable to the layout weight of the particles is given by:

$$\Delta P = (1 - e)(\rho_s - \rho)lg \qquad \text{------- (1)}$$

where: g is the acceleration due to gravity and

ρ_s and ρ are the densities of the particles and the fluid respectively.

PRESSURE DROP

Pressure drop through fixed bed of solids of uniform size (**dp**) of the length **L** is given by Ergun correlation:

$$\left(\frac{-\Delta P}{L}\right) = 150\frac{\mu u_o(1-e_m)^2}{(\emptyset s d_p)^2 e_m^3} + 1.75\frac{\rho_g u_o^2}{\emptyset s d_p}\frac{(1-e_m)}{e_m^3} \qquad \text{-------- (2)}$$

where μ is gas viscosity, d_p is solid diameter, ρ_g is gas density, u_o is superficial gas velocity, and e_m is the fractional voidage, which usually can be found experimentally for each specific system.

If flow conditions within the bed are streamline, the relation between fluid velocity u_c , pressure drop (ΔP) and voidage e is given, for a fixed bed of spherical particles of diameter dp, by the ***Carman-Kozeny equation*** which takes the form:

$$u_C = 0.0055\left(\frac{e^3}{(1-e)^2}\right)\left(\frac{-\Delta P d^2}{\mu l}\right) \text{ ------- (3)}$$

For a fluidized bed, the buoyant weight of the particles is counterbalanced by the frictional drag. Substituting for ΔP from equation (1) into equation (3) gives:

$$u_C = 0.0055\left(\frac{e^3}{(1-e)^2}\right)\left(\frac{d^2(\rho_s-\rho)g}{\mu}\right) \text{ ------- (4)}$$

Minimum fluidizing velocity

In this section one has to revise definitions of two dimensionless numbers:

Reynolds **:**

$$Re = \frac{d_p u_{mf}\rho_g}{\mu}$$

and

Archimedes **or** ***Ga 'Galileo number'*** **:**

$$Ar = \frac{d_p^3\rho_g(\rho_s-\rho_g)g}{\mu^2}$$

Under fluidization conditions, pressure – drop equals effective weight of solid, as intraparticle forces disappear and solids float in the bed exhibiting ‘liquid–like ‘behavior. For a fluidized bed of length of **L** and bed-porosity of **ε**.

$$\Delta P_{bed}A_t = A_t L_{mf}(1-e_{mf})[\rho_s-\rho_g)g]$$

The value of e_{mf} will be a function of the shape, size distribution and surface properties of the particles. Substituting a typical value of **0.4** for e_{mf} in equation(4) gives:

$$(u_{mf})_{e_{mf}=0.4} = 0.00059\left(\frac{d^2(\rho_s-\rho)g}{\mu}\right) \text{ ---------- (5)}$$

Substituting $e = e_{mf}$ at the incipient fluidization and for –ΔP from equation(1) equation (2) is then applicable at the minimum fluidization velocity u_{mf}, and gives: $(1-e_{mf})(\rho_S-\rho)g = 150\frac{\mu u_{mf}(1-e_{mf})^2}{d^2 e_{mf}^3} + 1.75\frac{\rho_g u_{mf}^2}{d_p}\frac{(1-e_{mf})}{e_{mf}^3}$ ----(6)

multiplying both sides by $\frac{\rho d^3}{\mu^2(1-e_{mf})}$ gives:

$$\frac{\rho(\rho_s-\rho)gd^3}{\mu^2} = 150\left(\frac{1-e_{mf}}{e_{mf}^3}\right)\left(\frac{\mu u_{mf}d\rho}{\mu}\right) + \left(\frac{1.75}{e_{mf}^3}\right)\left(\frac{u_{mf}d\rho}{\mu}\right)^2 ---(6)$$

In eqution (6):

$\frac{\rho(\rho_s-\rho)gd^3}{\mu^2} = Ga$ Where ***Ga*** is the *'Galileo number'*.

and: $\frac{\mu u_{mf} d\rho}{\mu} = Re'_{mf}$

where Re_{mf} is the reynolds number at the minimum fluidising velocity and equation (6) then becomes:

$$Ga = 150\left(\frac{1-e_{mf}}{e_{mf}^3}\right)Re'_{mf} + \left(\frac{1.75}{e_{mf}^3}\right)Re'^2_{mf} \quad \text{------------(7)}$$

