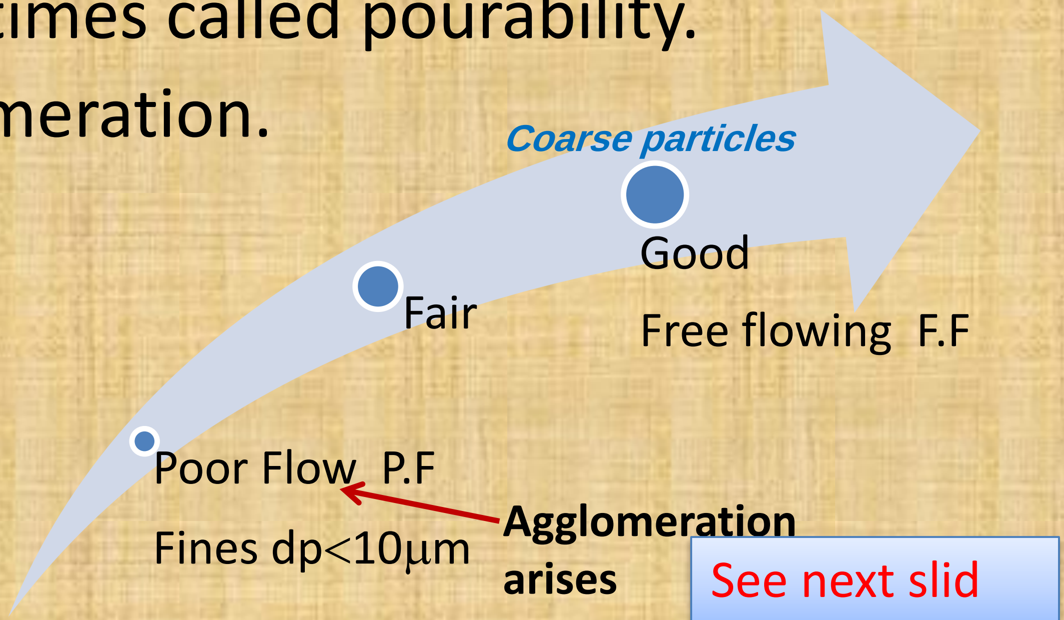
PARTICULATE SOLIDS IN BULK

Characteristics of solid Particulates & Hoppers & Conveyors & Classification of solid particles

PARTICULATE SOLIDS IN BULK

- fluid-solid & solid-solid interactions cause new behaviors and lead to new properties such as
  - Voidage & bulk density.
  - Flow properties "followability" ⇒ look to this flow chart. Followability shows the capability to flow. Sometimes called pourability.
  - Agglomeration.

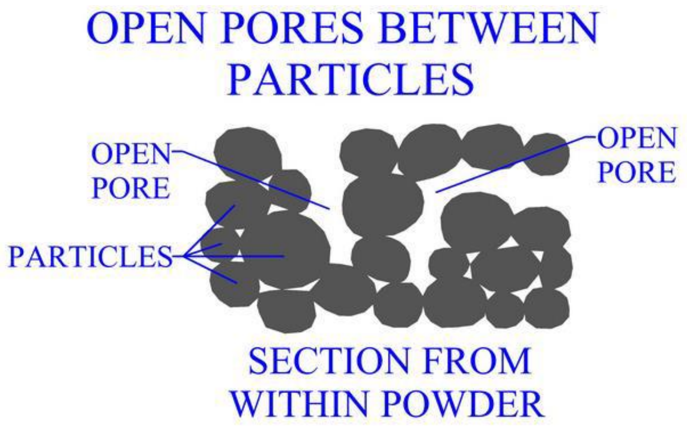


Definition_ Pourability "Flowability"

- It is defined as a measure of the time required for a standard quantity of material to flow through a funnel of specified dimension.
- It characterizes the handling properties of fine particles.

PROPTERTIES OF MASSES OF PARTICLES

- Bulk density or apparent density, ρ_b, is defined as the weigh per unit volume of material including voids inherent in the material as tested. It is a measure of the fluffiness of the material.



$$\rho_b = \frac{m}{V_T} = \frac{m}{V_p + V_v} \text{ and } \rho_t = \frac{m}{V_p}$$

- Voidage (Porosity), It is the ratio of the void volume and bulk volume.

$$\varepsilon = \frac{V_T - V_p}{V_T} = 1 - \frac{V_p}{m}\frac{m}{V_T} = 1 - \frac{\rho_b}{\rho_t}$$

Where,
V_p: volume particles,
V_v: volume of voids,
V_T: total volume,
m: mass of material,
ρ_b: bulk density
ρ_t: true or particle density without pores,
ε: voidage

Agglomeration

(1) ***Mechanical interlocking****. This can occur particularly if the particles are long and* thin in shape, in which case large masses may become completely interlocked.

(2) ***Surface attraction.*** *Surface forces, including van der Waals' forces, may give rise* to substantial bonds between particles, particularly where particles are very fine (*<10 µm), with the result that their surface per unit volume is high.*

In general, freshly formed surface, such as that resulting from particle fracture, gives rise to high surface forces.

*(3) **Plastic welding**. When irregular particles are in contact, the forces between the particles will be born on extremely small surfaces and the very high pressures developed may give rise to plastic welding.*

*(4) **Electrostatic attraction**. Particles may become charged as they are fed into equipment and significant electrostatic charges may be built up, particularly on fine solids.*

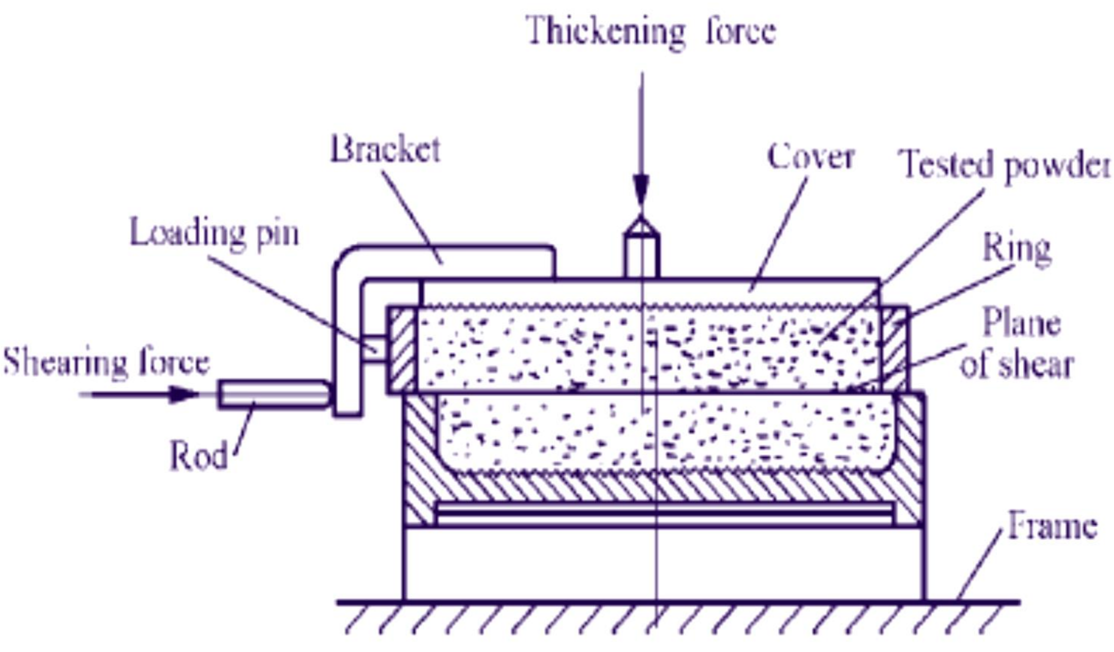
(5**) *Effect of moisture*.** *Moisture may have two effects. Firstly, it will tend to collect* near the points of contact between particles and give rise to surface tension effects. *Secondly*, it may dissolve a little of the solid, which then acts as a bonding agent on subsequent evaporation.

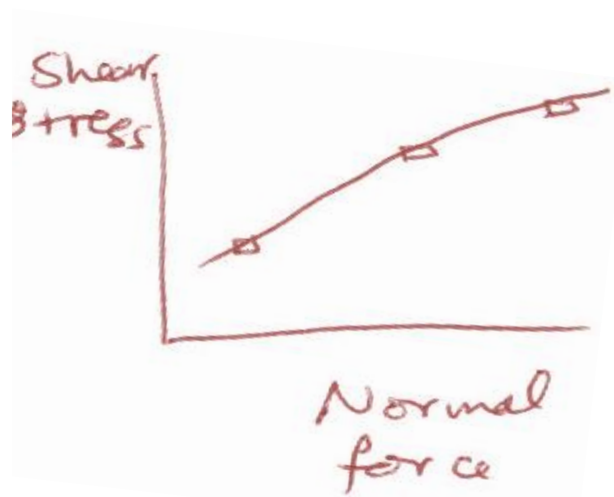
(6) ***Temperature fluctuations*** *give rise to changes in particle structure and to greater* cohesiveness.

- Resistance to shear and tensile forces

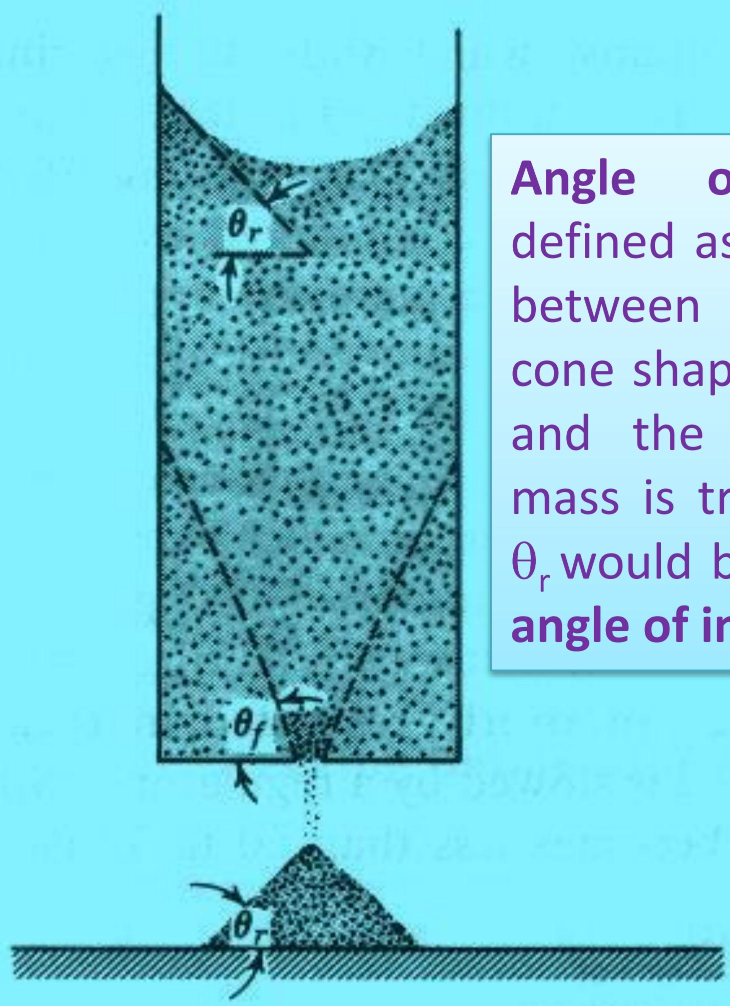
- Particulate material (agglomerated or non-agglomerated) shows a significant resistance to shear and tensile forces.
- This property is very important for flow characteristics of powder material. Moreover, it is very important for the hopper and silo designs.
- As the packing density material increases, the powder material shows a higher resistance to shear and tension.

- Shear forces are measured by using Jenike shear cell.





Angles of repose and of friction



Repose angle θ_r and angle of internal friction θ_f for fine solids.

