CHAPTER FOUR

SEPARATION OF SOLIDS BASED ON SPECIFIC PROPERTIES

TYPES OF SIZE SEPARATION BASED ON PROPERTIES

- In this chapter, we will deal with the methods for separating solid particles based on specific properties.
- Generally, screening is the most satisfactory method for separating relatively coarse materials/coarse solids according to size, but with very fine particles (which would clog the fine apertures of the screen or for which it is not possible to make the openings sufficiently fine), the method is impracticable and in such cases a form of settling process is used. This method of separation depends on differences in the behaviour of particles in a moving fluid and separate materials/solid particles according to their terminal falling velocities which in turn depend on size and density.
- Other methods of separation depend on differences in the magnetic properties (magnetic separation), electrical properties (electrostatic separation) or surface properties (froth flotation) of the materials.

Classification

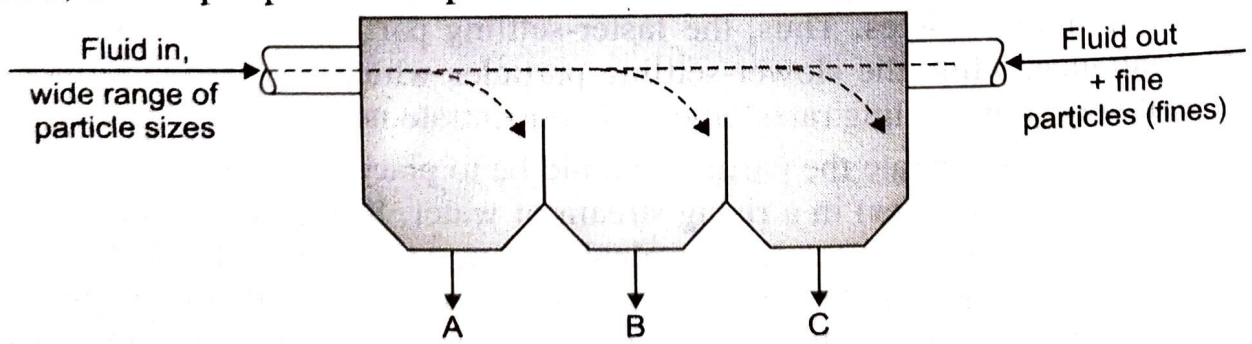
- *Classification is a method of separating solid particles into fractions based upon/according to their terminal falling/settling velocities.*
- Suppose, for example, that the solid particles to be separated are fed in suspension into a tank (containing water) of large cross-sectional area. When the feed stream enters the tank, the horizontal velocity component decreases and the particles start to settle. The faster-settling particles will reach the bottom of the tank before the slower-settling particles. Thus, the faster-settling particles will accumulate near the inlet/entrance, while the slower-settling particles which are carried farther (because of relatively slow-settling rates) and will concentrate nearer the exit/outlet.
- Another way to separate the particles would be to place two particles having different settling velocities (rates) in a rising stream of water. If the velocity of the water is so adjusted that it lies between the terminal settling velocities of the two particles then the slower-settling particle will be carried upward by the water and the faster-settling particle will simultaneously move downward against the water stream and settle out to the bottom, thus achieving a separation.
- A device that separates the solids into two fractions is called a classifier. The product streams that are obtained from any classifier are : (i) a partially drained fraction

containing the coarse material, called the sand and (ii) a fine fraction together with the remaining liquid medium, called the overflow.

- In the classification operation, the coarse solids that are settled at the bottom of a pool of fluid pulp are removed by gravity, mechanical means or induced pressure, while the solids which do not settle are taken out as an overflow from the pool.
- All wet classifiers work upon the difference in rate of settling/settling rate between coarse and fine particles. The settling rate of a particle depends upon its size and density and the particle will settle under the conditions of free settling or hindered settling depending upon the concentration of solids.
- When the particle is at sufficient distance from the vessel walls and from other particles, so that its fall is not affected by them, the process is called free settling. In practice, the concentrations of suspensions (high concentrations of solids to liquid) used in the industry is usually high so that the particles are very close together and thus the collision between the particles is practically continuous.
- When the motion of the particle is impeded or affected by other particles (as they being very close to each other), the process is called hindered settling.

