MODULE 1: CHARACTERIZATION OF SOLID PARTICLES

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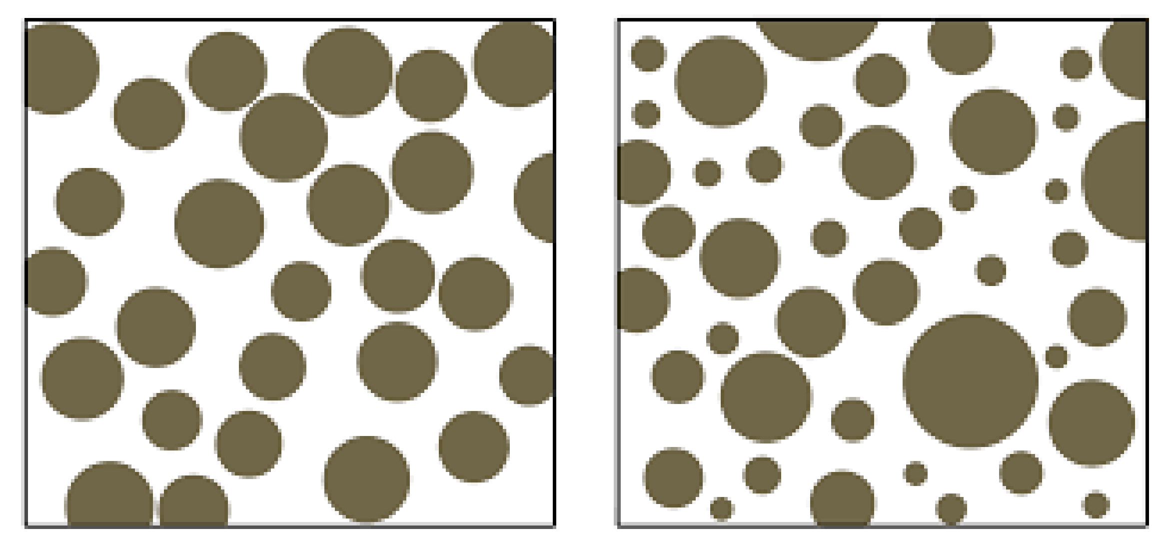
SYLLABUS

- Module 1: Characterization of solid particles: Particle Shape. Particle size analysis Differential and cumulative analysis. Properties of particulate masses: Bulk density, coefficient of Internal Friction, Storage of solids, Pressure distribution in hopper. Janssen Equation. Transportation of Solids: Studies on performance and operation of different conveyors eg. Belt, Screw, Apron, Flight etc. and elevators.

INTRODUCTION

Conglomerate: Sedimentary Rock



Particles of different size

DEFINITION

- Mechanical operation deals with the handling, processing, characterization and conversion of particulate material irrespective of size and state of materials.