Angle of repose, θ_r**,**is defined as the angle formed between sloping side of a cone shaped pile of material and the horizontal if the mass is truly homogeneous, θ_r would be equal to θ_f , the **angle of internal friction.**

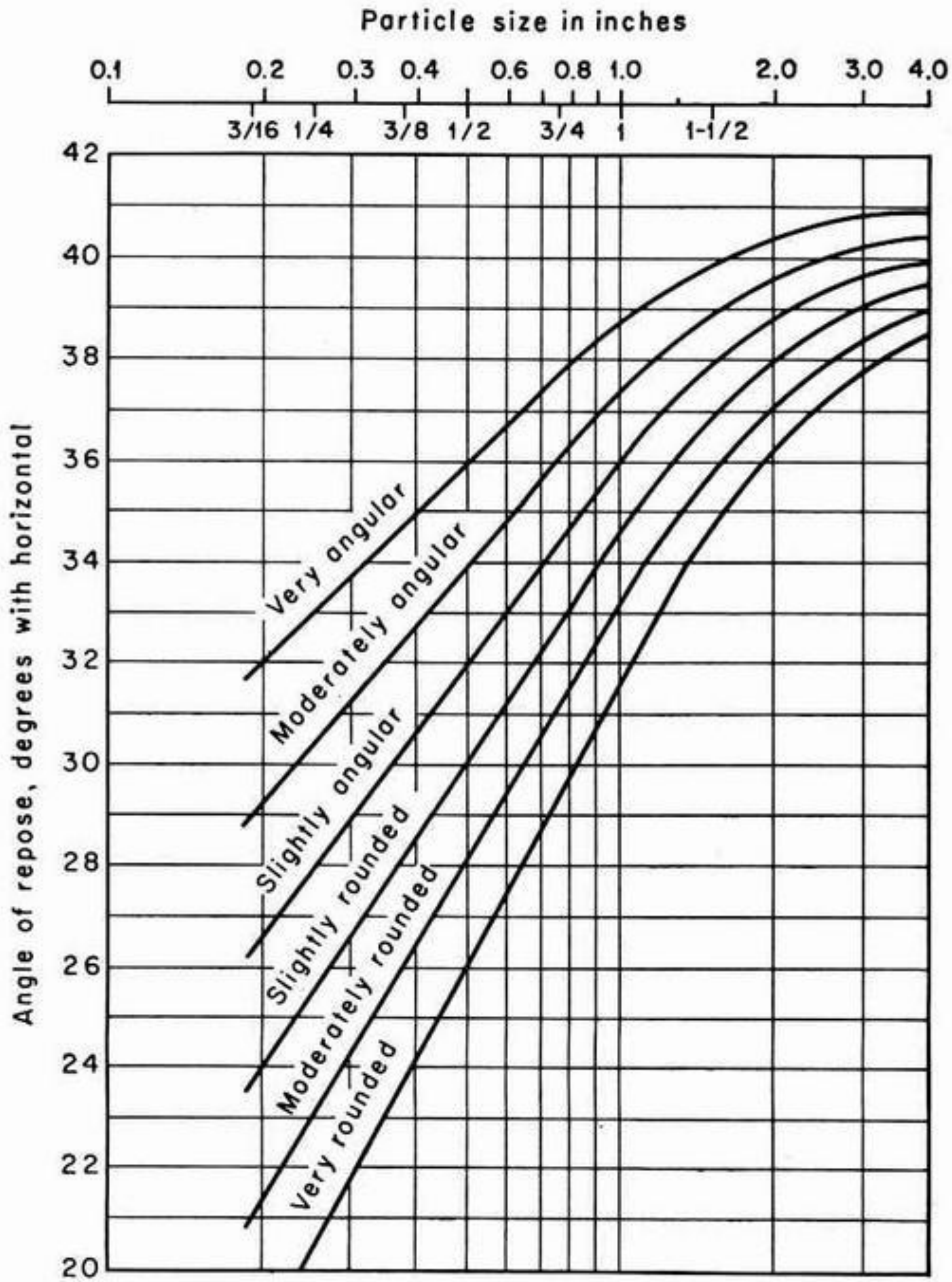
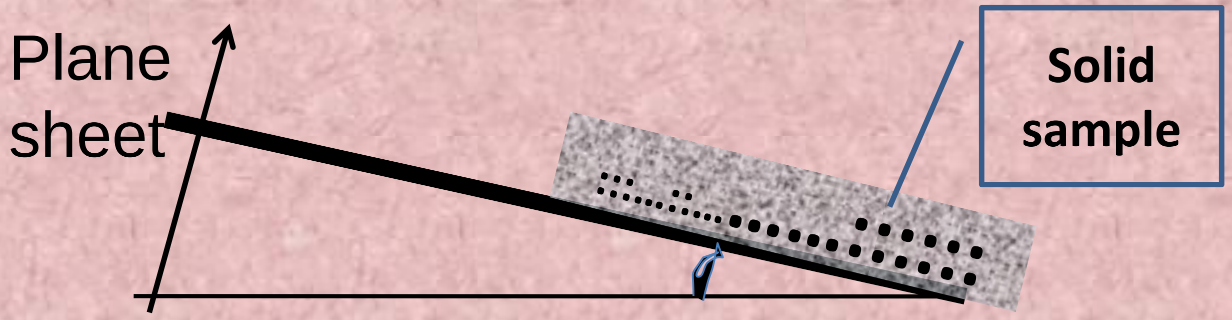


FIG. 7-9. Angles of repose of noncohesive material. (*U.S. Bureau of Reclamation.*)

Fine sand assumes a shallower angle of repose than angular pebbles do

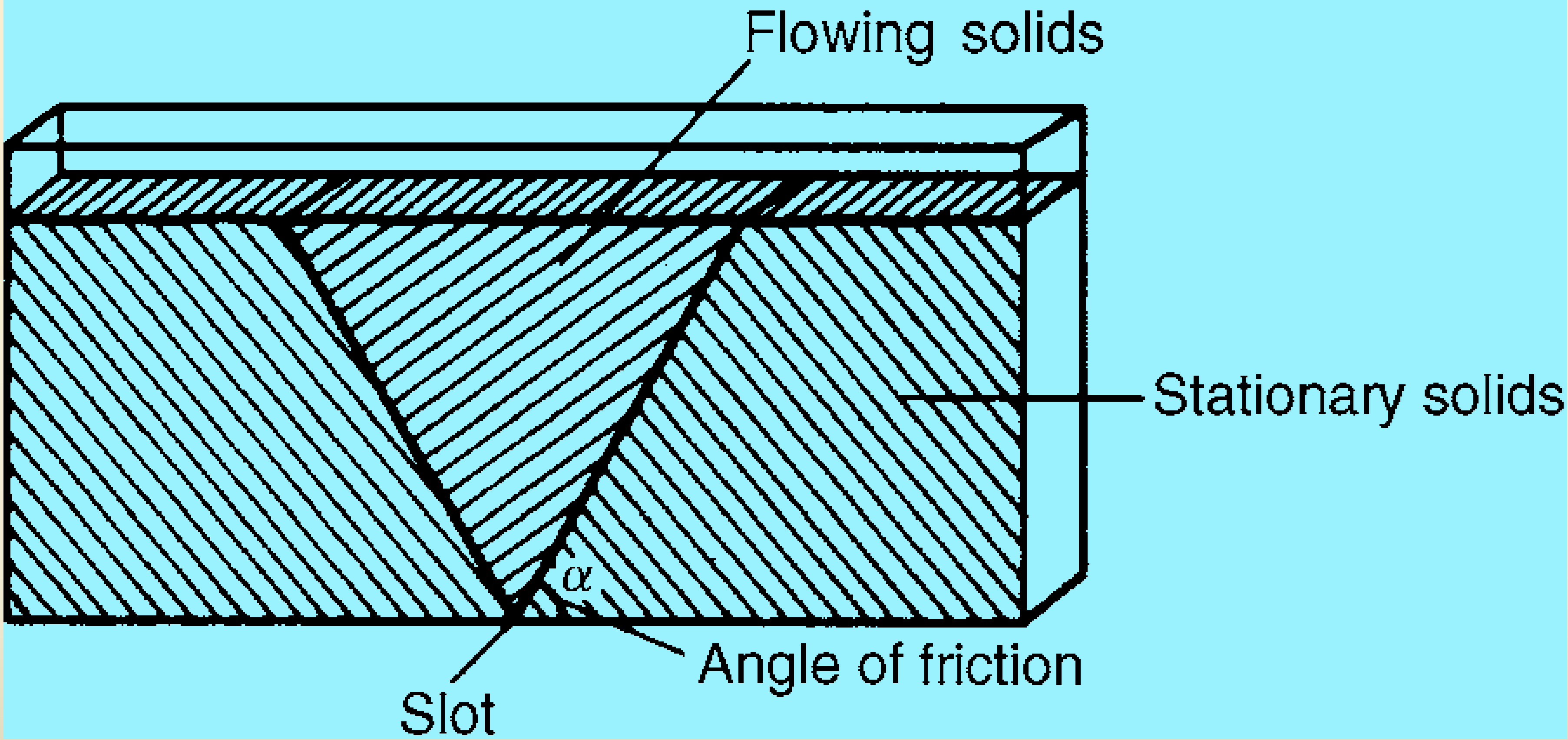
Angles of repose and of friction



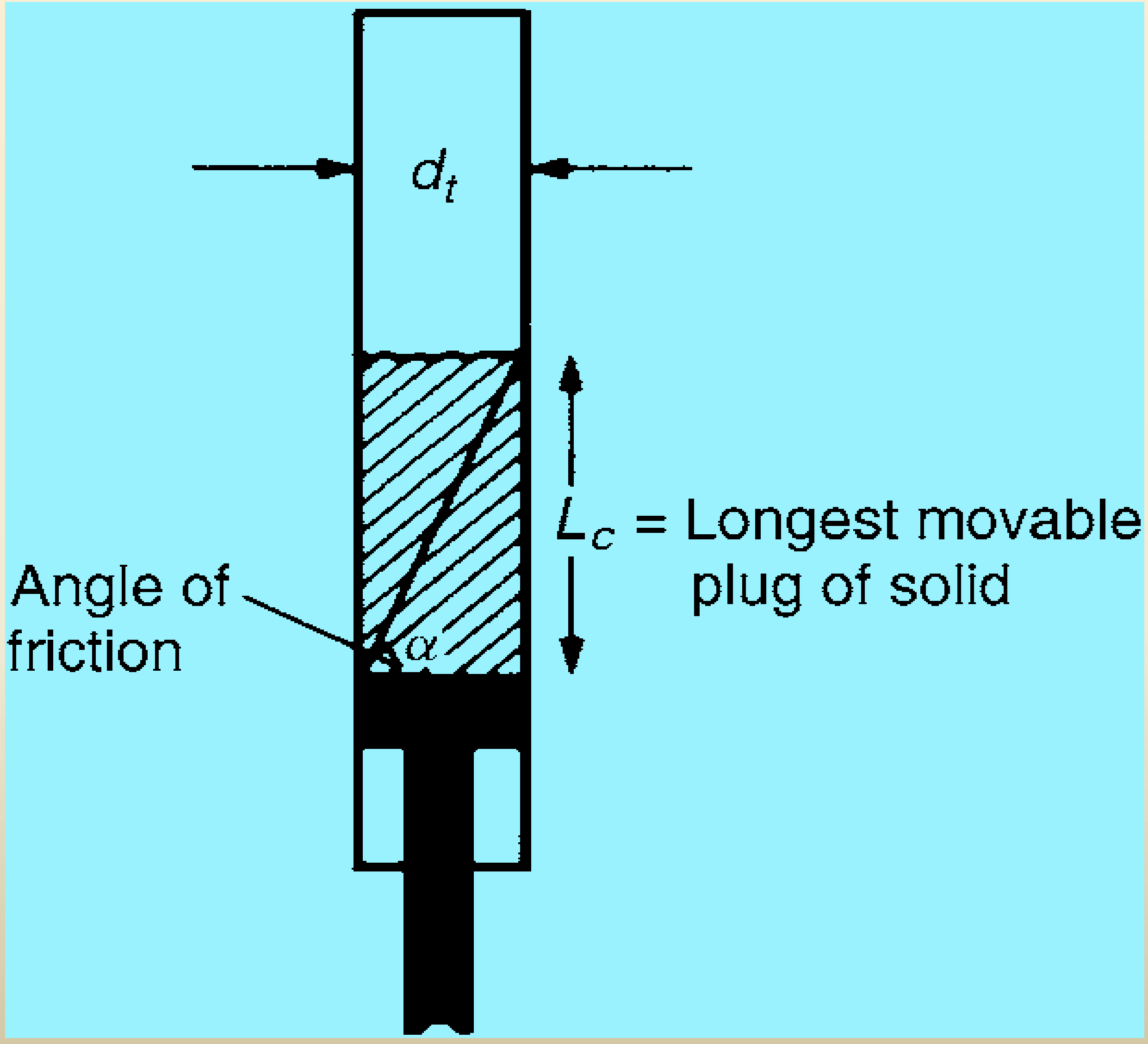
α_s **Angle of repose**
static angle

In general the range of repose angle is
20° - 60°
F.F P.F
90° highly agglomerated solid

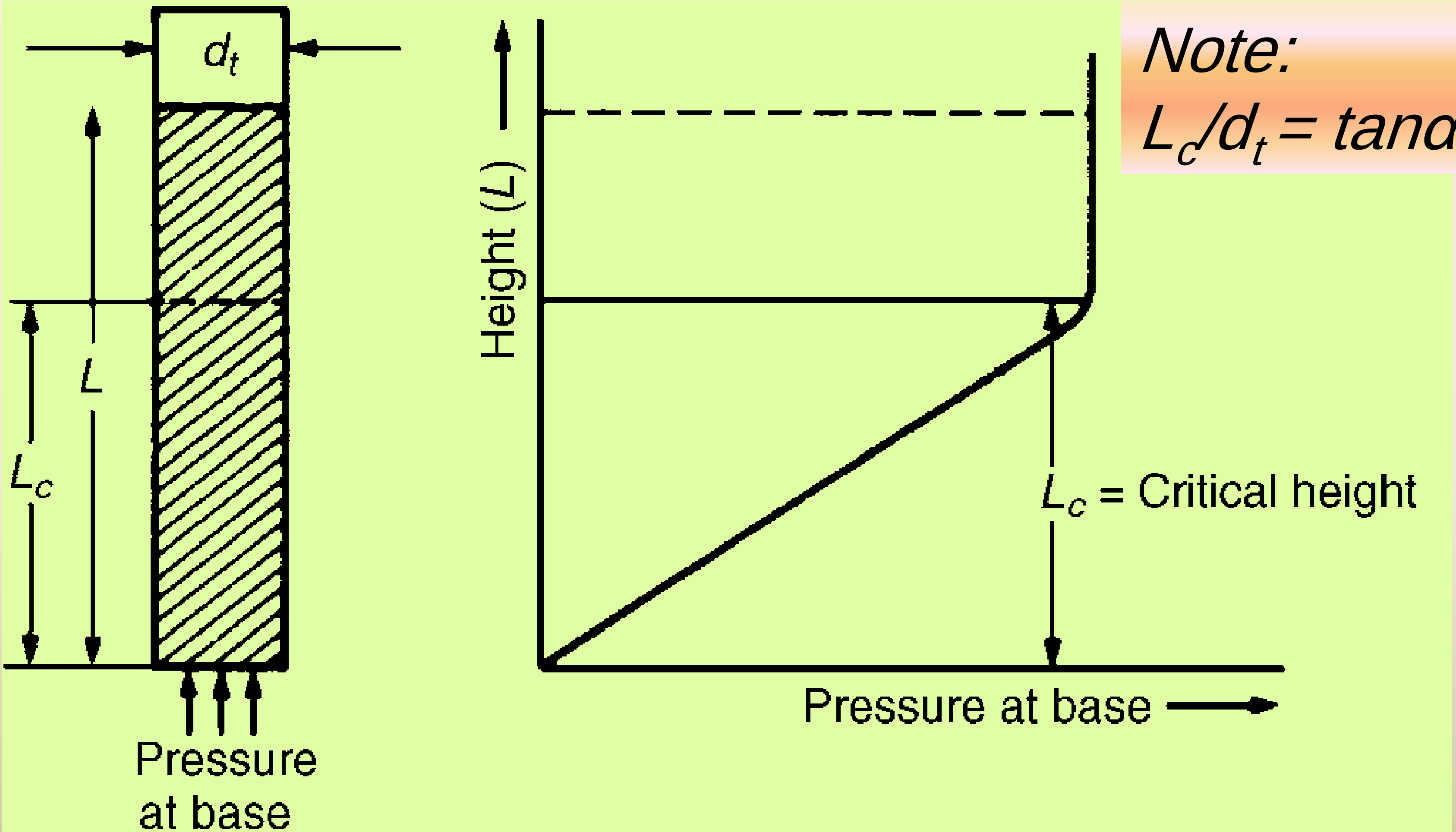
Angle of friction—flow through slot



Angle of friction—tube test



Angle of friction—pressure at base of column



Note:
$L_c/d_t = \tan\alpha$

Notes

Coefficient of internal friction is the measure of resistance present when one layer of solids over another layer of same particles. It is defined as:

Coeff. Of internal friction = **tan** α_m

For free flowing material α_m is between 15^0 to 30^0

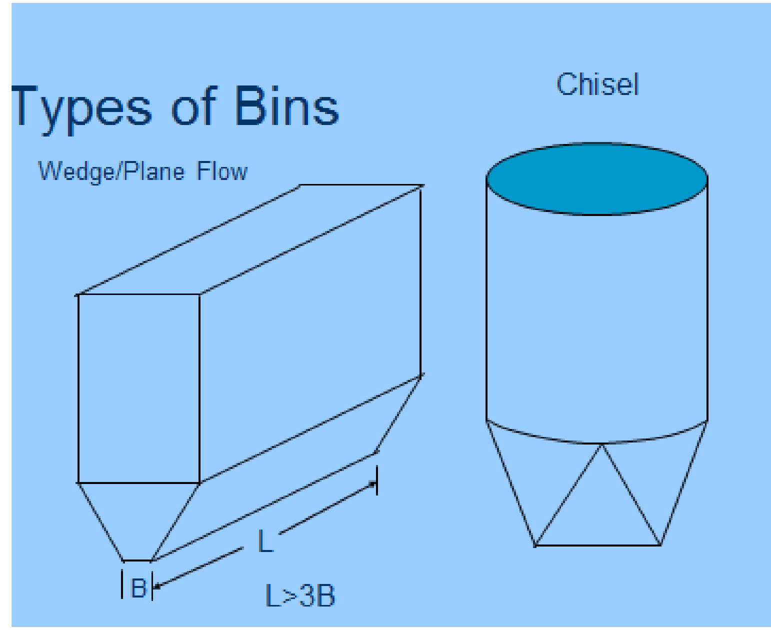
Coefficient of external friction is the measure of the resistance at an interface between particles and the wall of different material of construction.

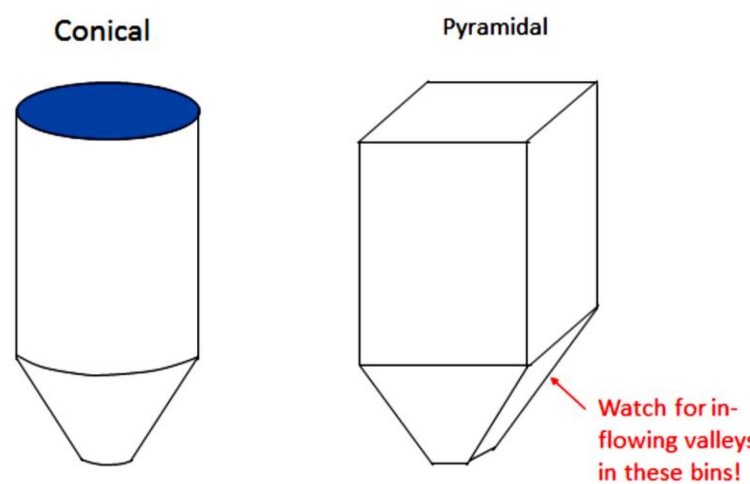
Coefficient of External friction = tan α_s

Where α_s is the angle of external friction of solid and material

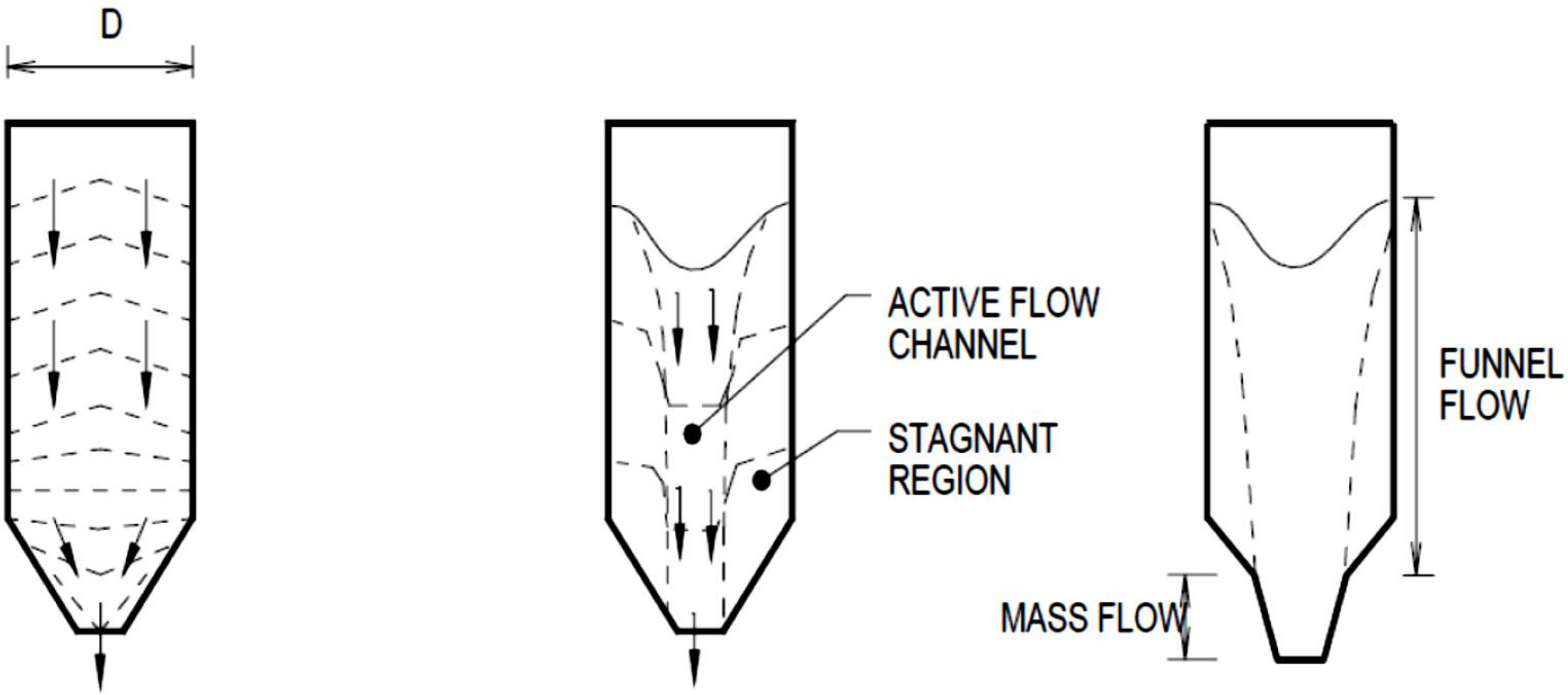
Storage of solid Particulates

- Bulk storage: coarse large quantity solids like gravel and coal outside in large piles.
- Protection storage:
  - ➢ Silos –tall and small diameter
  - ➢ Bins –fairly wide and Not tall
  - ➢ Hoppers –Small vessel with sloping bottom, generally temporary storage before feeding solids to a process.


Types of Bins
Chisel
Wedge/Plane Flow
L
B
L>3B


Conical
Pyramidal
Watch for in-
flowing valleys
in these bins!

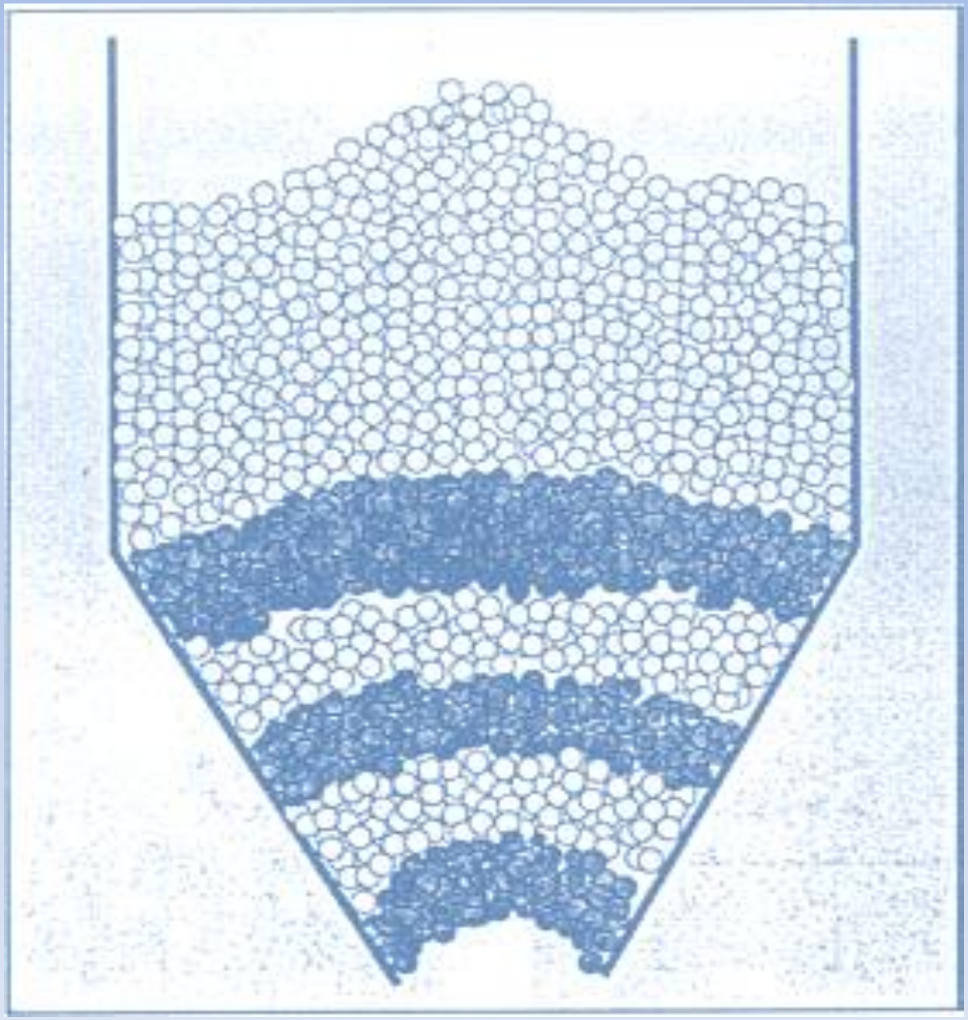
Flow of solids in hoppers



(A) MASS FLOW (B) FUNNEL FLOW (C) EXPANDED FLOW

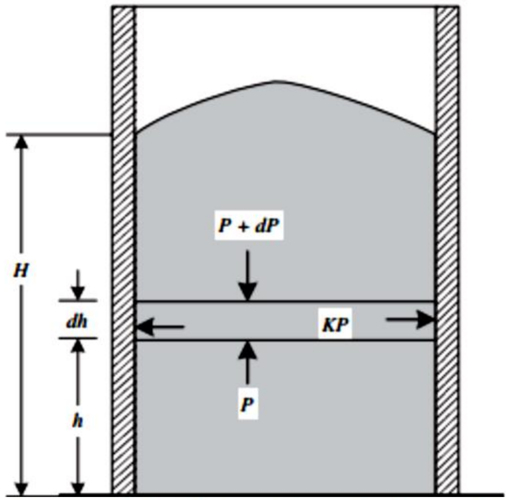
In mass flow (A) all material moves in the bin including near the walls. In funnel flow (B) the material moves in a central core with stagnant material near the walls. Expanded flow (C) is a combination of mass flow in the hopper exit and funnel flow in the bin above the hopper

Arch formation
Flow of solids in hoppers

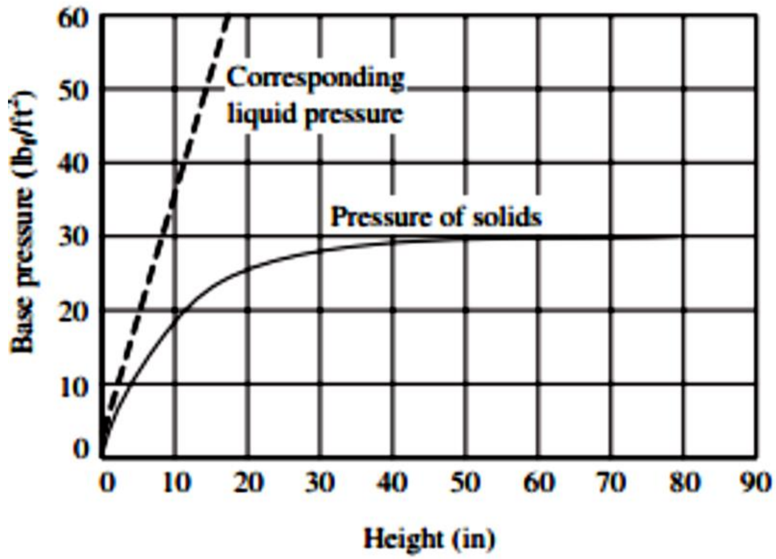


Discussion

Pressure at the base of a vertical bin filled with particulate solids



A Vertical bin filled with particulate solids



The Janssen equation for the vertical pressure P on dependence of the depth H below the bulk solids top level reads as follows for a cylindrical silo:

$$P = \frac{g\rho_b D}{4\mu' K'}\left[1 - e^{-\left(\frac{4\mu' K' H}{D}\right)}\right] \quad \text{...............(a)}$$

$$K' = \frac{1-\sin\alpha_s}{1+\sin\alpha_s} \quad \text{...............(b)}$$

where g is the acceleration due to gravity, ρ_b 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, which can be expressed as given in eq. b above.

where α_s is the angle of internal friction of solids.