Gravity Settling Tank

- It is the simplest type of classifier. It consists of a large tank with provisions for a suitable inlet and outlet.
- A slurry feed enters the tank through an inlet connection. As soon as the slurry feed enters the tank, its linear velocity decreases as a result of the enlargement of cross-sectional area. Solid particles start to settle under the influence of gravity.
- The faster-settling particles (coarse particles) will be collected at the bottom of the tank near the inlet/entrance, while the slower-settling particles (small particles) will be carried farther into the tank before they reach the bottom of the tank. The very fine particles are carried away in the liquid overflow from the tank.
- Vertical baffles placed at various distances from the inlet within the tank allow for the collection of several fractions (different grades of particles) according to the terminal falling velocities. Because of the occurrence of considerable overlapping of size, no sharp separation is possible with this classifier.



A = Coarse particles

B = Intermediate particles

C = Small particles

Fig. 4.1 : Gravity settling tank

Cone Classifier

- A cone classifier is simply a cone (conical vessel), installed point down, with a discharge launder around the top (of the cone).
- The feed is introduced in the form of a suspension through a fed inlet provided at the centre at the top. The coarse fraction (the partially drained fraction containing the coarse material) collects at the point of the cone (i.e., at the apex) and is withdrawn periodically or continuously. The fine fraction along with the remaining portion of the liquid is removed from the launder as an overflow. The separation achieved with this unit is only an approximate one.
- Cone classifiers are used for relatively crude work because of low cost of installation. They are used in ore-dressing plants.

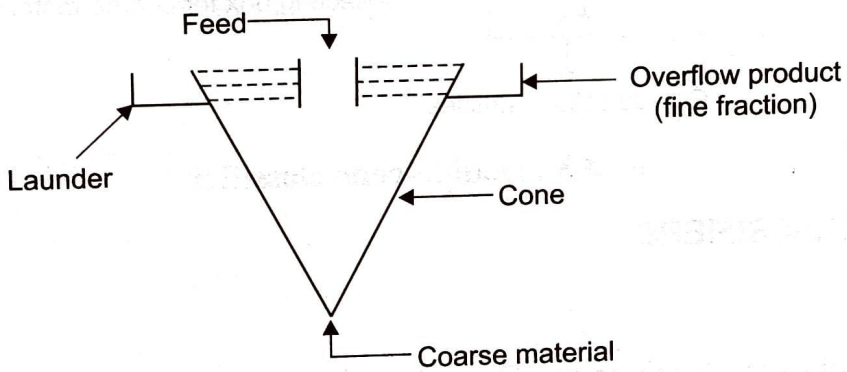


Fig. 4.2 : Cone classifier

Double-cone Classifier

- This classifier uses hydraulic water for classification (a stream of additional water supplied to a classifier is called hydraulic water).
- The double-cone classifier is shown in Fig. 4.3. It consists of a conical vessel incorporating a second hollow cone in it. The inner cone is slightly larger in angle, arranged apex downwards and is movable in a vertical direction. The bottom portion of the inner cone is cut away and its position (height) relative to the outer cone is regulated by a screw adjustment (not shown).
- The feed to be separated is fed in the form of a suspension to the centre of the inner cone. It flows downward through the inner cone and out at a baffle at the bottom of the inner cone. Hydraulic water is fed near the outlet for the coarse material. The solids from the inner cone and a rising stream of water are mixed below the inner cone. Then they flow through an annular space between the two cones. Classification occurs in the annular space, the small/fine particles are carried away in the overflow, whereas the large particles/coarse particles settle against the hydraulic water to the bottom and are removed periodically.