For value of $e_{mf} = 0.4$:

$$Ga = 1406Re'_{mf} + 27.3Re'^2_{mf} \quad \text{------------ (8)}$$

Thus : $Re'^2_{mf} + Re'_{mf} - 0.0366Ga = 0$ -------------(9)

and : $(Re'_{mf})_{e_{mf}=0.4} = 25.7\left\{\sqrt{(1 + 5.53 \times 10^{-5}Ga)} - 1\right\}$ ---- (10)

and, *similarly for* $e_{mf} = 0.45$:

$$(Re'_{mf})_{e_{mf}=0.45} = 23.6\left\{\sqrt{(1 + 9.39 \times 10^{-5}Ga)} - 1\right\} \quad \text{--------(11)}$$

By definition: $u_{mf} = \frac{\mu}{d\rho}Re'_{mf}$ -------- (12)

Thus: $\emptyset_s = \frac{d}{d_p}$ ------ (13)

Where: $d = \frac{6V_p}{A_p}$ *and* $d_p = (6V_p/\pi)^{1/3}$

Where: $\emptyset_s$ = The ratio of the diameter of the sphere of the same specific as the particle ***d***, as used in the Ergun eqution to the diameter of the sphere with the same volume as the particle d_p.

For small particles $R_{emf} < 20$

$$u_{mf} = \frac{d_p^2(\rho_p-\rho_f)g}{150\mu_f}\left(\frac{e_{mf}^3\,\emptyset_s^2}{1-e_{mf}}\right)$$

For large particles $Re_{mf} > 1000$

$$u_{mf}^2 = \frac{d_p(\rho_p-\rho_f)g}{1.75\,\rho_f}e_{mf}^3\emptyset_s$$

To avoid or reduce carryover of particles from the fluidizes bed, kepp the gas velocity between u_{mf} and u_t recall

Terminal velocity , $u_t = \frac{g d_p^2(\rho_p - \rho_{f\rho})}{18\mu_f}$ for *low Reynolds number* .

Terminal velocity , $u_t = 1.75 \frac{\sqrt{g d_p(\rho_p - \rho_f)}}{18\mu_f}$ for *high Reynolds number*.

Example (1):

A bed consists of uniform spherical particles of diameter **3 *mm*** and density **4200 *kg/m³***. What will be the minimum fludizing velocity in a liquid of viscosity **3*mNs/m²*** and density **1100 *kg/m³***?

Solution:

By definition : ***Galileo number,*** $Ga = \frac{\rho(\rho_s - \rho)g d^3}{\mu^2}$

$Ga = ((3\times 10^{-3})^3 \times 1100 \times (4200 - 1100) \times 9.81)/(3 \times 10^{-3})^2$

$= 1.003 \times 10^5$

Assuming a value of **0.4** for e_{mf} equation:

$$\left(Re'_{mf}\right)_{e_{mf}=0.4} = 25.7\left\{\sqrt{(1 + 5.53 \times 10^{-5}Ga}\right) - 1\right\}$$

$$\left(Re'_{mf}\right) = 25.7\left\{\sqrt{(1 + 5.53 \times 10^{-5}}(1.003 \times 10^5)\right) - 1\right\} = 40$$

$$u_{mf} = \frac{\mu}{d \times \rho} Re'_{mf}$$

and: $u_{mf} = \frac{40 \times 3 \times 10^{-3}}{3 \times 10^{-3} \times 1100} = 0.0364\, m/s \text{ or } 36.4\ mm/s$

Example (2):

Seawater is passed through a column containing a bed of resin beads. Density of seawater **1025 *kg/m³***, density of resin beads **1330 *kg/m³*** and dimeter of resin beads **50 *µm*** ,and have void fraction of the bed at the onset of fluidization 0.4.Acceleration due to gravity **9.8 *m/s²***. Find the pressure drop per unit length of the bed at the onset of fluidization ?

Solution:

$$\frac{\Delta P}{L} = (1 - e)(\rho_s - \rho)g$$

$$\frac{\Delta P}{L} = (1 - 04) \times (1330 - 1025) \times 9.81 = 1795\ Pa.m^{-1}$$

Example (3):

Oil , of density **900 *kg/m³*** and viscosity **3 *mNs/m²*** , is passed vertically upwards through a bedof catalyst consisting of approximately spherical particle of diameter **0.1 *mm*** and density **2600 *kg/m³***. At approximately what mass rate of flow per unit area of bed will fluidization?