Flow of solids through orifices

$$G = \frac{\pi}{4}\rho_s d_{eff}^{2.5} g^{0.5}\left(\frac{1-\cos\beta}{2\sin^3\beta}\right)^{0.5}$$

where: *G is the mass flow rate,*

ρ_s is the density of the solid particles,

*d_{eff} is the effective diameter of the orifice (orifice - 1.25*particle diameter),*

g is the acceleration due to gravity, and

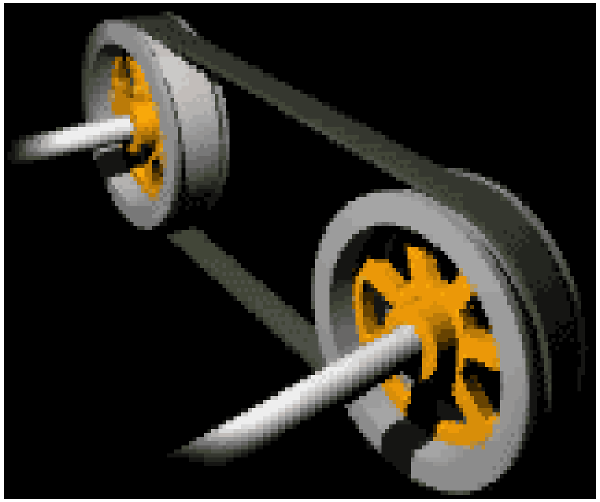
β is the acute angle between the cone wall and the horizontal.

Conveying of solids

- ***Gravity chutes*** *—down which the solids fall under the action of gravity.*
- ***Air slides*** *—where the particles, which are maintained partially suspended in a* channel by the upward flow of air through a porous distributor, flow at a small angle to the horizontal.

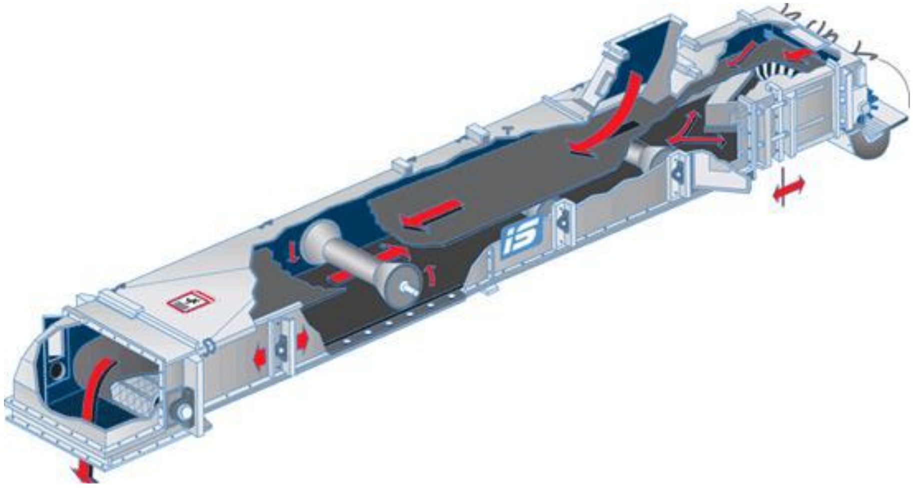
- ***Belt conveyors*** *—where the solids are conveyed horizontally, or at small angles to* the horizontal, on a continuous moving belt.
- ***Screw conveyors*** *—in which the solids are moved along a pipe or channel by a* rotating helical impeller, as in a screw lift elevator.
- ***Bucket elevators*** *—in which the particles are carried upwards in buckets attached* to a continuously moving vertical belt, as illustrated in the figures in the next slides.

Belt conveyor



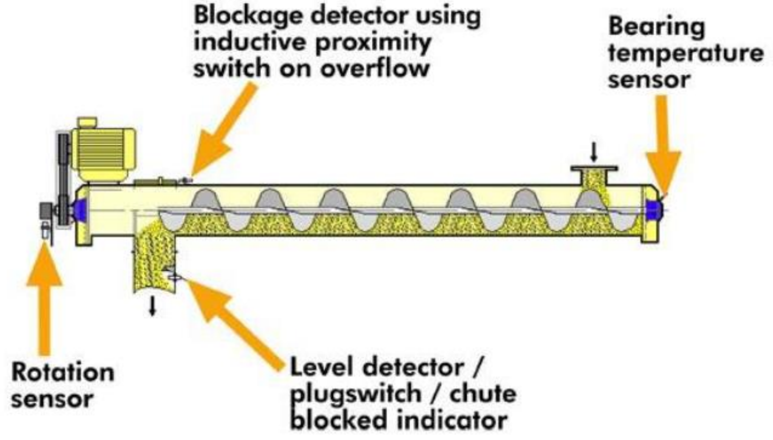
Continuous belt passing around two large pulleys at two ends, one drive pulley other tail pulley.

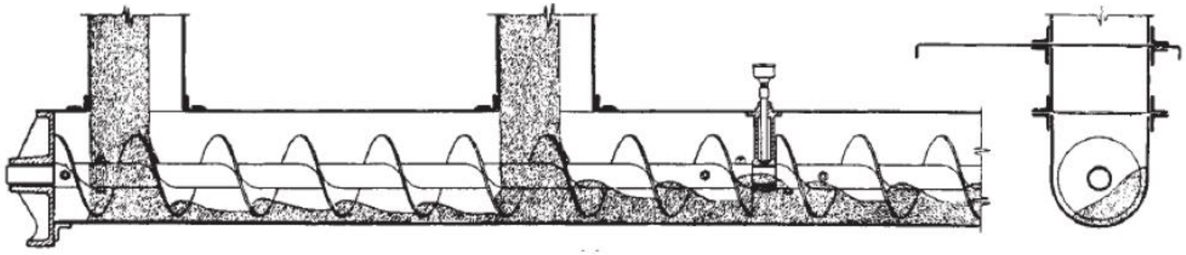
A conveyor belt uses a wide belt and pulleys and is supported by rollers or a flat pan along its path.



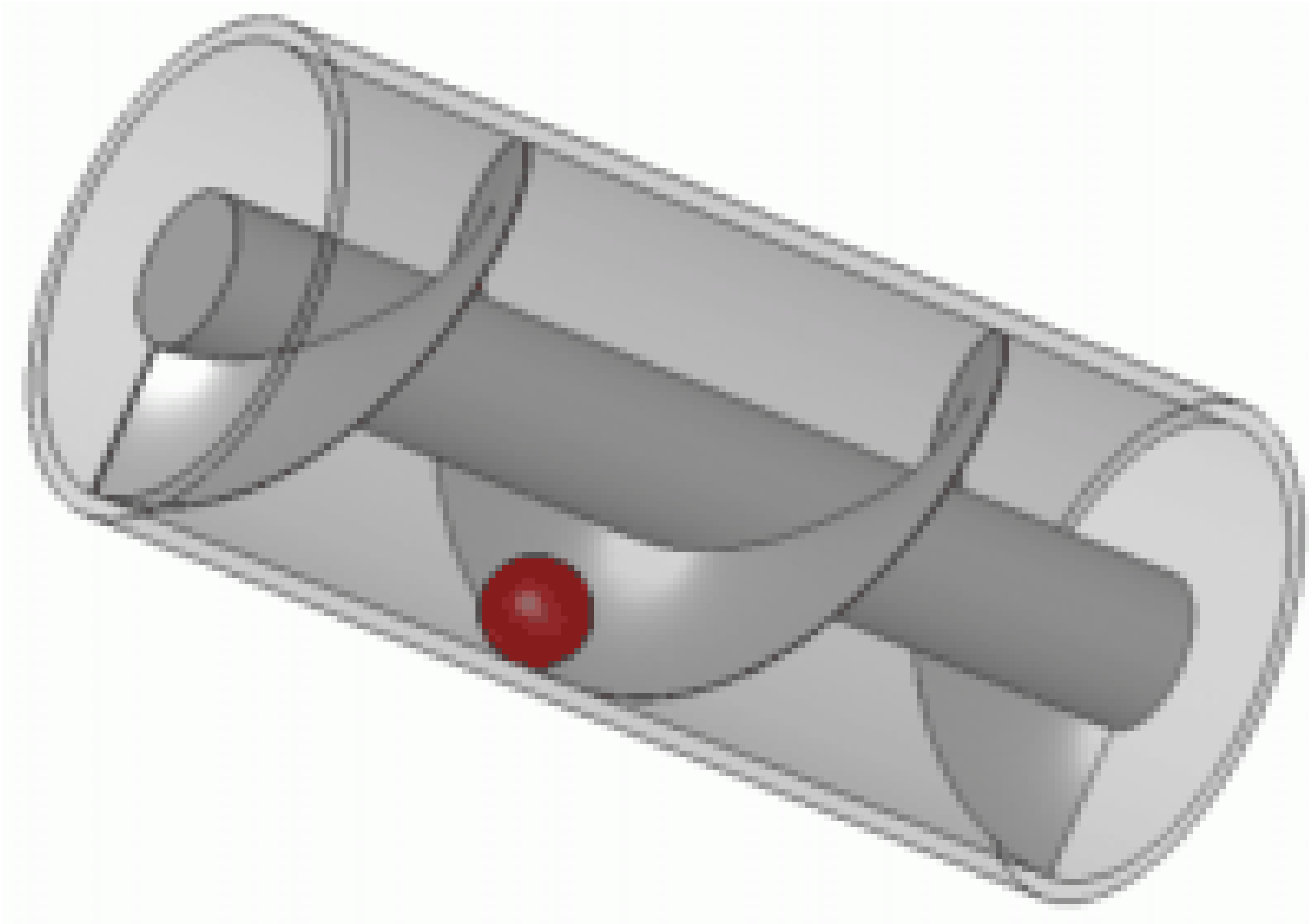
Screw conveyor

Helicoid (helix rolled from flat steel bar) or sectional flight mounted on a pipe or shaft rotating in a U shaped trough.