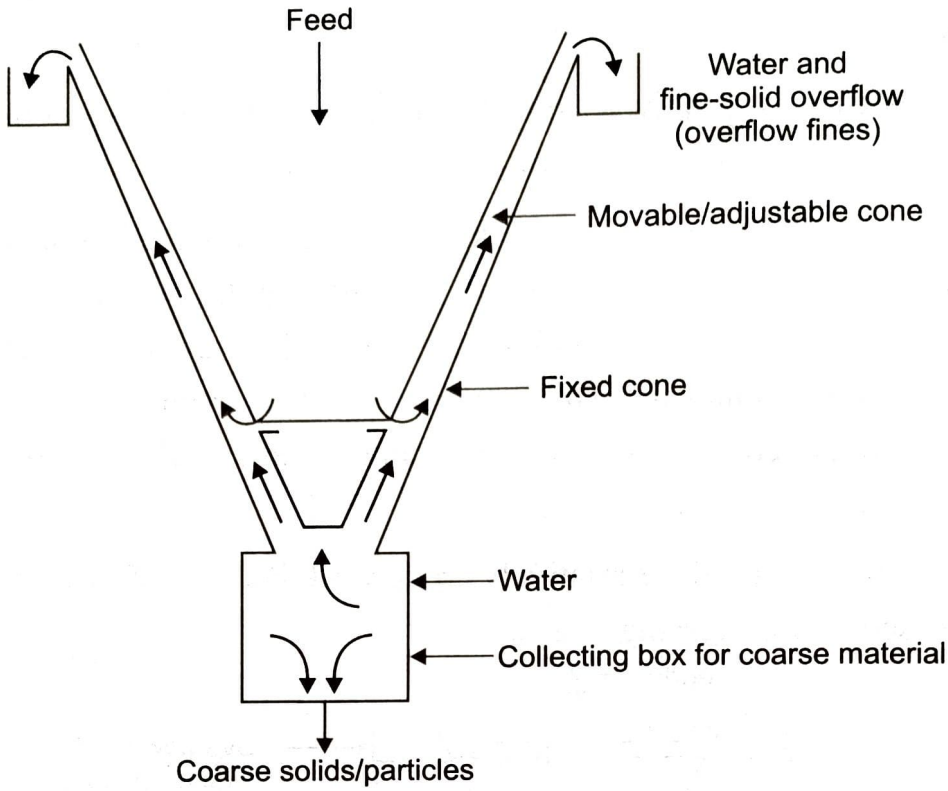


Fig. 4.3 : Double-cone classifier

MECHANICAL CLASSIFIERS

Rake Classifier

- The rake classifier such as the Dorr classifier consists of a rectangular tank with a sloping/inclined bottom. The tank is provided with movable rakes (reciprocating rakes). The feed in the form of suspension (slurry) is introduced continuously near the middle of the tank. The lower end of the tank has a weir overflow (discharge weir) from which the fines that are not settled leave with the overflow liquid.

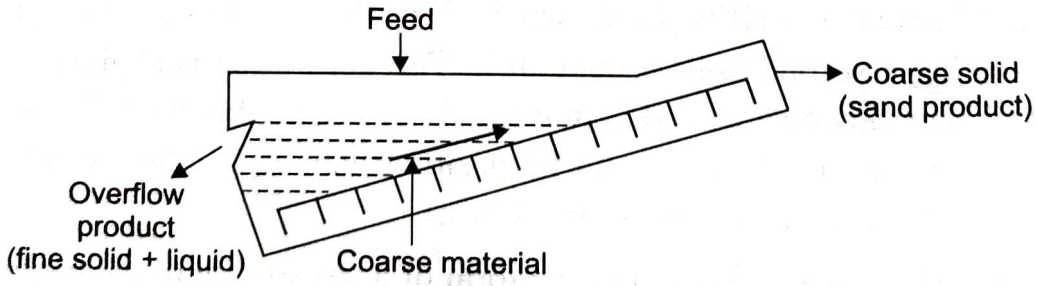


Fig. 4.4 : Rake classifier

- The heavy material (coarser particles) sink to the bottom of the tank. The rakes scrap the settled solids and move them upwards along the bottom of the tank towards the top/upper end of the tank from where they are discharged. The reciprocating rakes keep the slurry in continuous agitation. The time of raking stroke is so adjusted that

fines do not have time to settle and so remain near the surface of the slurry, while the heavy particles have time to settle [they settle, scrapped upward and removed as a dense slurry (called the sand)].