Solution:

To determine the fluidizing velocity, u_{mf}

$u = (1/K'')(e^3/(S^2(1-e)^2(1/\mu)(-\Delta P/l)$ -------(13)

$$\frac{\Delta P}{L} = (1-e)(\rho_s - \rho)g$$

Where S = surface area /volume, which,for a sphere = $\frac{\pi d^2}{\frac{\pi d^3}{6}} = \frac{6}{d}$

Substituting $K'' = 5$, $S = 6/d$ and $-\Delta P/l$ from eq(1) in to (13) gives:

$$u_C = 0.0055\left(\frac{e^3}{(1-e)}\right)\left(\frac{d^2(\rho_s-\rho)g}{\mu}\right)$$

Hence: $G'_{mf} = \rho u = \rho \times 0.0055\left(\frac{e^3}{(1-e)}\right)\left(\frac{d^2(\rho_s-\rho)g}{\mu}\right)$

$\rho_s = 2600\ kg/m^3$, $\rho = 900\ kg/m^3$, $\mu = 3.0\times 10^{-3} Ns/m^2$ and $d = 0.1\ mm$

As no value of the voidage is available, ***e*** will be estimated by considering eight closely packed spheres of diameter d in a cube of side **2*d***. Thus:

Volume of spheres = $8(\frac{\pi}{6})d^3$

Volume of the enclosure = $(2d)^3 = 8d^3$

And hence: voidage, $e = \left[8d^3 - 8\left(\frac{\pi}{6}\right)d^3\right]/8d^3 = 0.478$, say, 0.48

Thus: $G'_{mf} = 0.0055(0.48)^3(10^{-4})^2((900 \text{ x}1700) \text{ x } 9.81)/((1-0.48) \text{ x } 3\text{x } 10^{-3}$

$= 0.059\ kg/m^2.s$

Advantages and disadvantages of fluidization

Advantages	Disadvantages
Large surface area exposed	Pumping costs
Flatter temperature gradient	Solid aggregates(stops fluidization)
High heat transfer coefficient	Solid attrition (blows away)
Suspension can be pumped around	Narrow velocity window between fludization and slugging
Lake of moving parts	

Types of fluidization

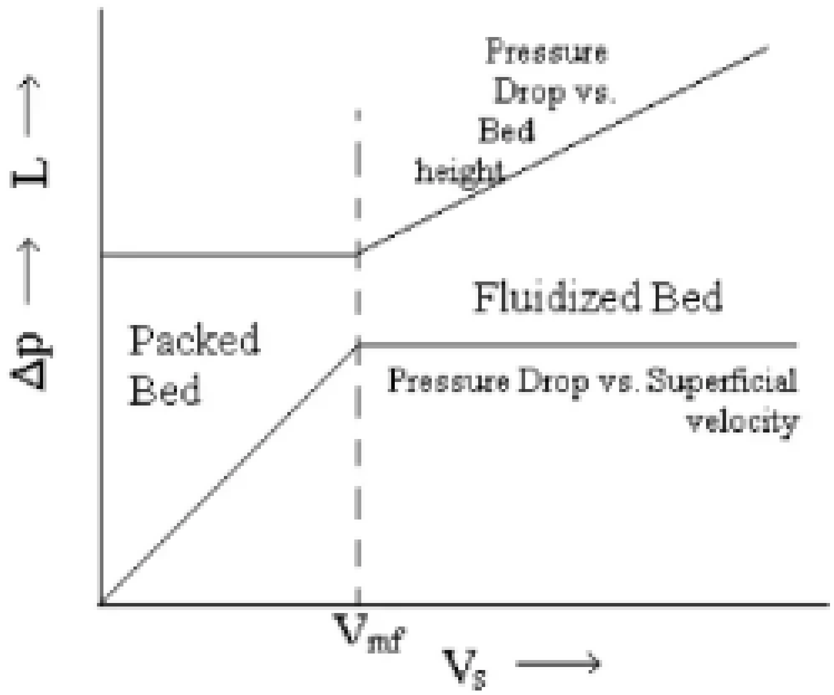
1- Particulate fluidization:

- This occurs mainly with liquid – solid fluidized system.eg, when peas are fluidized by brine soluition during bleaching.

2- Aggregative fluidization:

- This occurs with gas – solid fluidized system.
- As gas velocity increases, a fraction of the gas will pass through the bed in the form of bubbles.
- The velocity at which the bubble first from is known as the minimum bubbling velocity (u_{mb}).

Condition for fluidization



Transition from packed bed to fuidized bed.

Application of fluidization

❖ Most of the fluidization applications use one or more of three important characteristics of fluidized bed:

- Fluidized solid can be easily transferred between reactors.
- The intense mixing within a fluidized bed means that its temperature is uniform.

- There is excellent heat transfer between a fluidized bed and heat exchangers immersed in the bed.

❖ Gas – Solid Reaction:

- Fluid catalytic craking , reforming.
- Fischer-tropsch synthesis.
- Oxidation of SO2 to SO3.
- Fluid cooking.
- Catalyst regeneration.

❖ Physical Process:

- Drying of particles.
- Coating of surfaces.
- Granulation (growing particles).
- Filtration.
- Blending.