APPLICATION

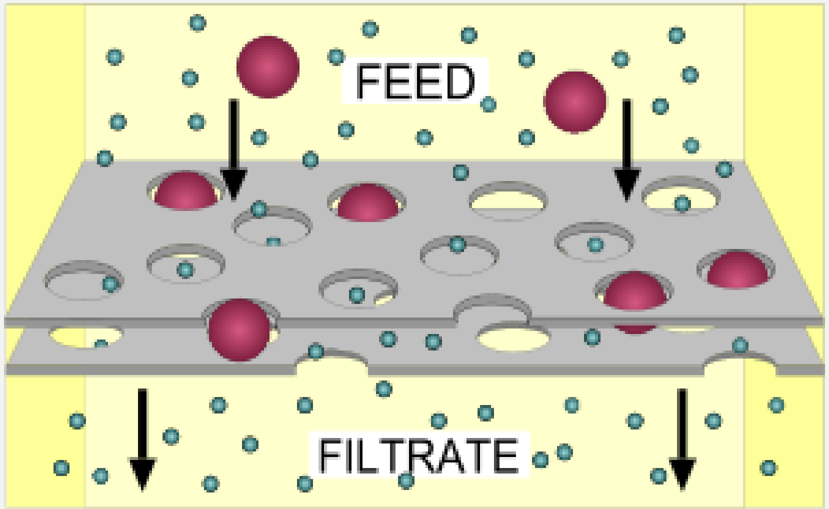


Fig 1

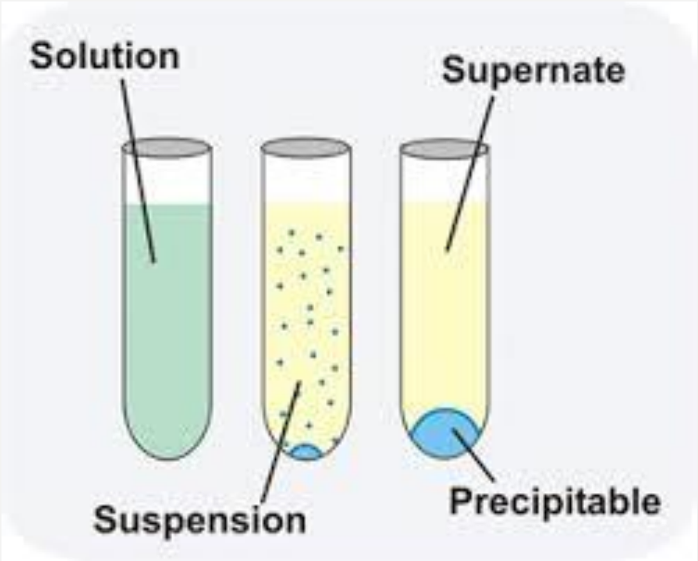


Fig 2

APPLICATION

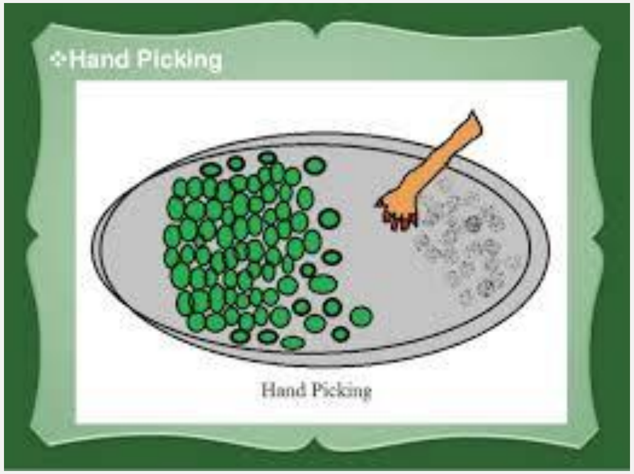


Fig 3

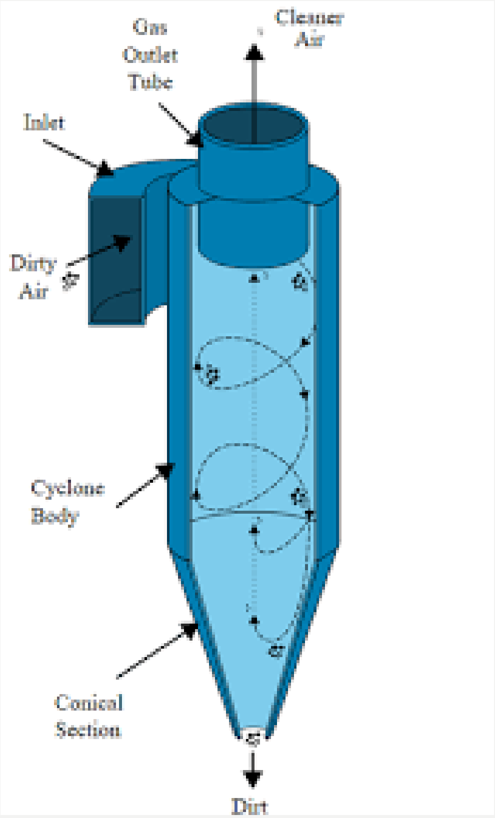


Fig 4

APPLICATION

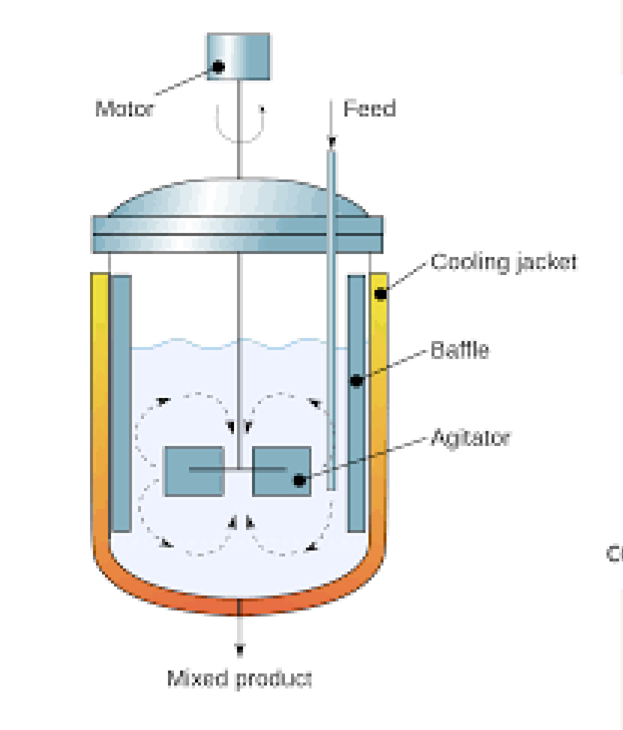


Fig 5

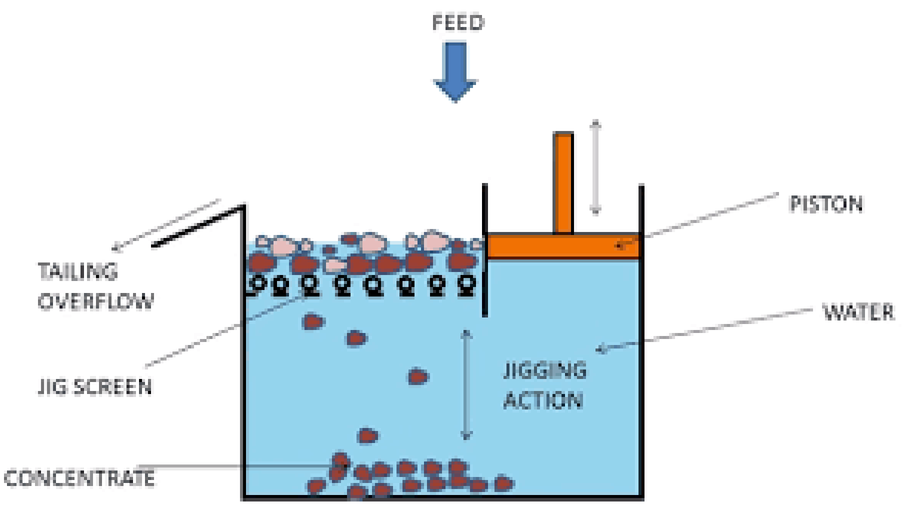


Fig 6

APPLICATION

Fig 7

Fig 8

Fig 9

CHARACTERIZATION OF SOLID PARTICLES

- Solid particles are characterized by their particle Shape, particle size and density.
- The shape of particles are either regular or irregular.
- Ex: square, cube sphere are regular shape and grains, flakes are irregular in shape.
- The shape of individual particle is expresses in terms of sphericity.

PARTICLE SHAPE

- Sphericity is defined as:

$$\Phi_s \equiv \frac{6v_p}{D_p . s_p} = \frac{6 \times volume\_of\_one\_particle}{equivalent\_dia \times surface\_\_of\_one\_particle}$$

- Sphericity of some irregular shape particles:

Berl saddles (0.3), Ottawa sand (0.95), coal dust (0.73), mica flakes (0.28) etc.

Q. What is the sphericity of spherical, cubical and cylindrical particles?

cube

cylinder

$\phi_s < 1$

$$\phi_s = \frac{(V/S)_p}{(V/S)_{sp}}$$

max → (V/S)

$$\phi_s = \frac{(V/S)_p}{(V/S)_{sph}}$$

$$\left(\frac{V}{S}\right)_{sph} = \frac{\frac{1}{6}\pi D_s^3}{\pi D_s^2} = \frac{D_s}{6}$$

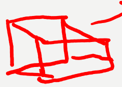
$$= \frac{6}{D_s}\left(\frac{V}{S}\right)_p$$

$$= \frac{6}{D_p}\left(\frac{V}{S}\right)_p$$

$$V_p = \frac{1}{6}\pi D_s^3$$

↓ Equ. dia

$$\phi_s = 1$$



→ a

$$\left(\frac{V}{S}\right)_p = \frac{a^3}{6a^2} = \frac{a}{6}$$

$$V_p = V_{sp}$$

D_p

$$\Rightarrow a^3 = \frac{1}{6} D_p^3 \cdot \pi$$

$$\Rightarrow D_p = \sqrt[3]{\frac{6}{\pi}} \cdot a$$

$$\phi_s = \frac{6}{\sqrt[3]{\frac{6}{\pi}} \cdot a} \cdot \frac{a}{6}$$

$$\phi_s = \sqrt[3]{\frac{\pi}{6}} = 0.806$$

Cylinder (L = D)

$$\phi_s = \left(\frac{V}{S}\right)_{cy} \cdot \frac{6}{D_p}$$

$$S = \pi D L + \frac{\pi D^2}{2}$$

$$= \pi D^2 + \frac{\pi D^2}{2}$$

$$= \frac{3}{2}\pi D^2$$

$$\left(\frac{V}{S}\right)_{cy} = \frac{\pi D^3}{4} \times \frac{2}{3\pi D^2}$$

$$\left(\frac{V}{S}\right)_{cy} = \frac{1}{6} D$$

$$V_{sp} = V_{cy}$$

$$\frac{\pi}{6} D_p^3 = \frac{\pi D^3}{4}$$

$$D_p = \sqrt[3]{\frac{3}{2}} \cdot D$$

L ≠ D

L = D ⟹

$$V = \frac{\pi D^2}{4} L$$

L = D

$$V = \frac{\pi D^3}{4}$$ ✓

L = D/2

$$V = \frac{\pi D^3}{8}$$

$$\phi_{cy} = \frac{6}{\sqrt[3]{\frac{3}{2}} \cdot D} \cdot \frac{D}{6}$$

$$= \sqrt[3]{\frac{2}{3}}$$

$$= 0.874$$

SPHERICITY OF CUBICAL PARTICLE

$$\phi = \frac{6 V_p}{D_p \cdot S_p}$$

For cubical particle.

$$\frac{1}{6} \times \pi \times D_p^3 = a^3$$

$$D_p = \sqrt[3]{\frac{6}{\pi}} \cdot a$$

$$\phi = \frac{6 \times a^3}{\sqrt[3]{\frac{6}{\pi}} \cdot a \cdot 6a^2}$$

$$= \frac{6}{6} \times \sqrt[3]{\frac{\pi}{6}} = \sqrt[3]{\frac{\pi}{6}} = 0.805$$

SPHERICITY OF CYLINDRICAL PARTICLE

For cylinder

Volume $V_p = \frac{\pi D^2}{4} L$

Area $S_p = \pi D L + \frac{\pi D^2}{2}$

Eqv. Dia $= D_p = \sqrt[3]{\dfrac{\frac{\pi D^2}{4} L}{\frac{1}{6}\pi}}$

$= \sqrt[3]{\frac{3}{2} D^2 L}$

$\phi = \dfrac{\frac{1}{6} \times \frac{\pi D^2}{4} L}{D_p \cdot \left(\pi D L + \frac{\pi D^2}{2}\right)}$

For $D = L$

$V_p = \frac{\pi D^3}{4}$

$S_p = \frac{3}{2} \pi D^2$

$D_p = \sqrt[3]{\frac{3}{2}} \cdot D$

$D_p = \dfrac{6 \times \frac{\pi D^3}{4}}{\sqrt[3]{\frac{3}{2}} \cdot D \cdot \frac{3}{2} \pi D^2}$

$= 0.873$

For $L = \frac{D}{2}$

$V_p = \frac{\pi D^3}{8}$

$S_p = \pi D^2$

$D_p = \sqrt[3]{\frac{3}{4}}\ D$

$D_p = \dfrac{6 \times \frac{\pi D^3}{8}}{\sqrt[3]{\frac{3}{4}} \times D \times \pi D^2}$

$= 0.825$

PARTICLE SIZE

- If the particles are not equi-dimensional like needle, equivalent diameter will not able to characterize the particle.
- General convention to define such particle size are:

➢ inch or mm for course particles

➢ Screen size for fine particle

➢ Micro or nano-meter for very fine particles

➢ surface area per unit mass for ultra fine particles.

DENSITY OF PARTICLES

- Density of particles are also not constant for heterogeneous materials.
- Ex: the metal-bearing ore have various densities after breaking up in small parcicles.

PARTICLE SIZE ANALYSIS

- In a mixture of uniform particles, the number of particles are defined as follows:

$$N = \frac{m}{\rho_p . v_p}$$

Total mass

volume of one particle

mass of single particle

- The total surface area:

$$A = N . s_p = \frac{6m}{\Phi_s . \rho_p . D_p}$$

$$\phi_s = \frac{6 V_p}{D_p s_p}$$

$$s_p = \frac{6 V_p}{\phi_s D_p}$$

$$\frac{m}{\rho_p V_p} \cdot s_p = \frac{m}{\rho_p V_p} \times \frac{6 V_p}{\phi_s D_p} = \frac{6m}{\rho_p \phi_s D_p}$$

SIEVE ANALYSIS

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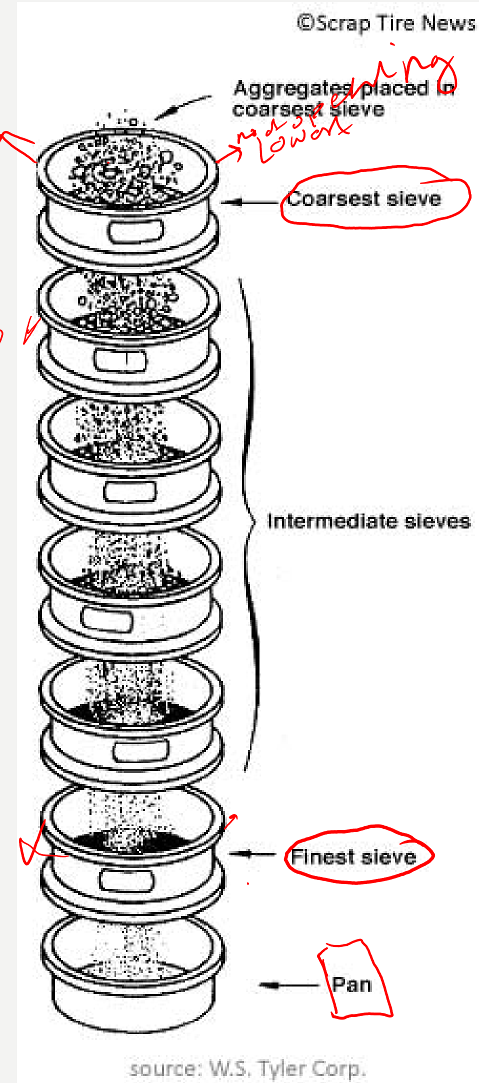