Spiral Classifier

- It is a mechanical classifier. The spiral classifier such as the Akins classifier consists of a semicylindrical trough (a trough which is semicircular in cross-section) inclined to the horizontal. The trough is provided with a slow-rotating spiral conveyor and a liquid overflow at the lower end. The spiral conveyor moves the solids which settle to the bottom upward towards the top of the trough.
- Slurry is fed continuously near the middle of the trough. The slurry feed rate is so adjusted that fines do not have time to settle and are carried out with the overflow liquid. Heavy particles have time to settle, they settle to the bottom of the trough and the spiral conveyor moves the settled solids upward along the floor of the trough towards the top of the trough from where they are discharged.
- Rake and spiral classifiers are used along with ball mills in closed-circuit grinding.

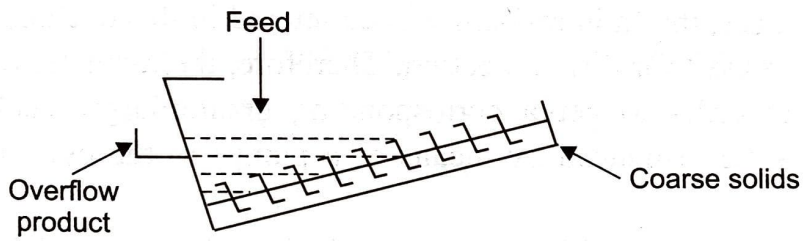


Fig. 4.5 : Spiral classifier

SEPARATION OF SOLID PARTICLES FROM LIQUID AND GAS BY CYCLONES/CYCLONE SEPARATION

- A cyclone/cyclone separator is essentially a settling chamber in which the gravitational separating force is replaced by a much stronger centrifugal separating force (to increase the settling rate).
- Cyclones/cyclone separators are used for the separation of solids from fluids. They offer one of the least expensive means of dust collection (separation of dust particles from gases). They utilize a centrifugal force to effect the separation which depends on particle size and/or on particle density. Thus, cyclones are used to effect a separation on the basis of particle size or particle density or both.
- It consists of a tappering cylindrical vessel, i.e., a cylindrical vessel consisting of a top vertical section and lower conical/tappering section terminating in an apex opening - a short vertical cylinder which is closed by a flat plate on top and by a conical bottom (Refer Fig. 4.6). It is provided with a tangential feed inlet nozzle in the cylindrical section near the top and an outlet for the gas, centrally on the top. The

outlet is provided with a downward extending pipe - a pipe that extends inward into the cylindrical section - to prevent the gas short-circuiting directly from the inlet to the outlet and for cutting the vortex.

- In this separator, used for the separation of dust particles or mist from gases, the dust laden gas is introduced tangentially into a cylindrical vessel at a high velocity (30 m/s). Centrifugal force throws the solid particles out against the wall of the vessel and they drop into a conical section of the cyclone and removed from the bottom/apex opening. The clean gas is taken out through a central outlet at the top.
- Cyclones are widely used for collecting heavy and coarse dusts. These units may also be used for separating coarse materials from fine dust.

Liquid Cyclone (Hydroclone) :

- Cyclone separators may also be used to effect the classification of solid particles suspended in a liquid. In such cases, the commonly used liquid is water.
- Liquid cyclone has a top cylindrical section and a lower conical section terminating in an apex opening. The top vertical section is covered by a flat plate and is provided with a tangential inlet at the top. The cover has a downward-extending pipe to cut the vortex and remove the overflow product since the viscosity of water is much higher than that of a gas, the fluid resistance encountered in this cyclone is greater than that in the cyclone used for dust collection. Therefore, the diameter of this cyclone must be smaller in order to get a corresponding greater/larger centrifugal force. The pressure of a feed (induced by means of a pump) to the cyclone lie between 5 to 120 psi.
- The slurry feed is pumped into the cylindrical section tangentially. Coarse or heavy solids thrown out against the walls, travel down the sides of the cone section and are discharged in a partially dewatered form from the apex, while the smaller or lighter solids along with the remaining portion of water are removed from the downward extending pipe at the top. Liquid cyclones are used in degritting operations in alumina production, classifying pigments and ore-dressing practice.