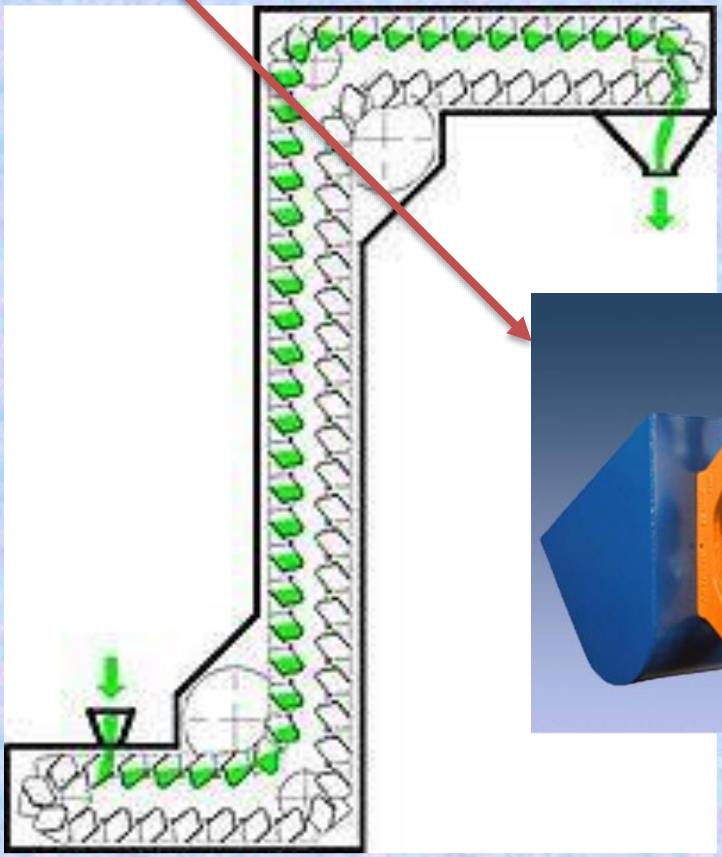
Screw conveyor

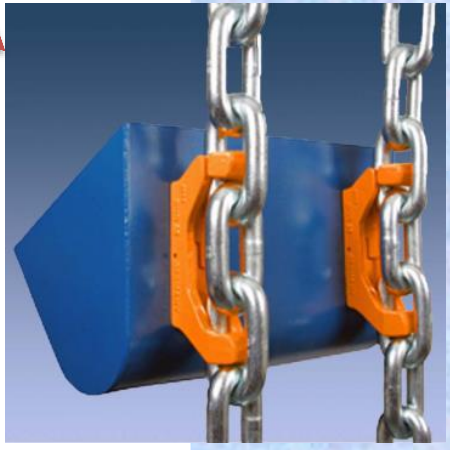


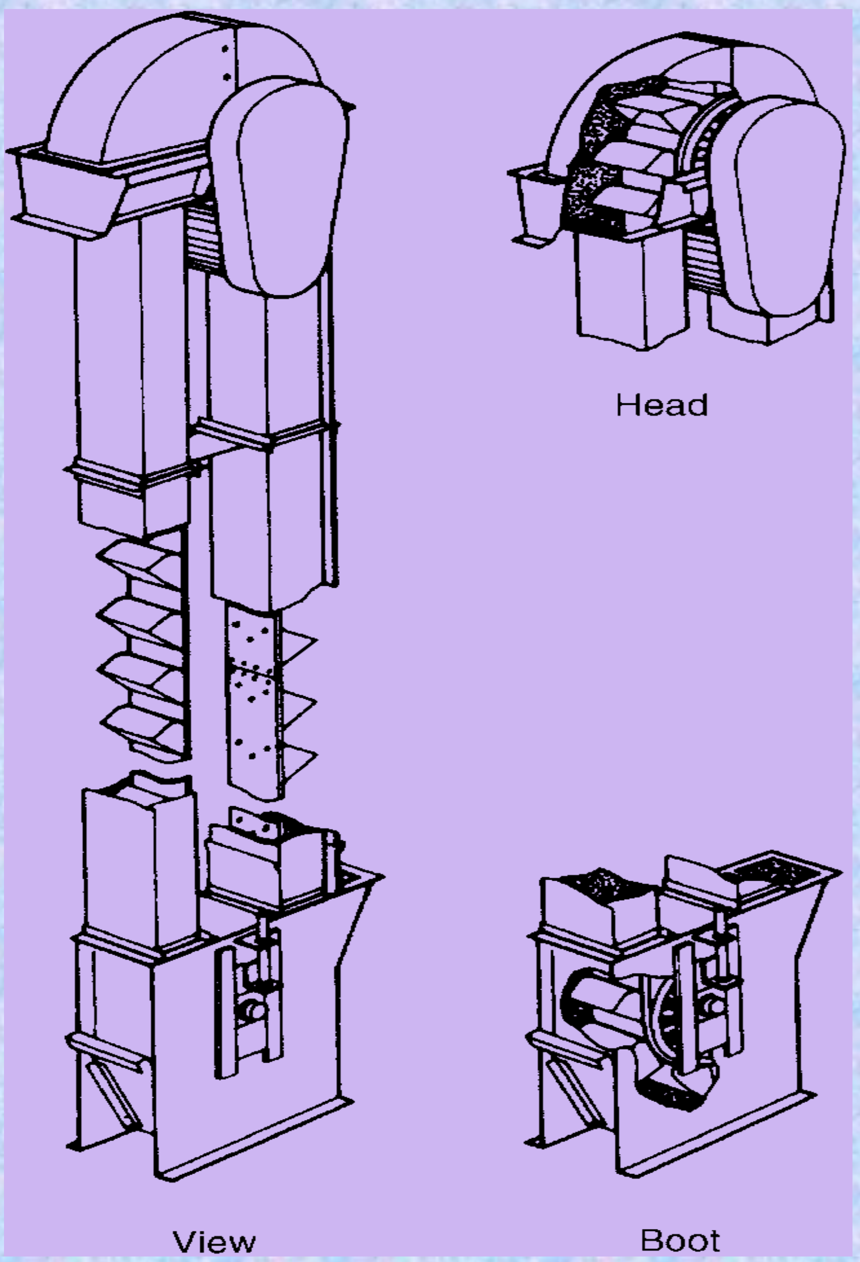
Screw conveyors

Bucket elevator

Bucket elevator consists of a number of buckets attached to a continuous double strand chain which passes over two pulleys







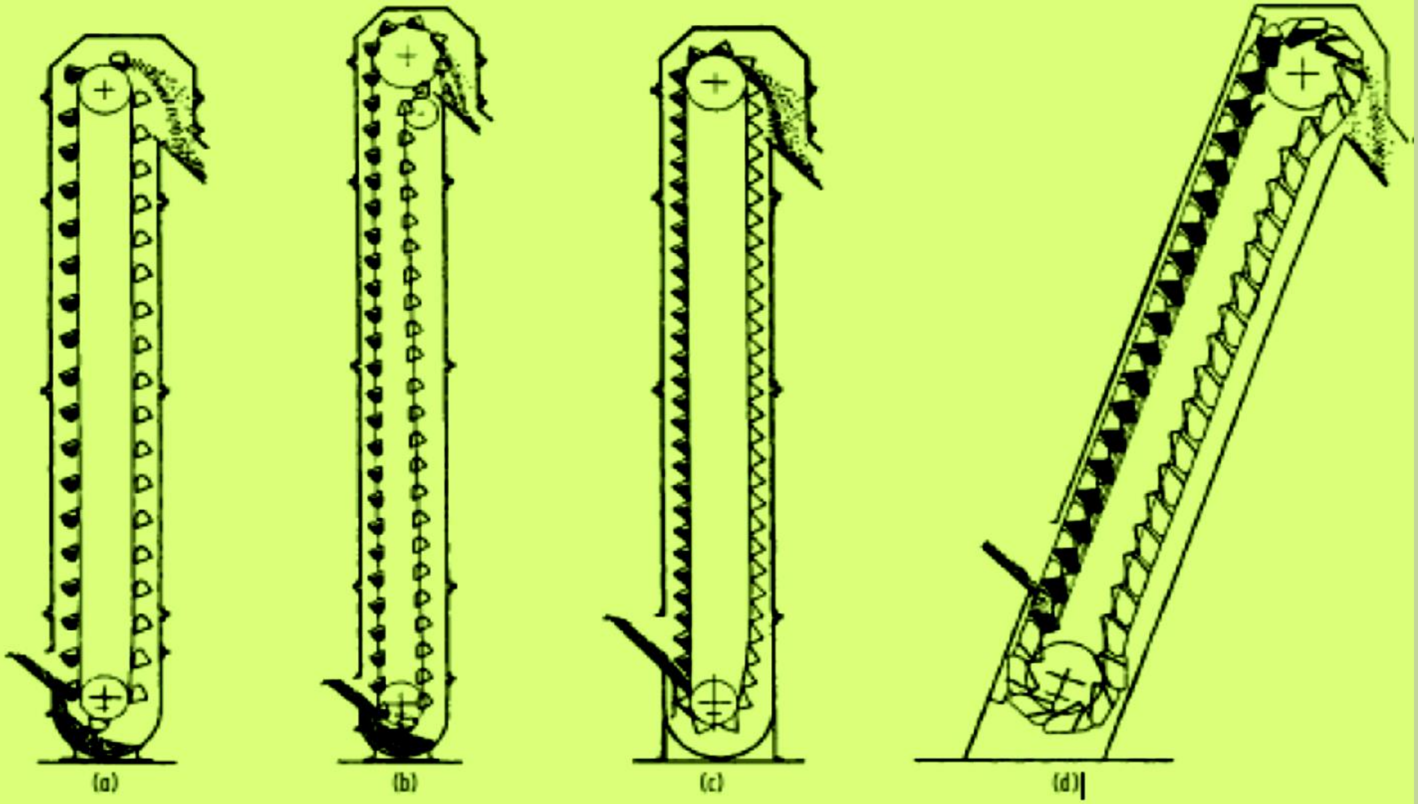
BUCKET ELEVATORS

(a)Spaced-Bucket Centrifugal-Discharge Elevators

(b)Spaced-Bucket Positive-Discharge Elevators

(c)Continuous-Bucket Elevators

(d)Supercapacity Continuous-Bucket Elevators



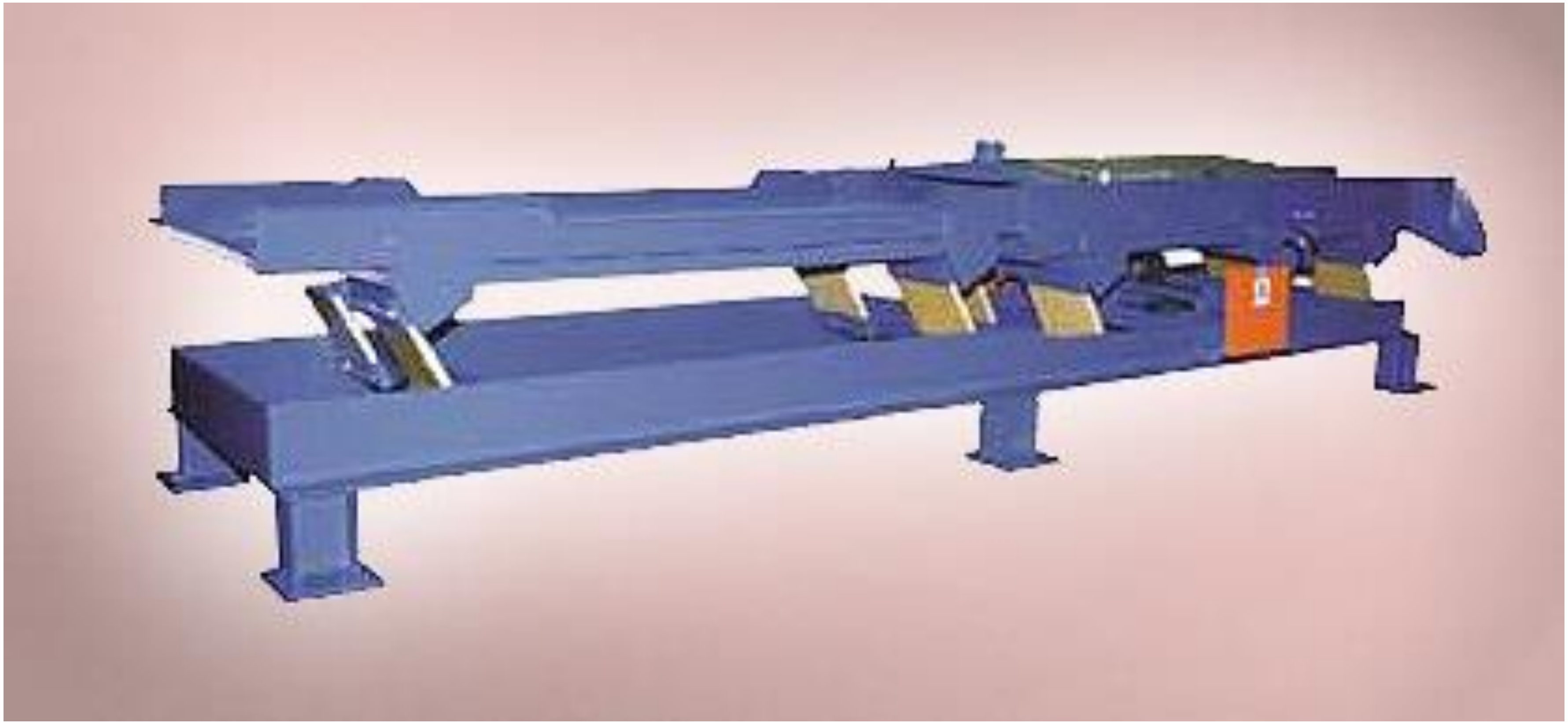
See next slide for definitions.