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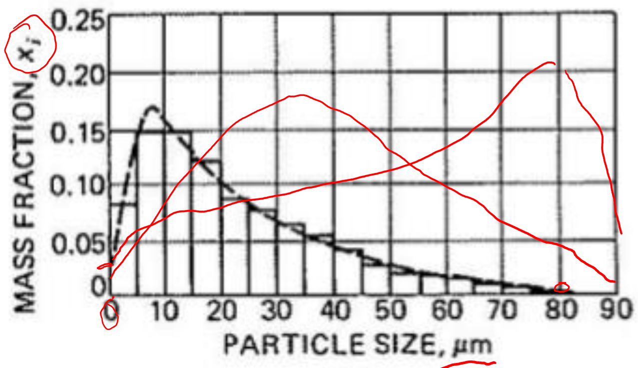
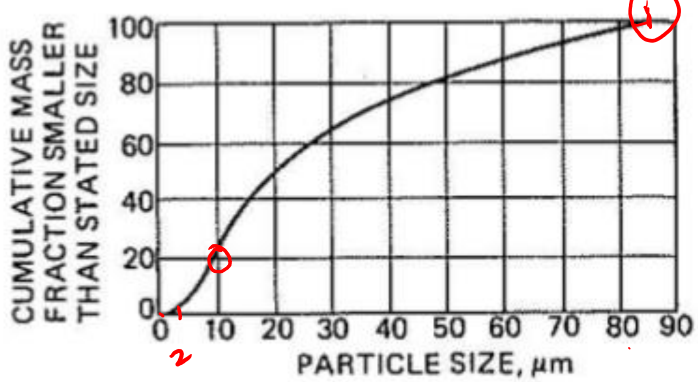
PARTICLE SIZE DISTRIBUTION



(a)

Differential Analysis

Cumulative Analysis



(b)

APPLICATION OF SIZE ANALYSIS

- Specific surface area is the total surface of a unit mass of particle.

$$A_w = \frac{6}{\Phi_s \rho_p} \sum_{i=1}^{n} \frac{x_i}{\overline{D}_{pi}}$$

- Average particle size is defined as the volume-surface mean dia

$$\overline{D}_s \equiv \frac{6}{\Phi_s . A_w . \rho_p} = \frac{1}{\sum_{i=1}^{n} (x_i / \overline{D}_{pi})}$$

APPLICATION OF SIZE ANALYSIS

- Arithmetic mean dia:

$$\overline{D}_N = \frac{\sum_{i=1}^{n} N_i \overline{D}_{pi}}{\sum_{i=1}^{n} N_i}$$

- Mass mean dia

$$\overline{D}_w = \sum_{i=1}^{n} x_i \overline{D}_{pi}$$

- Volume mean dia

$$\overline{D}_v = \left(\frac{1}{\sum_{i=1}^{n} (x_i / \overline{D}_{pi}^3)} \right)^{1/3}$$

SCREEN ANALYSIS

- Standard screens are used to measure the size and size distribution.
- The size of particles measured using std. screen are between 76mm to 38µm.
- These screen or sieves are made of woven wire screen.

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SCREEN ANALYSIS

- The mesh opening are square and defined as meshes per inch.
- Practically the number of actual openings are less than the mesh number because of wire thickness.
- The ratio of actual mesh dimension of any screen to that of next smaller sta. screen is $\sqrt{2} = 1.41$
- Std. screens is arranged serially in a stack with the smallest mesh at bottom and largest at top.
- The sample is feed to the top and stack is shaken mechanically for around 20min.
- Thereafter the mass of particle remained on each size is measured.

SIEVE ANALYSIS

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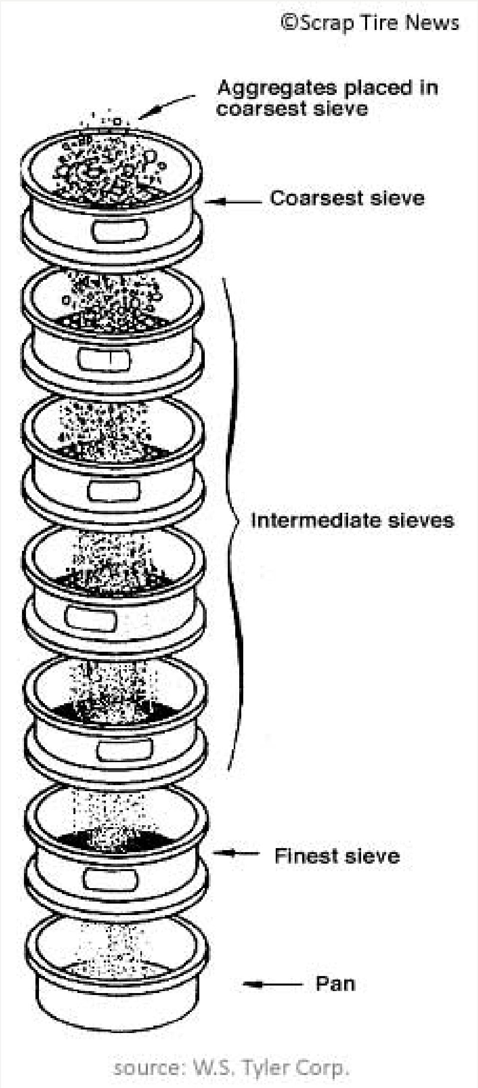

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SCREEN ANALYSIS

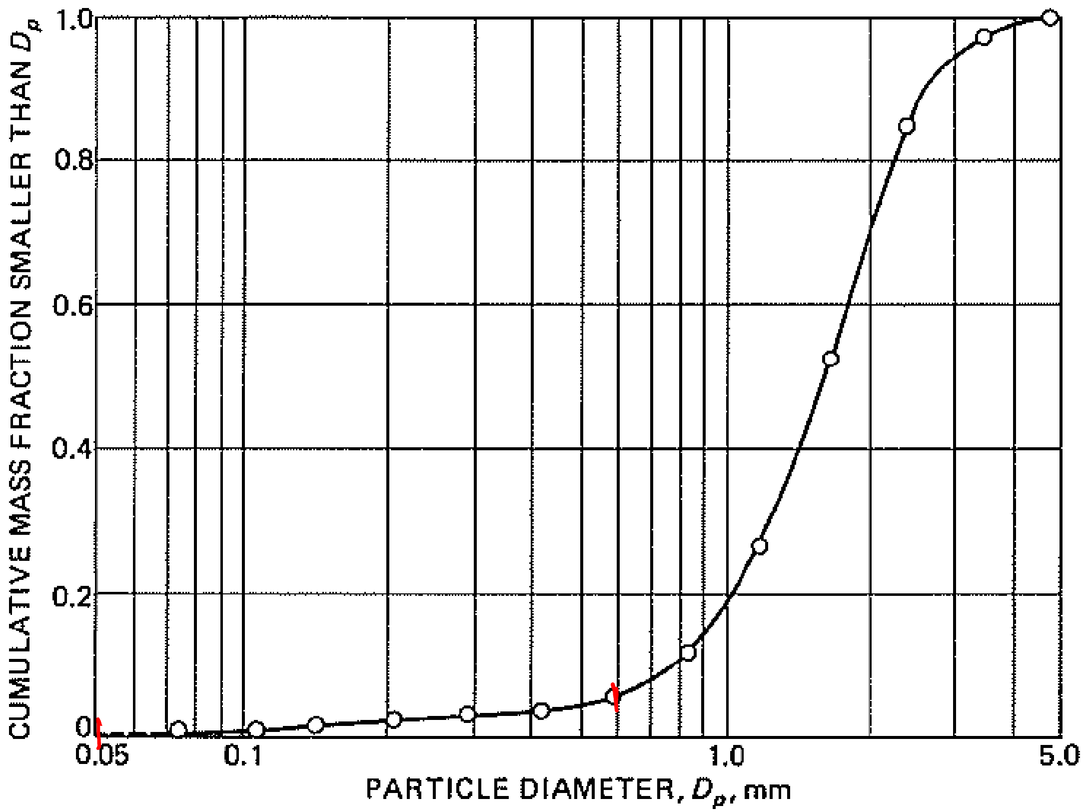


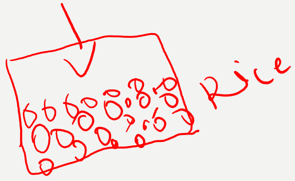
FIGURE 28.3
Cumulative screen analysis.