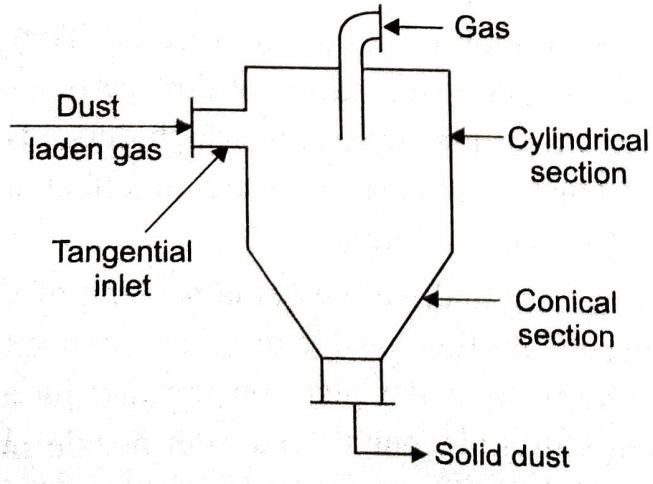


Fig. 4.6 : Cyclone separator/Cyclone

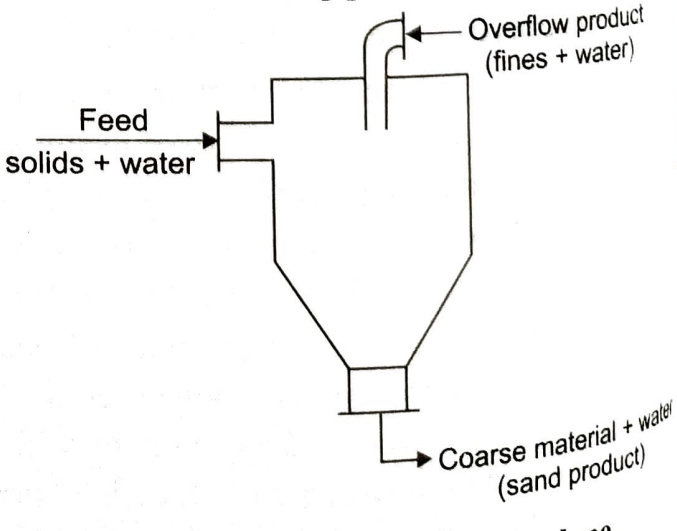


Fig. 4.7 : Liquid cyclone

JIGGING

- A **jig** is a mechanical device used for the separation of materials of different specific gravities by pulsating a stream of liquid (usually water) flowing through a bed of materials resting on a screen.
- Jigging is a method of separating materials of different specific gravities by the pulsation of a stream of liquid (water) flowing through a bed of materials resting on a screen.

  [pulsate ⇒ oscillate ⇒ move or swing back and forth at a regular rate.

  Jig ⇒ move up and down with a quick jerky motion.]

Principle of operation :

- Jigs separate solids by difference in density and size.
- Jigging is *a process of gravity concentration where solids are separated based upon the differences in the behaviour of particles through a moving fluid which in turn, depends upon densities/specific gravities.*
- Separation of solids of different specific gravities is achieved by the pulsation of a liquid stream flowing through a bed of solids on a screen. The liquid pulsates or jigs up and down and this action causes the heavy material to move towards the bottom of the bed and the lighter material to rise to the top. Each product is taken out separately.