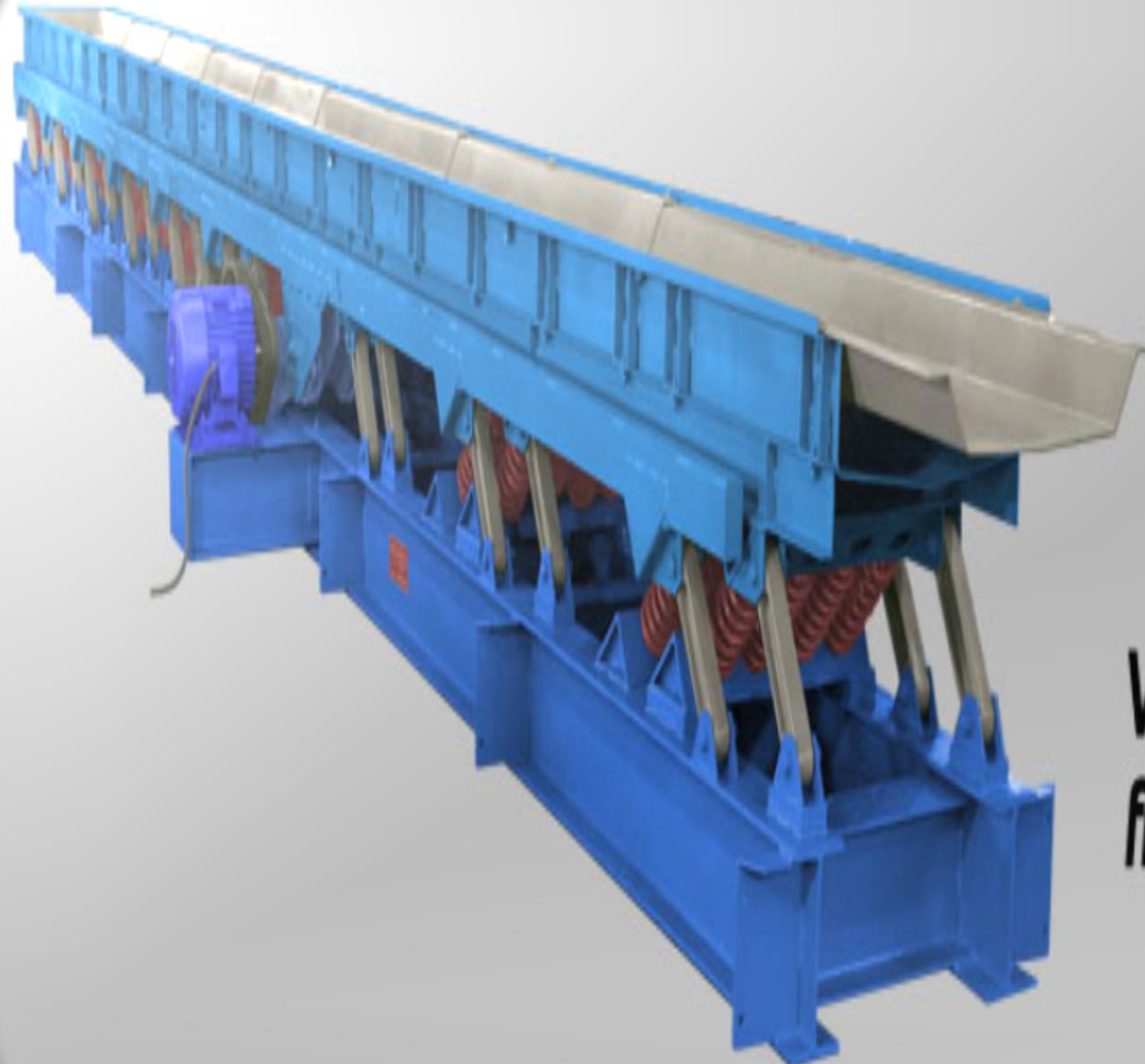
- Spaced bucket ; Centrifugal discharge –free flowing, fine or small lump material like grain, coal, sand or dry chemicals
- Spaced bucket positive discharge-buckets are for sticky materials which tend to lump, inverted for positive discharge, knockers can also be used
- Continuous –finely pulverized or fluffy materials, the back of the preceding bucket serves as a discharge chute for the bucket. Gentle movement Preventing degradation.
- Super capacity continuous bucket: Very high tonnage, big particles, Generally inclined

- ***Vibrating conveyors*** *—in which the particles are subjected to an asymmetric* vibration and travel in a series of steps over a table. During the forward stroke of the table the particles are carried forward in contact with it, but the acceleration in the reverse stroke is so high that the table slips under the particles. With fine powders, vibration of sufficient intensity results in a fluid-like behaviour.

- ***Pneumatic/hydraulic*** *conveying installations—in which the particles are transported* in a stream of air/water.

Vibratory conveyor

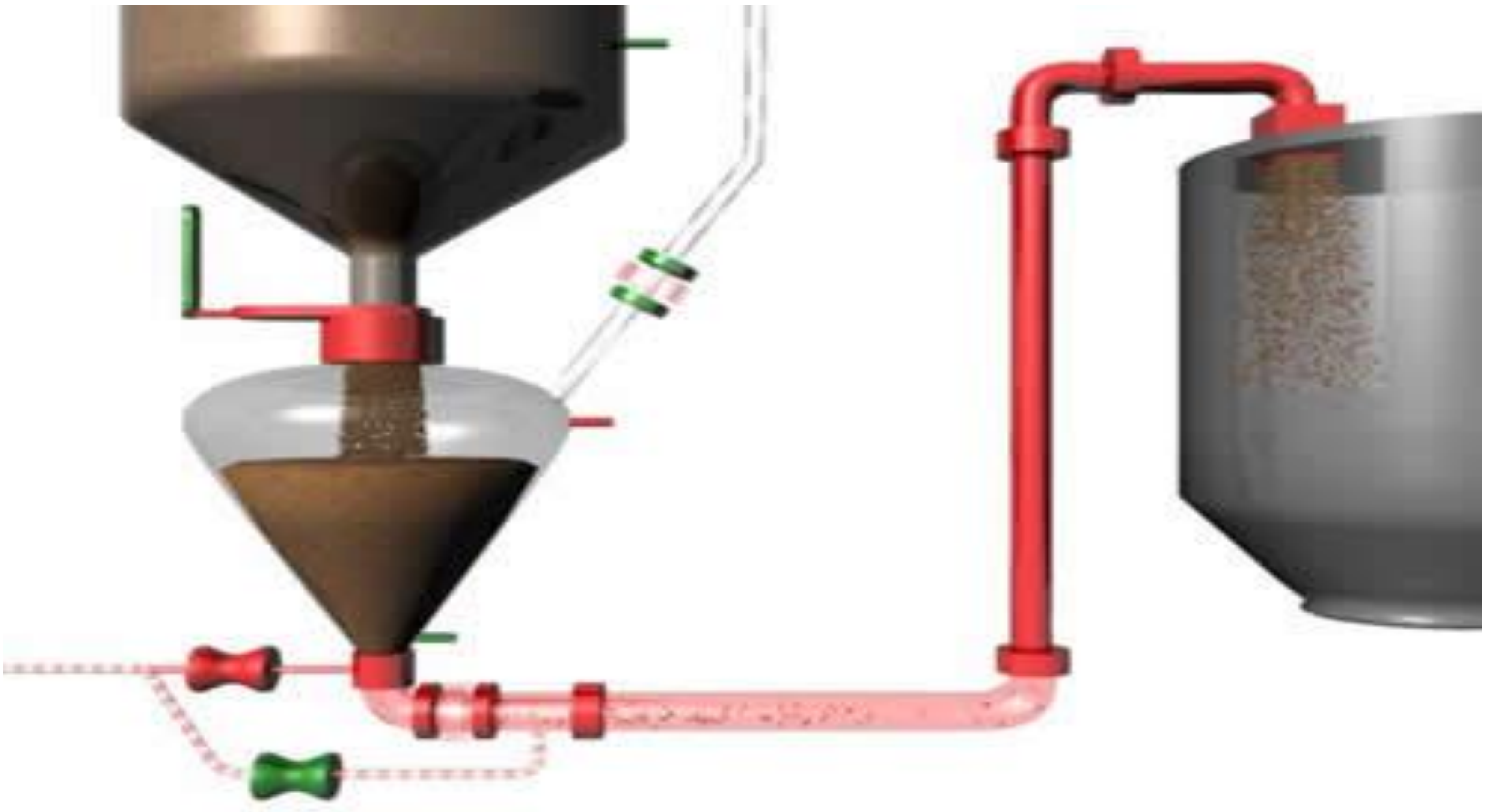




GENERAL KINEMATICS®

Vibratory Conveyors
from the conveyor experts.

Pneumatic or hydraulic conveyor



Flow rates control

- Flow rates control: Screw feeders
- Flow rates control: Rotating tables
- Flow rates control: Vibrating feeders