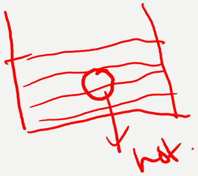
Cumulative screen analysis on semi-logarithmic paper

SOLID PARTICULATE MASSES

SOLID PARTICULATE MASSES

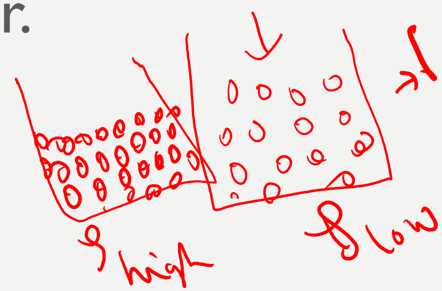
- The properties of solids in bulk are a function of the properties of the individual particles.
- It includes shapes and sizes and size distribution, and of the way in which the particles interact with one another.
- particulate material is always interspersed with a fluid, generally air.
- The interaction between the fluid and the particles decide the behavior of bulk material.



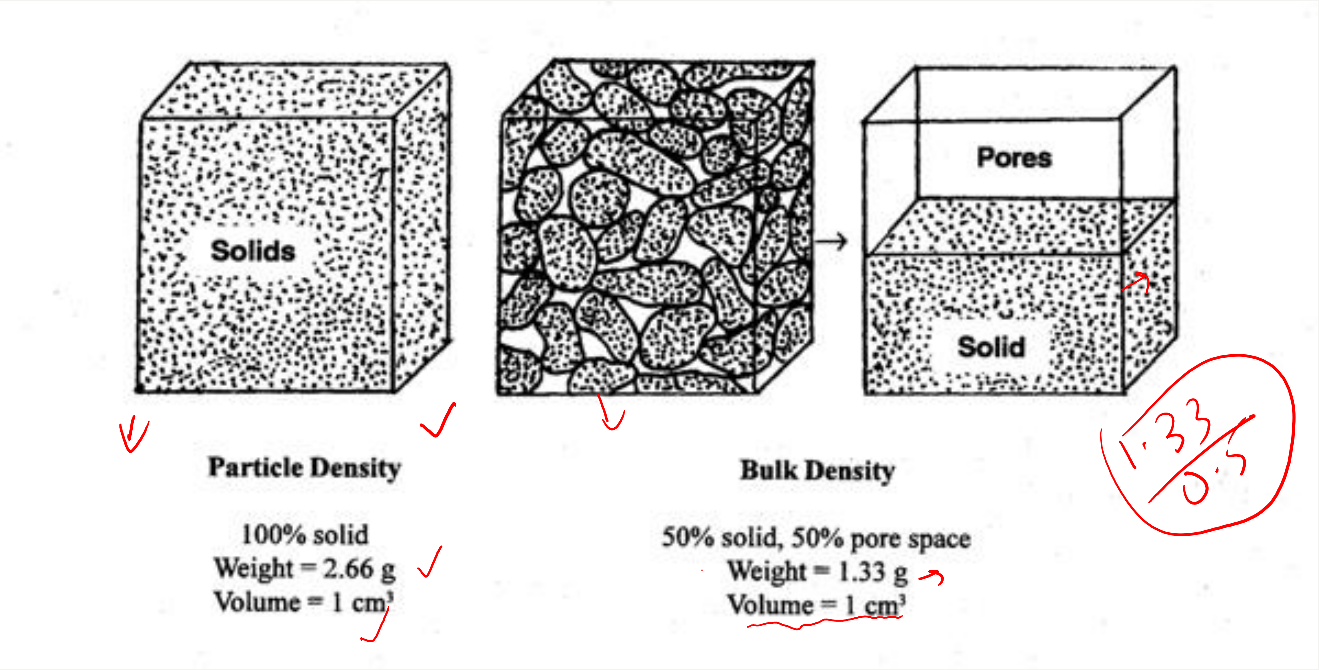


SOLID PARTICULATE MASSES

- Void-age or void fraction is the important property of solid particulate. Bulk density of the materials depend on it.
- low void-age indicates a high density of packing of the particles.
- The way in which the particles pack depends not only on their physical properties, including shape and size distribution.
- The more rapidly material is poured on to a surface or into a vessel, the more densely will it pack. If it is then subjected to vibration, further consolidation may occur.



BULK-DENSITY & TRUE DENSITY



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DENSITY

Density

- True density: $\rho_t = \frac{m}{V_a}$
- Apparent density: $\rho_a = \frac{m}{V_a + V_{cc}}$
- Bulk-density: $\rho_b = \frac{m}{V_a + V_{cc} + V_v}$

ρ_t = True density

ρ_a = Apparent density

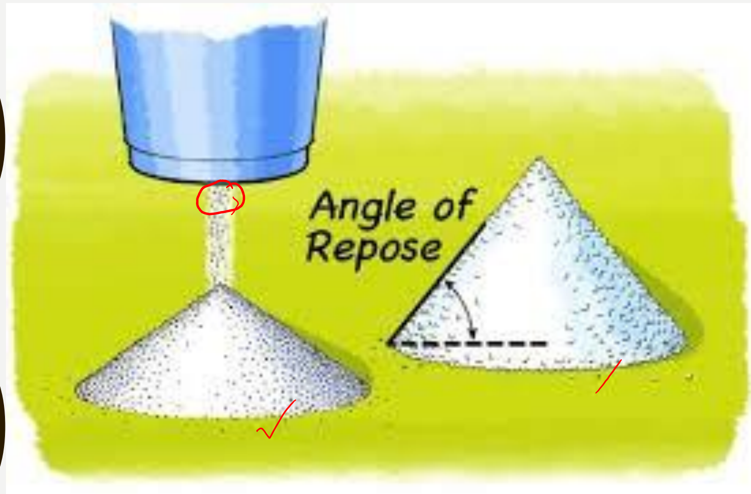
ρ_b = Bulk density

V_a = actual volume of solid with out inner & outer void volume

V_{cc} = inner void volume of solid

V_v = outer void volume of solid

ANGLE OF REPOSE



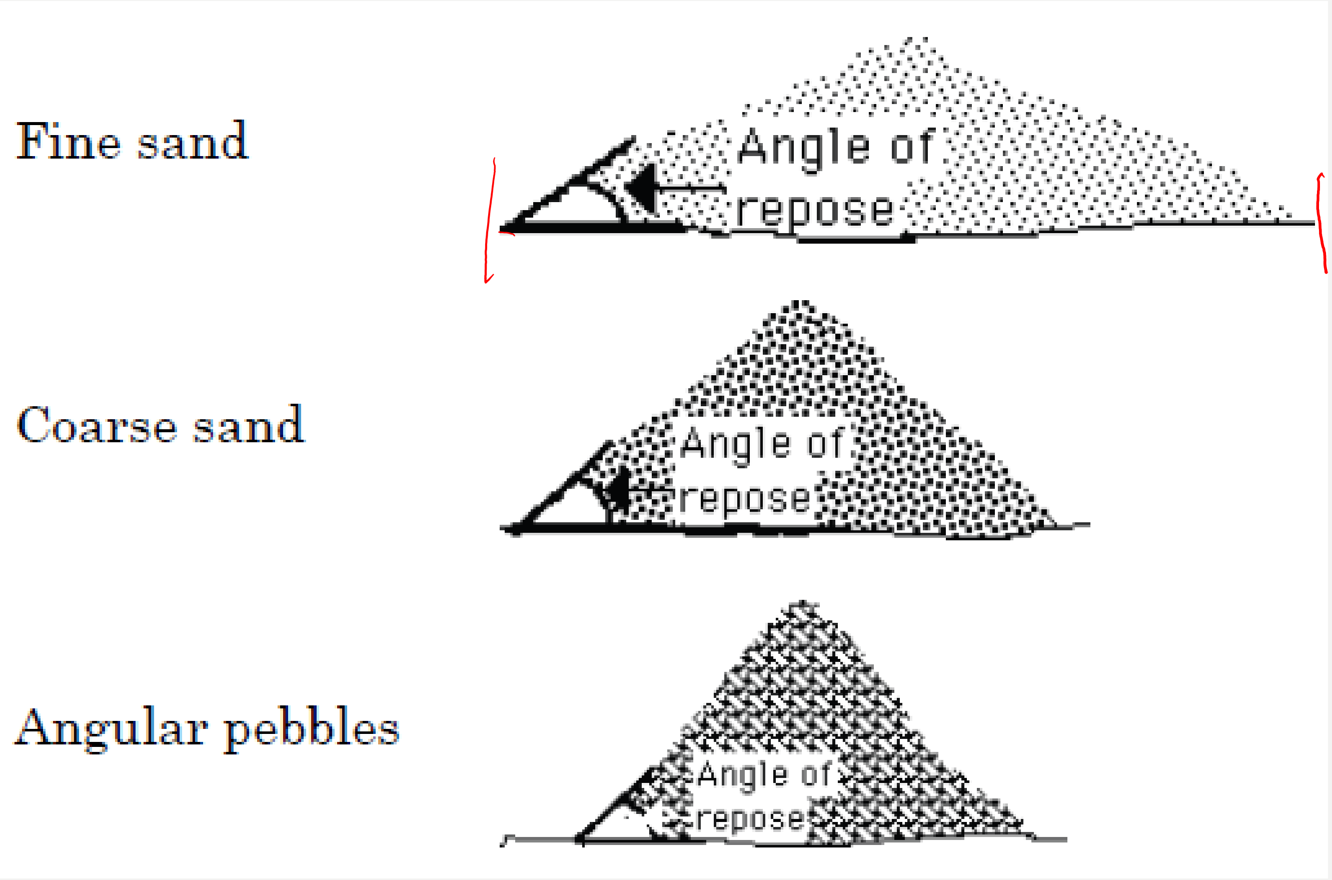
Dynamic angle of repose or the poured angle

Sides of solid grains piled up on a plane or flat surface make a definite reproducible angle with the horizontal. This angle is known as angle of repose.