Applications :

- Jigging is used for concentrating heavy minerals from the light minerals. It is commonly employed for coarse material having a size 20-mesh and above and where there is a sizeable/fairly large difference between the effective specific gravity (effective sp. gr. = sp. gr. of mineral – sp. gr. of water) of the valuable and the waste material.
- Jigs are simple in operation, consume very large quantities of water and have high tailings losses on metallic ores. They are used mostly to treat iron ores, few lead-zinc ores, etc.

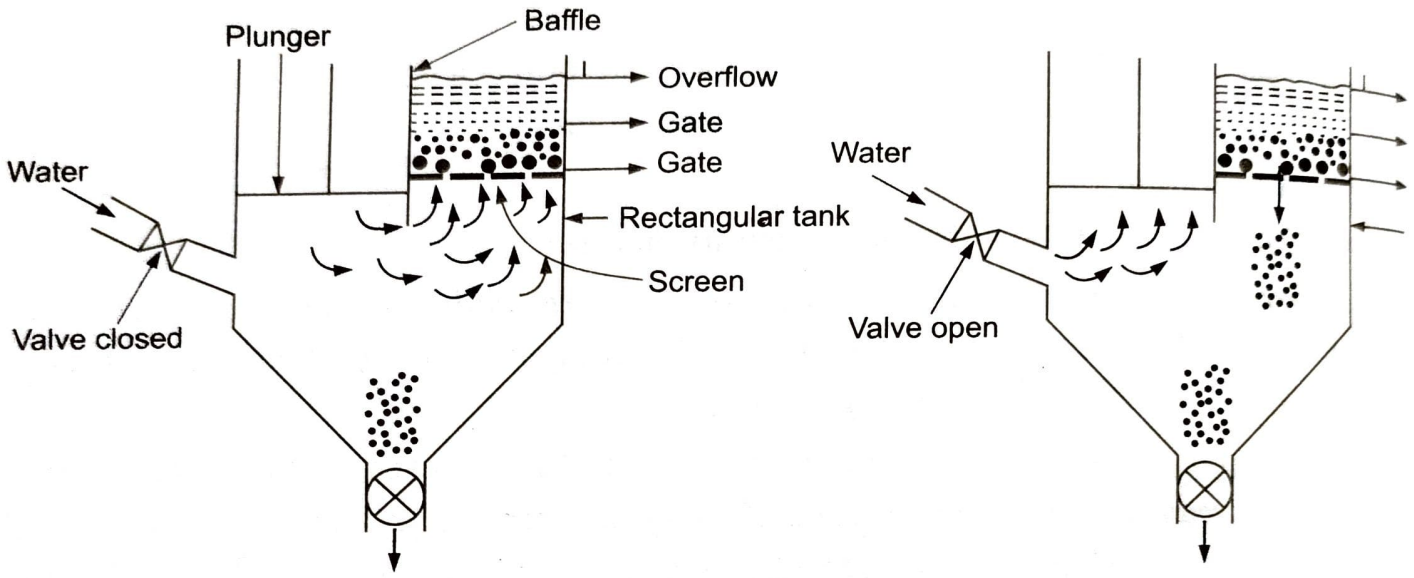
Hydraulic Jig :

- It operates by providing very short periods for materials to settle due to which the particles do not attain their terminal falling velocities and initial velocities cause the separation. Thus, it is suitable for the separation of materials of a wide size range into various fractions.

Construction :

- Fig. 4.8 shows a hydraulic jig. It consists of a rectangular section tank with a tappered bottom. The tank is divided into two portions/compartments by a vertical

baffle. In one compartment, a plunger is incorporated. It operates in a vertical direction giving a pulsating motion to the liquid. In the other compartment, a screen is incorporated. The separation of material is carried out over this screen. It is provided with a connection for feeding liquid during the upstroke. It is also provided with a bottom discharge connection for the removal of small particles of heavy material and gates at the side of jig for the removal of particles settled on the screen and for overflow.