How to measure the flow rates

Monitoring the solids leave the hopper via

Monitoring the solids come to the conveyor

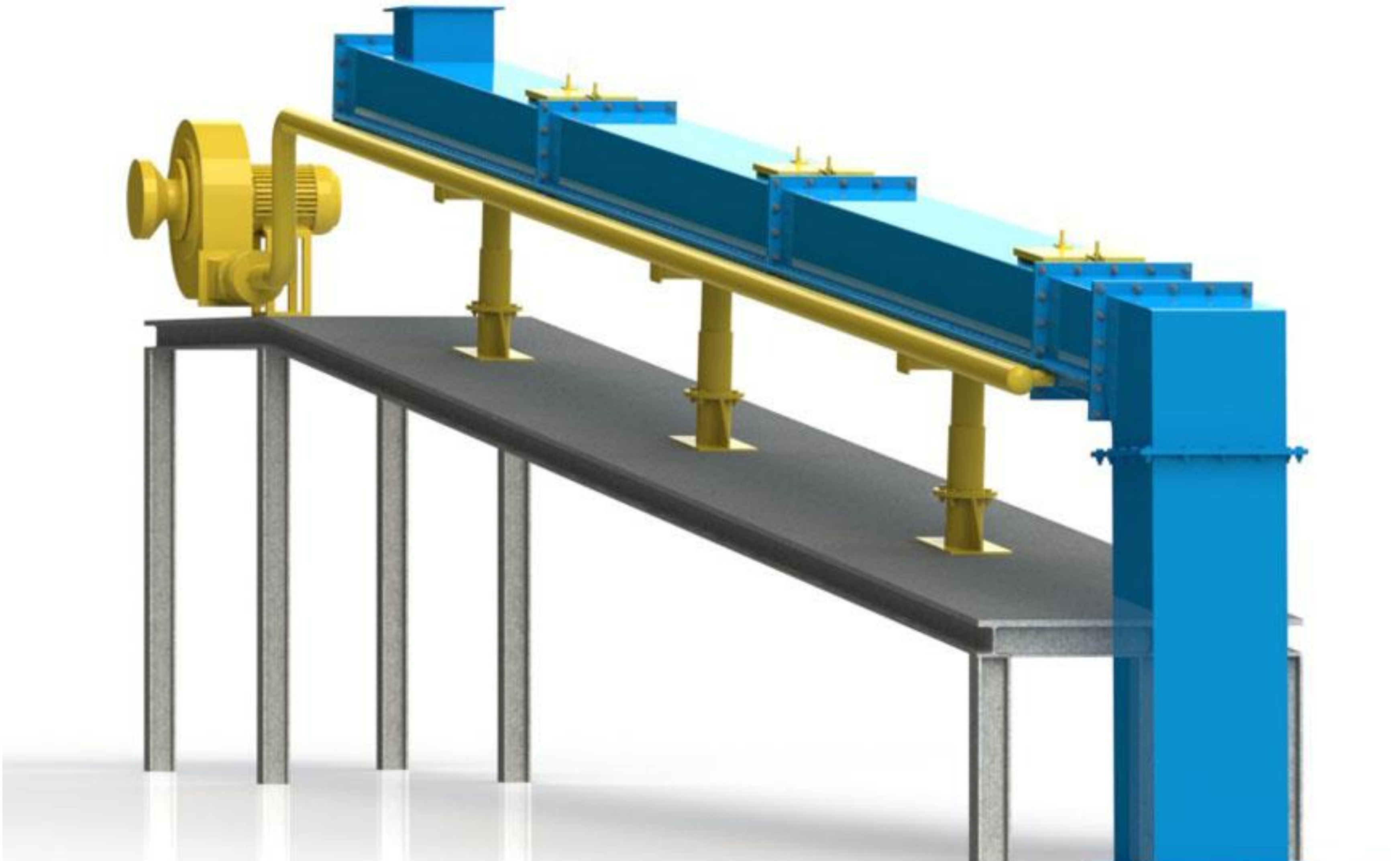
Load cell

Recording the level

Continuous weighing

Gravity Chute

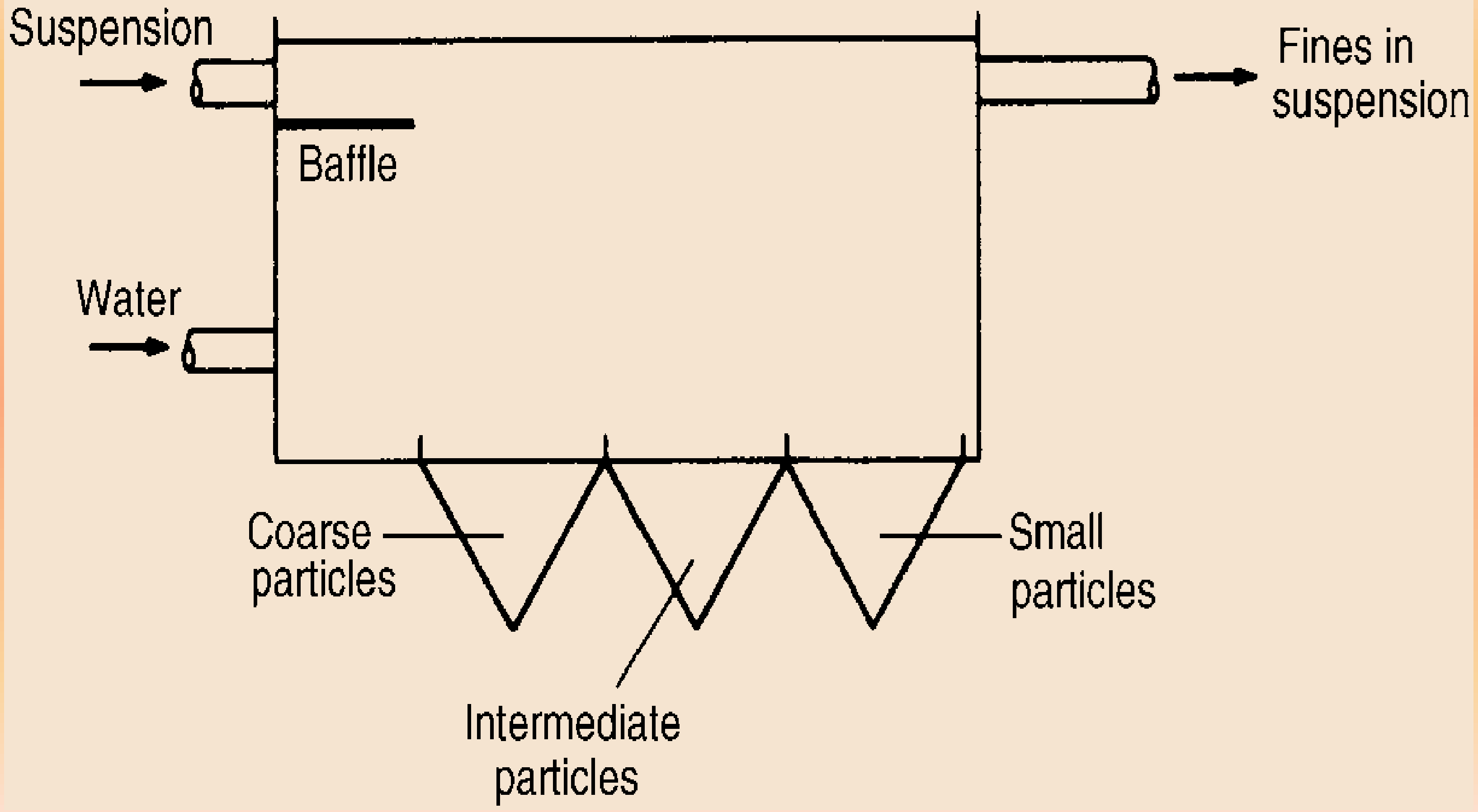
Air slide



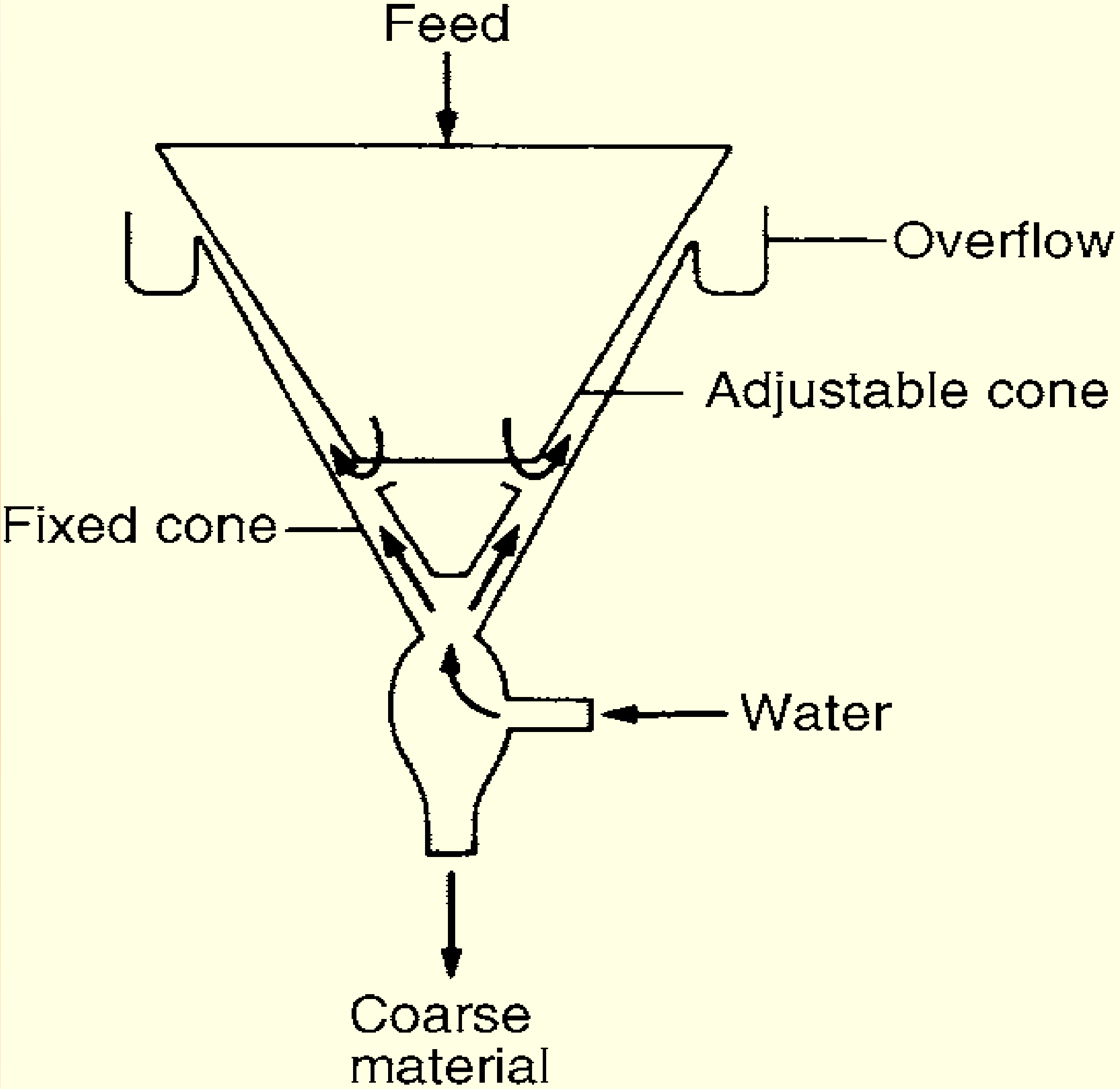
CLASSIFICATION OF SOLID PARTICLES

Fluid Separation

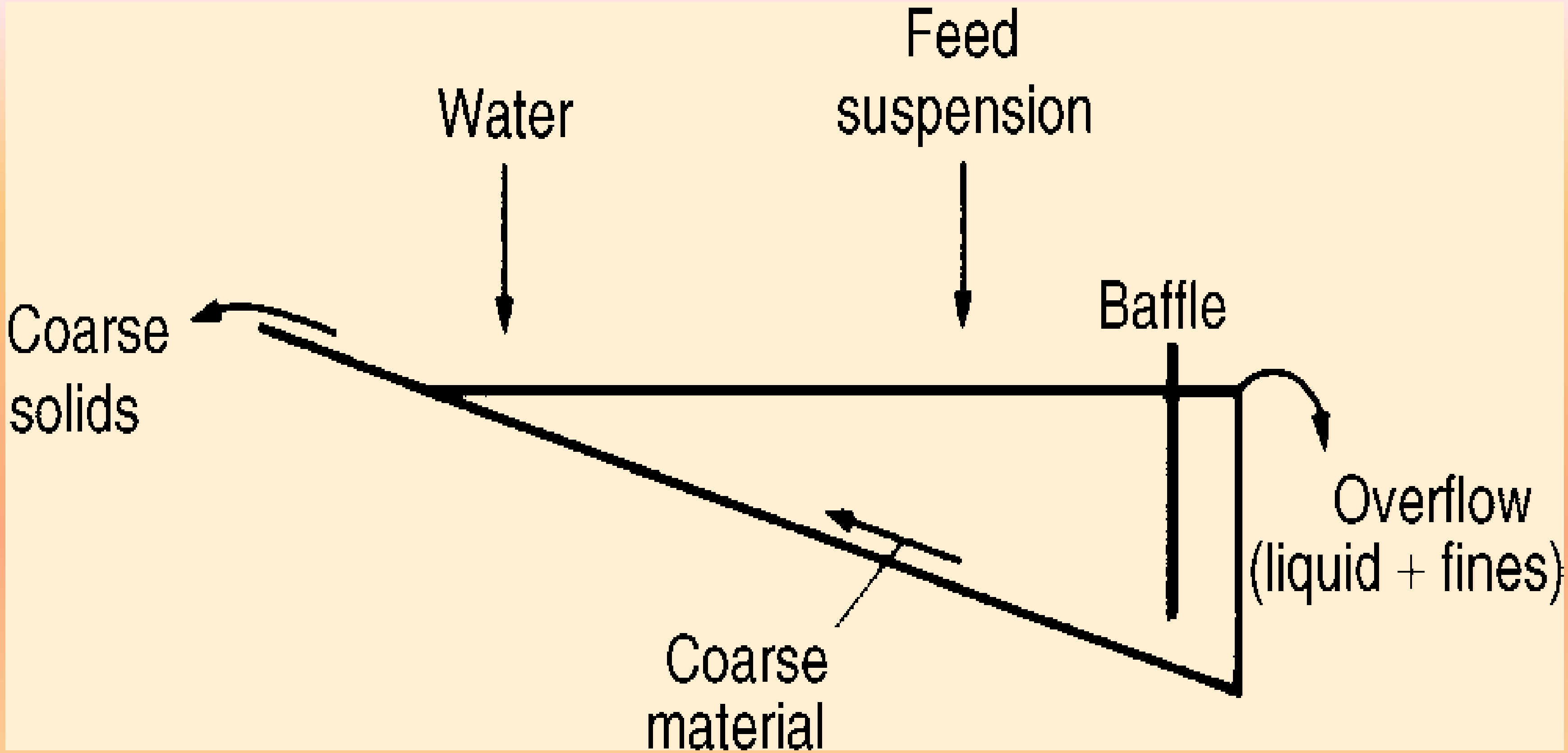
1.Gravity settling tank



2. Double cone classifier



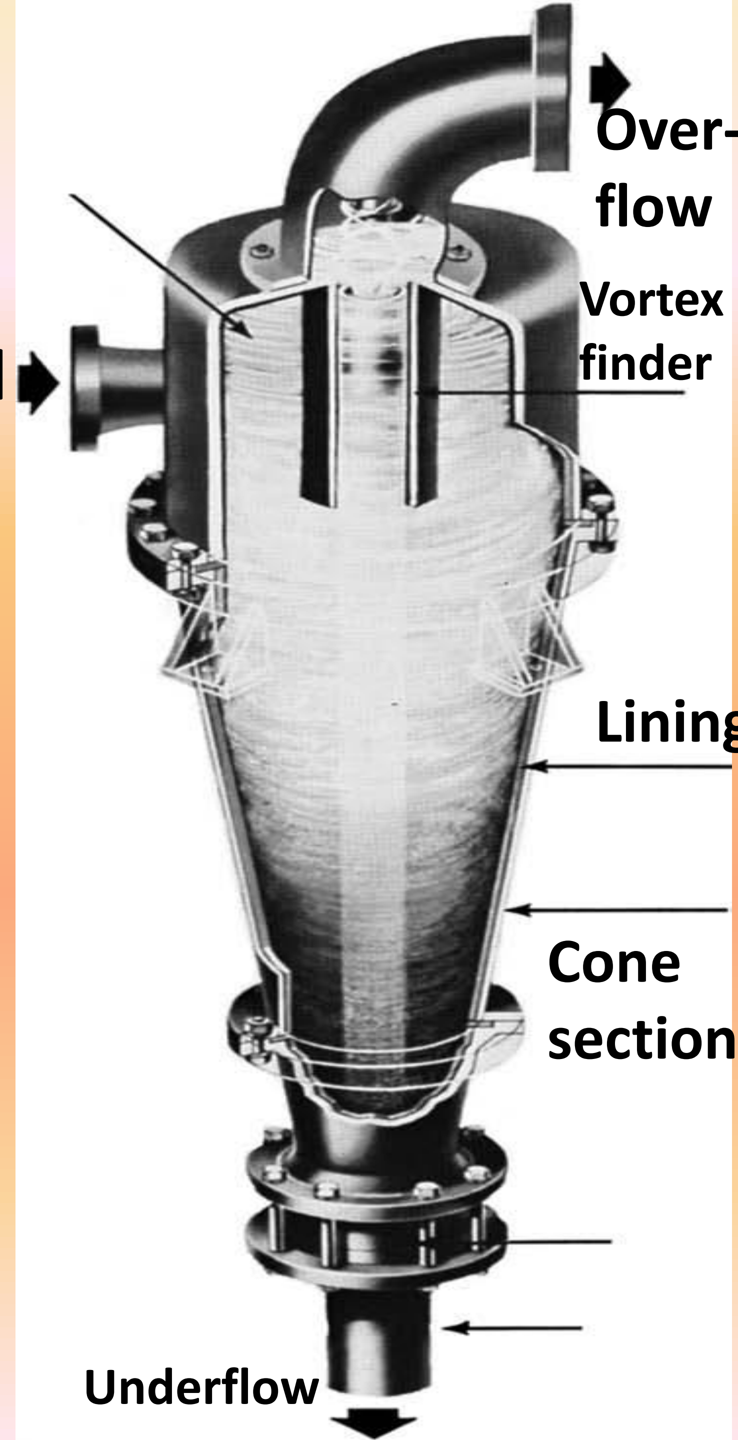
Mechanical classifier



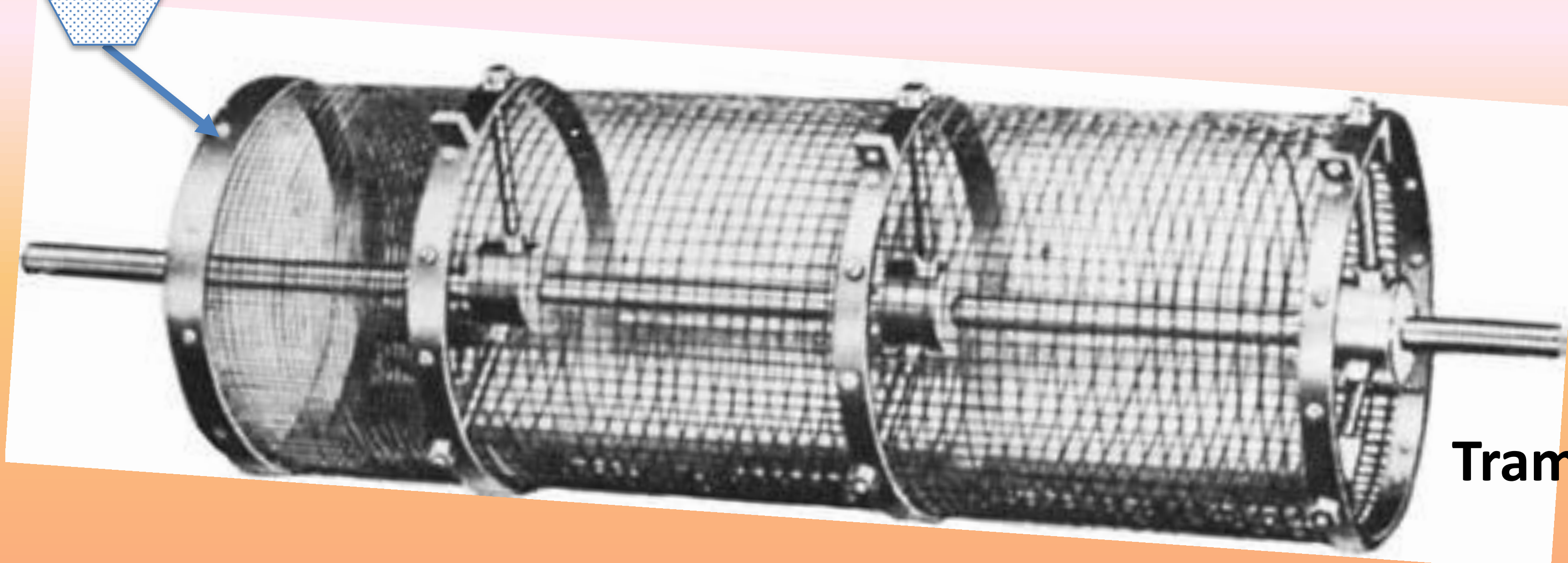
Removed by rake that moves mechanically

Centrifugal Separator

Liquid cyclone



Sieves or screens



Trammel or

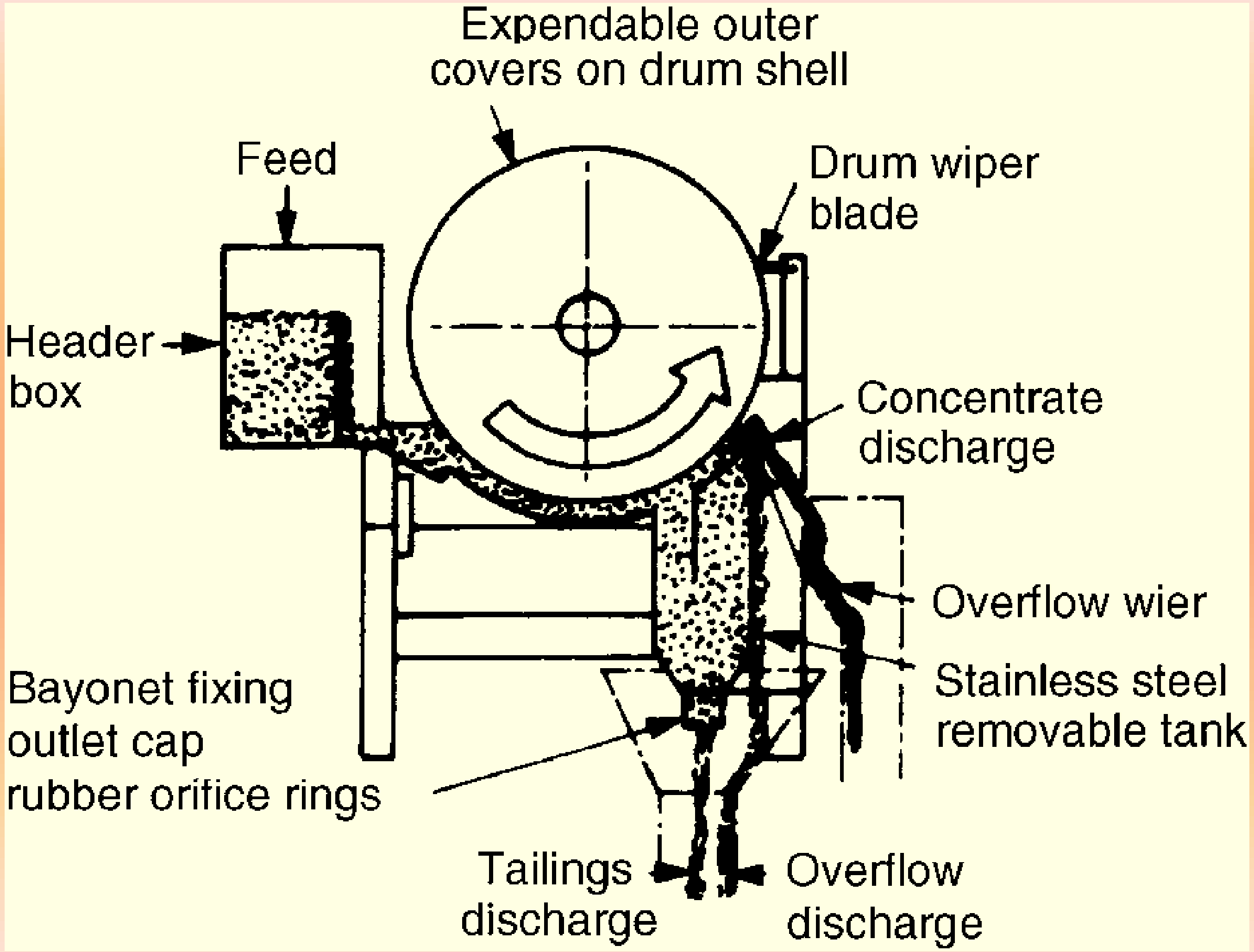
✓It consists of a slowly rotating perforated cylinder with its axis at a slight angle to the horizontal.

✓The material to be screened is fed in at the top and gradually moves down the screen and passes over apertures of gradually increasing size, with the result that all the material has to pass over the finest screen.

Magnetic separators