ANGLE OF REPOSE

- The angle of repose may also be measured using a plane sheet to which is stuck a layer of particles from the powder. Loose powder is then poured on to the sheet which is then tilted until the powder slides. The angle of slide is known as the *static angle of repose* or the *drained angle.*
- Angles of repose vary from about 20◦ with free-flowing solids, to about 60◦ with solids with poor flow characteristics.
- In extreme cases of highly agglomerated solids, angles of repose up to nearly 90◦ can be obtained.
- Generally, material which contains no particles smaller than 100 μm has a low angle of repose.

ANGLE OF REPOSE



FLOW CHARACTERISTICS

- The flow properties of solid particulates are very important during processing or storage the materials.
- The flow characteristics of particles with size less 10μm is very poor.
- If the particles tend to agglomerate, poor flow properties may again be expected.

FLOW CHARACTERISTICS OF SOLID PARTICULATE MASSES

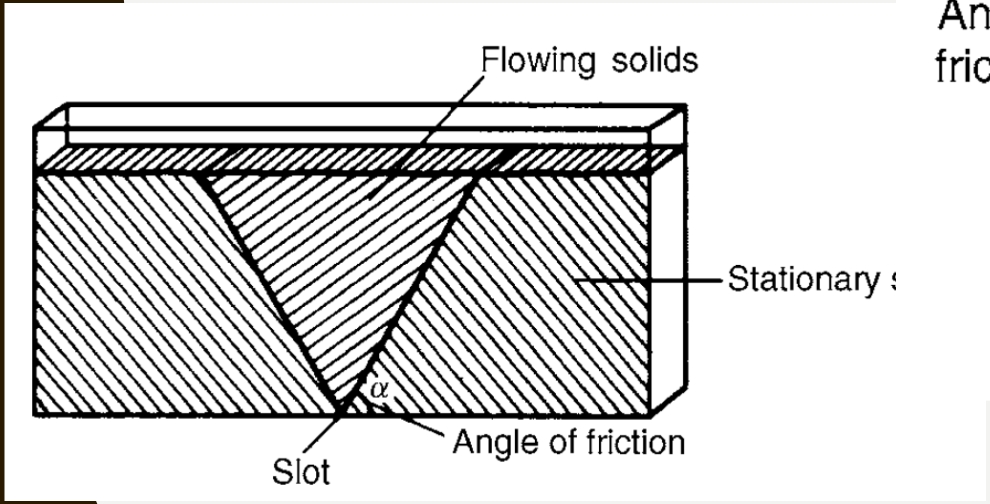
- Solid masses also exert pressure on the sides of container like fluids.
- Flow of non-sticky, dry and free flowing solids are like flow of liquid through an opening.
- Deformation of solid particulate required a specific pressure for breaking the interlock between masses before flow starts. For very small size particles increase in pressure sometimes make the mass more compact which decreases the flowability.
- During flow of solid masses appreciable amount of friction force exerted in the both sides of sliding solid layers. For fluids, the frictional force is negligible and same at the both sides of fluid layer.
- Pressure in a container with solid grains are not uniform in all directions like Newtonian fluids. It is minimum at the normal direction of the applied pressure to the solid masses.

FLOW CHARACTERISTICS OF SOLID PARTICULATE MASSES

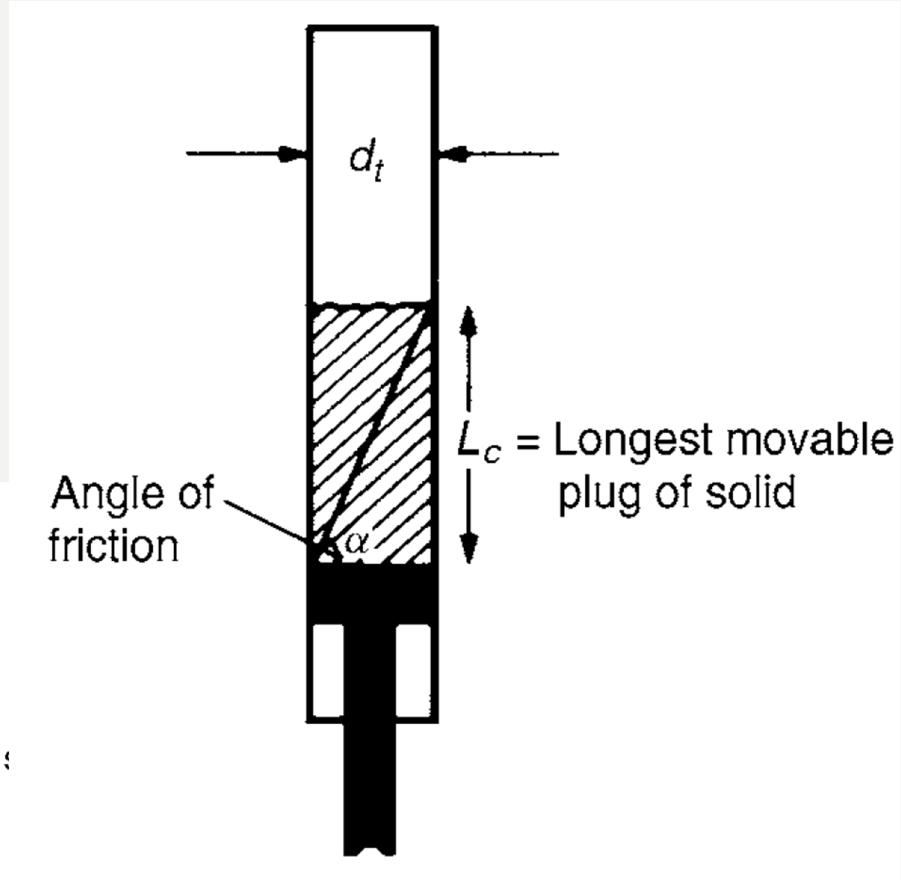
- For homogeneous masses, the ratio of normal pressure & applied pressure is constant(K'). The value of constant depends on size, shape, stickiness and interlocking properties of mass.
- For non-free flowing small size particles K' is not function of size.
- Shear stress also transmitted through the layers until failure occurs.

Q. **What are the approximate values of K for cohesive and non-cohesive solids?**

ANGLE OF FRICTION



Angle of friction –flow through slot



Angle of friction – test tube

STORAGE OF SOLIDS

Storage of solids

Bulk storage

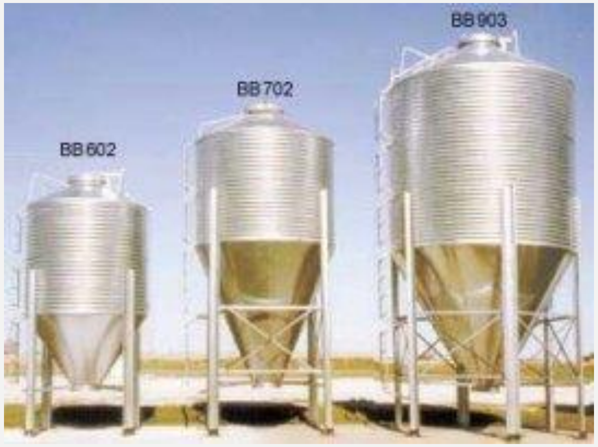
1. Used for large amount of material storage.
2. Less costly and non-soluble materials are stored.
3. Stored openly.
4. Effects the environment.
5. Losses in material due weather occurs.

Bin storage

1. Used for small amount of material storage.
2. Costly and soluble materials are stored.

- Bins (wide in size)
- Silos (tall in size)
- Hopper (feed system)

STORAGE OF SOLIDS



Hopper

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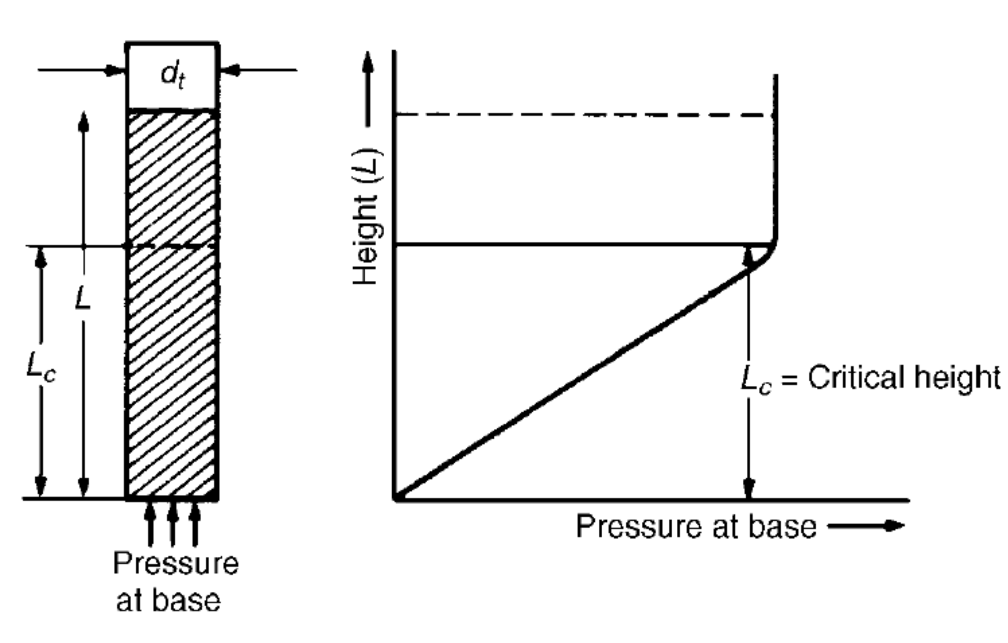
https://www.google.com/url?sa=i&url=https%3A%2F%2Fwww.ilfbpartners.com%2Ffarm%2Fthe-difference-between-grain-bins-and-silos%2F&psig=AOvVaw0KZaAbHIi9tXGD5F_HOuHo&ust=1598686732067000&source=images&cd=vfe&ved=0CAIQjRxqFwoTCLip7a2yvesCFQAAAAAdAAAAABAD