(a) Downward stroke **(b) Upward stroke**

Fig. 4.8 : Hydraulic jig

Working :

- The material to be separated is fed over a screen and is subjected to a pulsating action by oscillating liquid with the help of a reciprocating plunger. During the upward stroke of the plunger, input water is taken into the jig and there is no net flow through the bed of solids. During the downward stroke, water inlet is closed and particles on the screen are brought into suspension and they segregate according to their size and density such that the dense material is collected near the bottom of screen.
- Very small particles of the dense material will pass through the screen and are collected at the bottom of the jig. Small particles of the less dense material (light material) carried by the liquid water are removed through an overflow. The material retained on the screen is removed through gates provided at the side.

The following four fractions are obtained from the jig :

1. Small and dense material passing through the screen collected at the bottom of the tank.
2. Small size less dense material in the liquid overflow.
3. Large size dense material segregated near a screen removed through a gate at the side.
4. Large size less dense material segregated above the dense material removed through a gate at the side.

FROTH FLOTATION

- Froth flotation processes are used for the separation of finely divided solids.
- Flotation refers to *an operation in which one solid is separated from another by floating one of them at or on the liquid surface.* In froth flotation, separation of a solid feed mixture depends upon differences in the surface properties of the materials involved. This technique is commonly used in mineral dressing. Mineral dressing refers to the method of treating ores at or near the mine site to produce one or more concentrates of valuable minerals and a tailings composed of waste or less valuable minerals.
- Froth flotation is used for treating the metallic ores that are finer than 48 to 65 mesh, or coal and certain non-metallics that are finer than 10 to 48 mesh. It is not possible to treat a coarser feed by froth flotation as the same cannot be suitably mixed and suspended by a floatation machine.

Principle of operation :

- Separation by froth flotation depends on differences in the surface properties of the materials.
- If the mixture is suspended in an aerated liquid (water), the gas bubbles will tend to adhere preferentially to the constituent which is more difficult to wet by the liquid (hydrophobic constituent) and so its effective density will be reduced to such an extent that it will rise to the surface (i.e., it will float on the surface of the liquid) and the material which has affinity for the liquid (hydrophilic material) gets surrounded by the liquid and it will simply sink, thus, achieving a separation. Frothing agents inducing the formation of a froth of sufficient stability are added to suspend or retain the particles in the froth on the surface before they are discharged.

  [Hydrophobic – failing to mix with water – which will not wet by water and Hydrophilic – having tendency to mix with water – which will get wet by water].

Promotors, Collectors, Modifiers and Frothing Agents :

- Almost all the minerals and inorganic solids are hydrophilic, as the surfaces of these solids get easily wetted by water. Hydrophilic solids are unflotable as air bubbles do not surround or cover them to form a particle bubble aggregate. However, these solids can be made hydrophobic (water repellent) with the help of reagents known as collectors or promotors. The collectors or promotors are the materials which selectively render the desired particles air-avid and water repellent.

  (i) **Promotors :** These are materials which are adsorbed on the surface of the particles forming a unimolecular layer. A commonly used promotor is sodium ethyl xanthate.

  (ii) **Collectors :** These are materials which form surface films on the particles. A commonly used collector is pine oil.

(iii) **Frothing agents/Frothers :** These are materials which induce the formation of a froth (which produce a froth) of sufficient stability in order to retain the particles of the constituent which is to be floated to be discharged as an overflow. Commonly used frothers include liquid soaps, pine oil, cresylic acid, methyl amyl alcohol and methylisobutylcarbinol.

- The valuable concentrates from froth flotation may be either the froth product which is collected and removed from the top, or the underflow product. In case of metallic sulfide ores of copper, nickel, etc. the valuable product collects in the froth and is removed from the top. In glass-sand flotation, iron bearing minerals collect in the froth, while the valuable product (high grade silica) is removed as an underflow product.

Flotation Machine/Flotation Cell

Construction :

- The mechanically agitated flotation cell consists of a tank having square or circular cross-section. It is provided with an agitator which violently agitates the pulp. A compressor / blower is used to introduce air into the system through a downpipe surrounding the impeller shaft. The bottom of the tank is conical and is provided with a discharge for tailings. An overflow is provided at the top for mineralised froth (or froth) removal.