- **Eliminators (little duty)**, which are used for the removal of small quantities of *magnetic material* from the charge to a plant. These are frequently employed, for example, for the removal of stray pieces of scrap iron from the feed to crushing equipment. A common type of eliminator is a *magnetic pulley incorporated in a belt conveyor* so that the non-magnetic material is discharged in the normal manner and the magnetic material adheres to the belt and falls off from the underside.

➢**Concentrators**, which are used for the separation of magnetic ores from the accompanying mineral matter.



Principle of operation of a wet drum separator

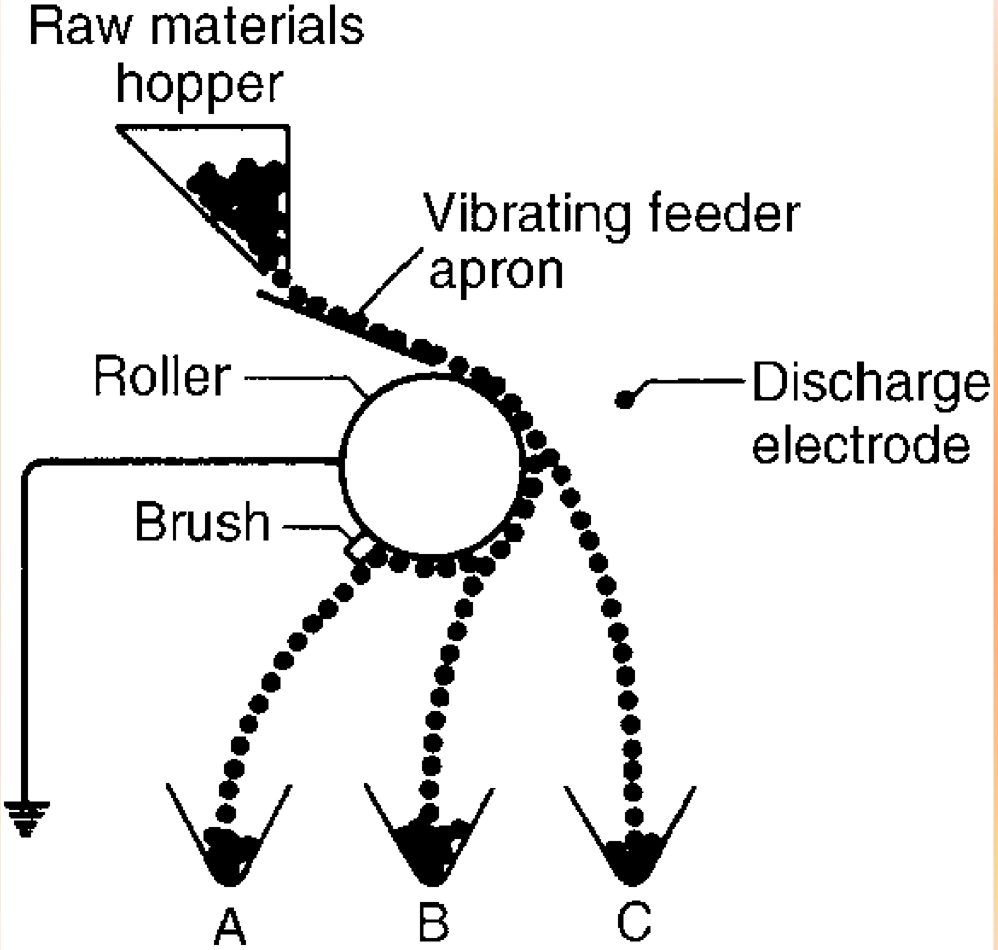
Dry or wet feeds

Electrostatic separator

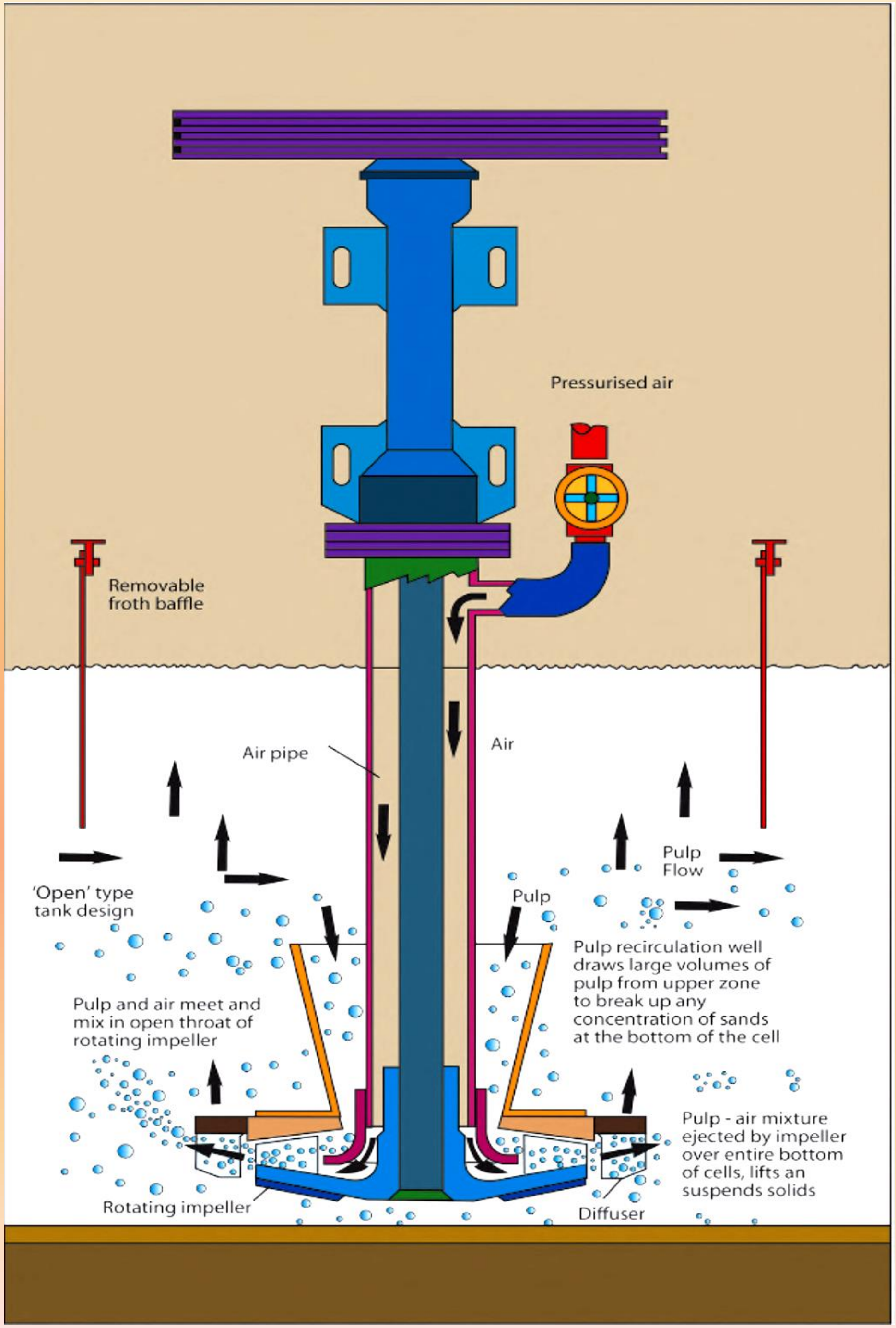
❖Differences in the electrical properties of the materials are exploited.

❖The solids are fed from a hopper on to a rotating drum, which is either charged or earthed, and an electrode bearing the opposite charge is situated at a small distance from the drum.

❖The point at which the material leaves the drum is determined by the charge it acquires.



Flotation



See the text for details. “self-reading”.