PRESSURE DISTRIBUTION IN HOPPER

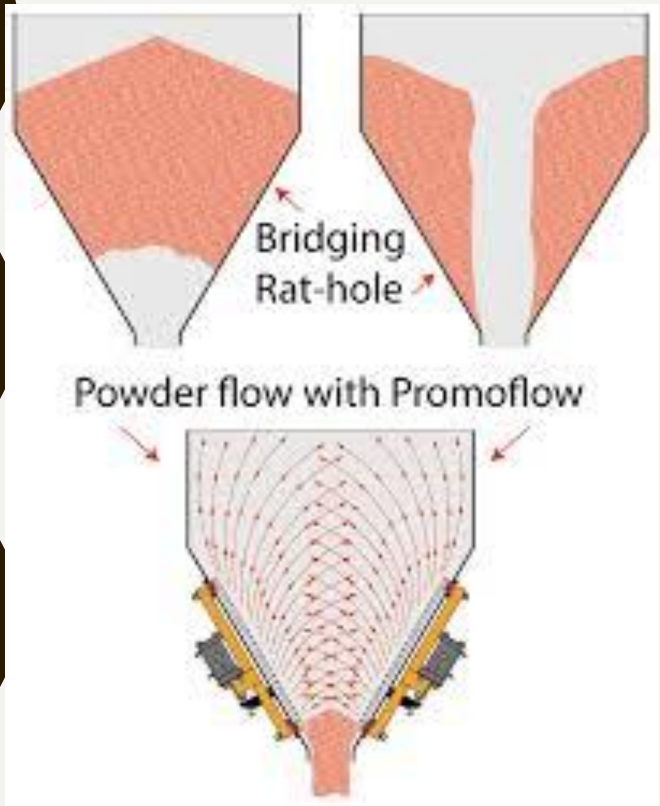
- The angle of friction is important in its effect on the design of bins and hoppers.
- If the pressure at the base of a column of solids is measured as a function of depth, it is found to increase approximately linearly with height up to a certain critical point beyond which it remains constant.

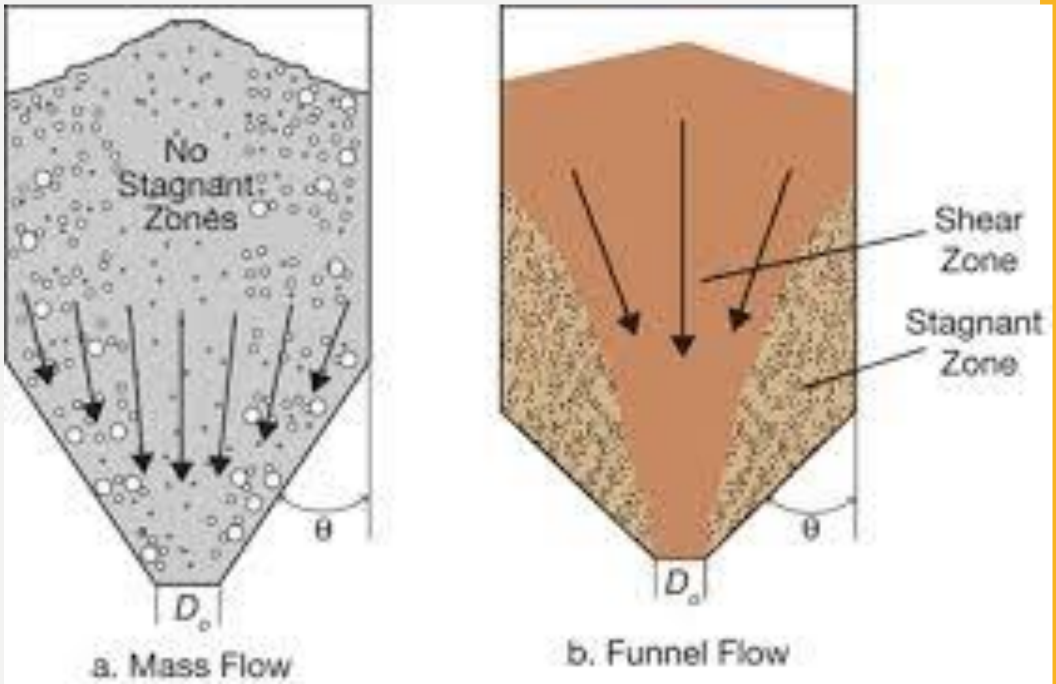


FLOW OF SOLIDS IN HOPPERS

- Frequently, solids are stored in hoppers which are usually circular or rectangular in cross-section, with conical or tapering sections at the bottom.
- The hopper is filled at the top and an appreciable size distribution of the particles causes some segregation. The larger particles tending to roll to the outside of the piles in the hopper.

FLOW OF SOLIDS IN HOPPERS





FLOW OF SOLIDS IN HOPPERS

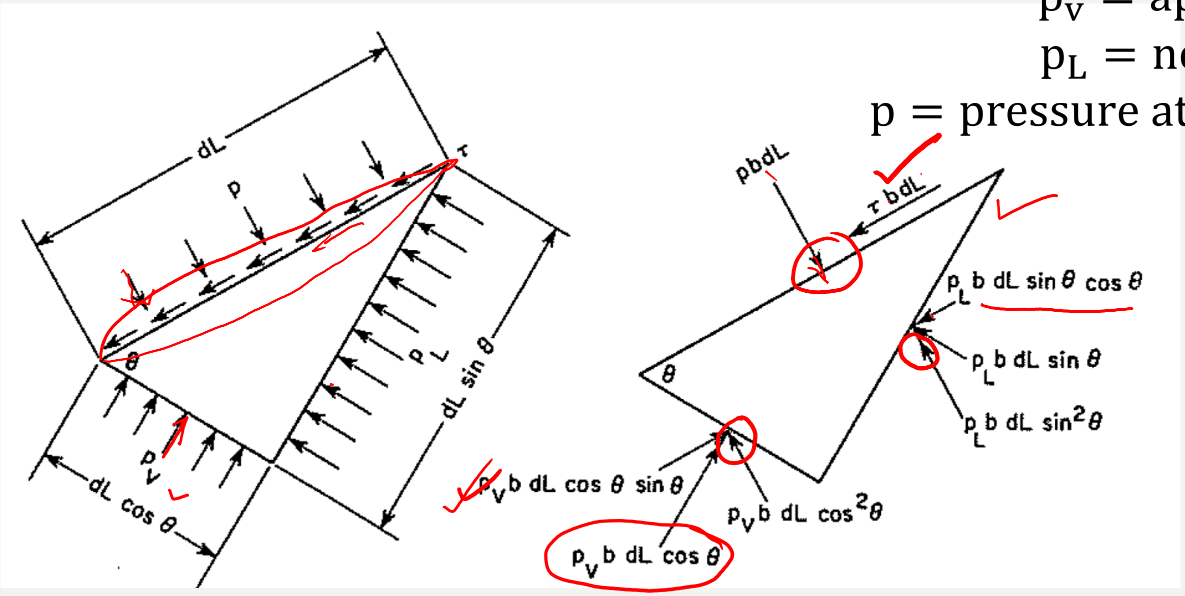
- Bridging of particles may take place and sometimes stable arches may form inside the hopper and, these can usually be broken down by vibrators attached to the walls.
- A further problem which is commonly encountered is that of “piping” or “rat-holing”, in which the central core of material is discharged leaving a stagnant surrounding mass of solids. As a result, some solids may be retained for long periods in the hopper and may deteriorate.

FLOW OF SOLIDS IN HOPPERS

- Ideally, “mass flow” is required in which the solids are in plug flow and move downwards in the hopper. The residence time of all particles in the hopper will then be the same.
- Tall thin hoppers give better flow characteristics than short wide ones.
- The use of long small-angle conical sections at the base is advantageous.
- The nature of the surface of the hopper is important and smooth surfaces give improved discharge characteristics.
- Monel metal cladding of steel is frequently used for this purpose.
- **Monel** is a group of nickel alloys, primarily composed of nickel (from 52 to 67%) and copper, with small amounts of iron, manganese, carbon, and silicon.

STRESSES AND FORCE IN SOLID GRANULAR SOLIDS

p_v = applied pressure
p_L = normal pressure
p = pressure at any intermediate angle



Force at right angle triangle to the hypotenuse

$$pb\ dL = p_L.b.dL\ sin^2\theta + p_v.b.dL\ cos^2\theta$$

$$p = p_L sin^2\theta + p_v\ cos^2\theta$$

$$p = (p_v - p_L)cos^2\theta + p_L$$

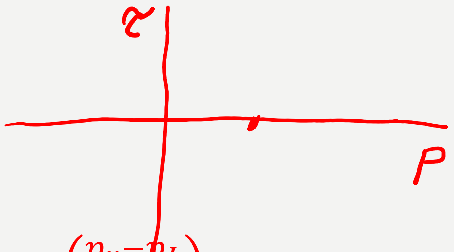
Forces parallel to hypotenuse

$$\tau b\ dL = p_v.b.dL\ sin\theta.cos\theta - p_L.b.dLsin\theta.cos\theta$$

$$\tau = (p_v - p_L)sin\theta.cos\theta$$

MOHR STRESS DIAGRAM FOR NON-COHESIVE SOLIDS

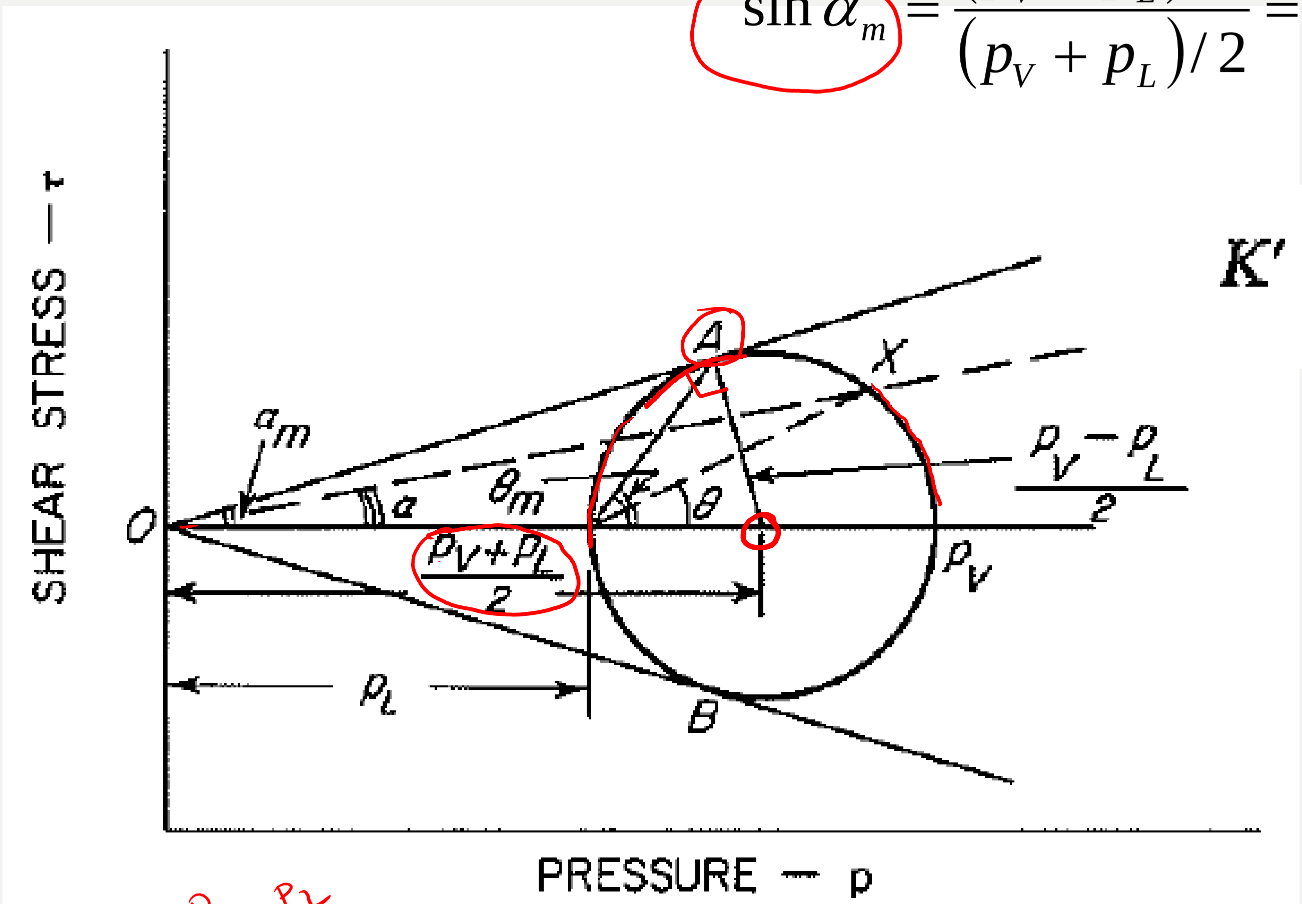
- $p = (p_v - p_L)cos^2\theta + p_L$
- $p - \frac{p_v+p_L}{2} = (p_v - p_L)cos^2\theta + \left(p_L - \frac{p_v+p_L}{2}\right)$
- $p - \frac{p_v+p_L}{2} = (p_v - p_L)cos^2\theta - \left(\frac{p_v-p_L}{2}\right)$
- $p - \frac{p_v+p_L}{2} = \left(\frac{p_v-p_L}{2}\right)(2cos^2\theta - 1\ ) = \left(\frac{p_v-p_L}{2}\right)cos2\theta$
- $\tau = (p_v - p_L)sin\theta.cos\theta = \left(\frac{p_v-p_L}{2}\right)sin2\theta$
- $\left(p - \frac{p_v+p_L}{2}\right)^2 + \tau^2 = \left(\frac{p_v-p_L}{2}\right)^2$ …(Mohr diagram)
- This is an equation of circle with centre $[\frac{p_v+p_L}{2}, 0]$ & radius $\left(\frac{p_v-p_L}{2}\right)$



MOHR STRESS DIAGRAM FOR NON-COHESIVE SOLIDS

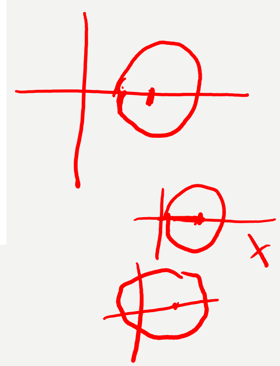
$$\sin\alpha_m = \frac{(p_V - p_L)/2}{(p_V + p_L)/2} = \frac{(p_V - p_L)}{(p_V + p_L)}$$

$$K' = \frac{1 - \sin\alpha_m}{1 + \sin\alpha_m}$$

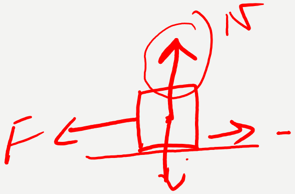


$$K' = \frac{1 - \frac{P_V - P_L}{P_V + P_L}}{1 + \frac{P_V - P_L}{P_V + P_L}} = \frac{2P_L}{2P_V} = \frac{P_L}{P_V} = \frac{\text{Normal Pr}}{\text{Applied Pr}}$$

$\frac{P_V + P_L}{2}, 0$



MOHR STRESS DIAGRAM FOR NON-COHESIVE SOLIDS



- α_m is angle of internal friction.
- This angle of friction is equal to angle of repose for homogeneous solids.

JANSSEN EQUATION

- Janssen derived an equation to calculate the vertical and horizontal pressures and wall shear stresses. In a vertical force balance at a slice element spanning the full cross section of a silo being filled with bulk solids and determined the wall friction coefficient with a shear tester as well as the horizontal pressure ratio from pressure measurements in a model bin. He also assumed, a constant vertical pressure across the cross section of the slice element and restricted his evaluation to vertical silo walls.
- The Janssen equation for the vertical pressure *p*v on dependence of the depth *h* below the bulk solids top level reads as follows for a cylindrical silo:

$$p_v = \frac{g\rho_b D}{4\mu' K'}\left[1 - e^{-\left(\frac{4\mu' K' h}{D}\right)}\right]$$

JANSSEN EQUATION

- where g is the acceleration due to gravity,
- ρb is the bulk density of solids,
- D is the silo diameter,
- μ′ is the sliding friction coefficient along the wall, and
- K' is the ratio of the horizontal to the vertical pressure
- Problem:

Suppose that the powder is stored in a silo 12 m high and 3 m diameter, while its bulk density is 850 kg/m3 and its friction coefficient about the silo wall is 0.45. Calculate the static vertical and horizontal pressures exerted at the base of the cylindrical part of the silo. Assume the angle of internal friction of solids is 42°.

CONVEYORS

- Conveyors are used to transport the bulk or grain solid material from one place to another.

  The transportation of material can be carried out by different methods depending upon the type of material to be transported and the position of the discharge point with reference to loading point.

TYPES OF CONVEYORS

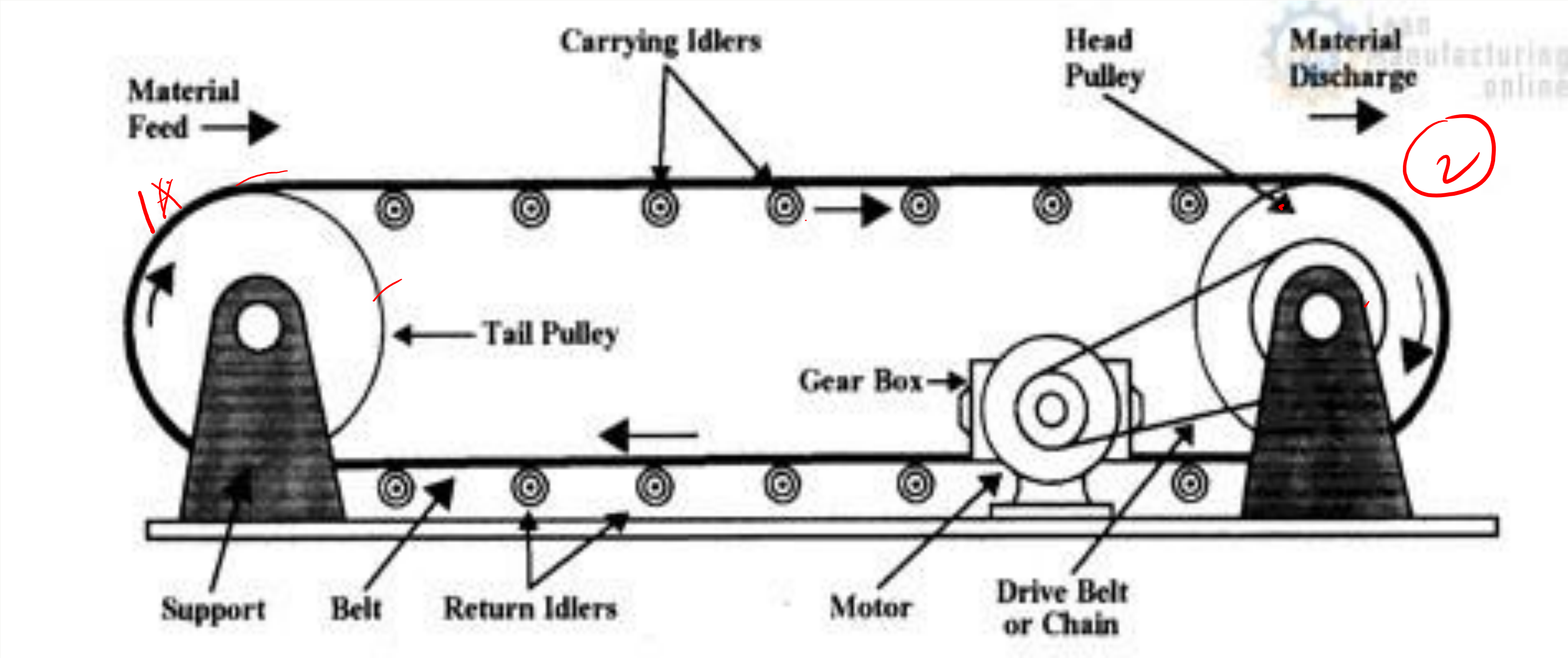
1. Belt conveyors
2. Screw conveyors
3. Pneumatic conveyors
4. Hydraulic conveyors
5. Roller conveyors
6. Chain conveyors
7. Bucket conveyor
8. Vibratory conveyors

BELT CONVEYOR

- The belt conveyors can carry a greater diversity of bulk solid products from fine grain to bulk material at higher rates and over longer distances.
- A belt conveyor is simply an endless strap of flexible material stretched between two drums and supported at intervals on idler rollers.
- When the drum rotated by the driving motor, the belt will move with roller due to frictional resistance, there by the material placed on the belt will be transported from one place to other.

PARTS OF THE BELT CONVEYOR

- Drums driving and non-driving
- Belt
- Idlers
- Belt tensioners



BELT CONVEYOR

- https://www.youtube.com/watch?v=pBIkfLm_8js

BELT CONVEYOR

ADVANTAGES OF BELT CONVEYORS

1. Noiseless operation.
2. Large length of conveying path
3. Lower power consumption.
4. Long life.
5. Adaptability to different types of goods.
6. Ability to carry almost any bulk material
7. High reliability of operation.
8. Can transport material in any direction.

LIMITATIONS OF BELT CONVEYORS

1. Complicated marshaling
2. The loss of light weight bulk material carried away as dust or spilled from the belt along its path is another objectionable features.
3. Continuous or periodic monitoring of belt is necessary.
4. Heat affects the material of belt.

USES

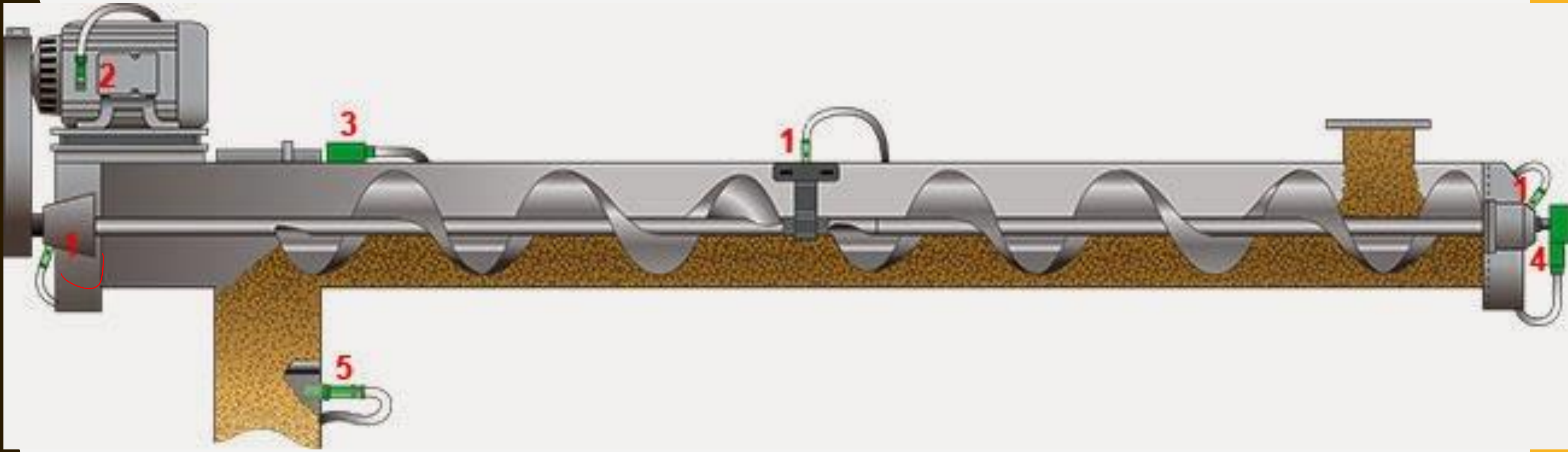
- Belt conveyors are used to mechanize material handling operations in foundries to distribute molding sand, mold-cores and cast articles.
- Belt conveyors are used for carrying coal, ores and minerals in power plants, mining industries, metallurgical process plants.
- For handling food grains and building materials belt conveyors are frequently employed.

SCREW CONVEYORS

- It consists of helicoid (helical flights rolled from flat steel bar) flight, mounted on a pipe on or shaft and turning in a trough.
- Screw conveyors are preferably used to transport and to dose powder, fine grain or fibrous materials.

PARTS OF SCREW CONVEYOR

1. Shaft
2. Drive
3. Trough
4. Helical flights
5. Hanger



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CLASSIFICATION OF SCREW CONVEYORS BY ITS LINE OF TRANSPORT

a. Horizontal screw conveyor
b. Angular screw conveyor
c. Vertical screw conveyor

PRINCIPLE OF OPERATION

- The intake end of conveyor is fed with a continuous supply of particulate material.
- The rotating screw in the trough or pipe will lift the material by a wedging action.
- The screw will be rotated by drive and supported on bearings.
- The screws are constructed in different fashion for special applications.

APRON OR PAN CONVEYORS

APRON OR PAN CONVEYORS

- Apron or Pan Conveyors usually consist of two strands of roller chain separated by overlapping plates, so called aprons. They form the carrying surface.
- While the apron conveyor is running, the product lies still on the aprons. These type of conveyors are especially useful as feeders and long horizontal or inclined high capacity conveyors.

ADVANTAGES

- Handling of raw, abrasive, heavy bulk products.
- Can be used as hot material and cooling conveyor.
- Very high capacities are possible.
- Smooth running, low maintenance. Can be used with different types of chains.

FLIGHT CONVEYOR

FLIGHT CONVEYOR

- Flight conveyors are used for applications that have the strictest hygienic demands. The Flight conveyors are suitable for conveying practically all powders and granulates. Capacities range from 30-400 m3/h. These conveyors are capable of inclined conveying up to an angle of 40°.

ELEVATOR

- An **elevator can be defined as** an **electric lift** which is used as vertical transportation of goods as well as people among the floors in buildings using bins otherwise silos.
- These are activated with the **electrical motors** that also to drive counterweight system cables for drive transaction such as a crane, otherwise, pump hydraulic fluid for raising a cylindrical piston such as a jack.
- The **working principle of an elevator or lift** is like the pulley system.

ELEVATOR

- The **different types of lifts or elevators** include **building lift**, capsule lift, hydraulic elevator, pneumatic elevator, passenger lift, **freight elevator**, traction elevator/**cable driven**, **residential elevators**, **machine room-less elevator**, etc.

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- E. Ortega. Unit operations of Particulate solids: Theory and Practice. CRC Press.