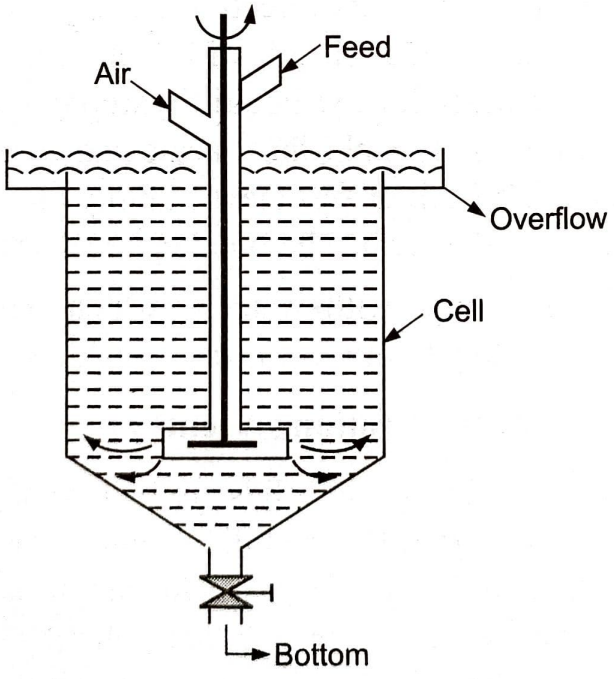


Fig. 4.9 : Froth flotation cell (Lab. model)

Working :

- Water is taken into the cell, material is fed to the cell. The promotors and frothers are added. Agitations are given and air is bubbled in the form of fine bubbles. Air-avid particles due to reduction in their effective density, will rise to the surface and be held in the froth before they are discharged from the overflow. Hydrophilic particles will sink to the bottom and removed from the discharge for tailings.

SEPARATION OF SOLID PARTICLES BASED ON ELECTRICAL AND MAGNETIC PROPERTIES

Electrostatic Separation

Principle : If one or more of the materials of a granular mixture can acquire a surface charge on or just before entering an electrostatic field, the grains/particles of that material will be attracted towards the active electrode or repelled from it depending upon the sign of the charge on the grains/particles.

- Electrostatic separation is a method of separation of solid particles based on the differential attraction or repulsion of charged particles under the influence of an electric field. Basically, the difference in electrical properties of different materials is responsible for such a separation.
- Charging of particles is an essential step in this separation. Solid particles can receive a surface charge by any one of the following methods :
  - (i) Contact electrification.
  - (ii) Electrification by conductive induction.
  - (iii) Electrification by bombardment.
- Electrification by conductive induction : When an uncharged solid particle is placed on a grounded conductor in the presence of an electric field (i.e., when it comes in contact with a charged surface), the particle will rapidly acquire a surface charge by induction. A conductive particle acquires the same charge as the grounded conductor (it becomes charged to the same potential as the grounded conductor within a very short period of time) through its contact with the conductor while a dielectric particle is polarised and thus no net charge is generated on it. As a consequence of this induction, the conducting particle will be repelled by the surface/grounded conductor, while the dielectric particle will be unaffected. This method is used for making a finite separation between relative conductors and non-conductors.

Electrostatic Separator

- Electrostatic separation depends on differences in the electrical properties (conductivity) of the materials to be treated.
- The electrostatic separator shown in Fig. 4.10 consists of a grounded rotor/rotating drum, a hopper for feeding the solids, an active electrode, situated/placed at a small distance from the drum and collecting bins.

- The solids to be separated are fed on to a rotating drum, either charged or grounded, from a hopper. The conductive particles in a very short time will assume the potential of the rotating drum, which is opposite to that of an active electrode and hence, they get attracted towards the active electrode. The non-conductive material is repelled by the electrode and attracted by the drum. The non-conductive material falls down straight under the influence of gravity and is collected in a separate bin.

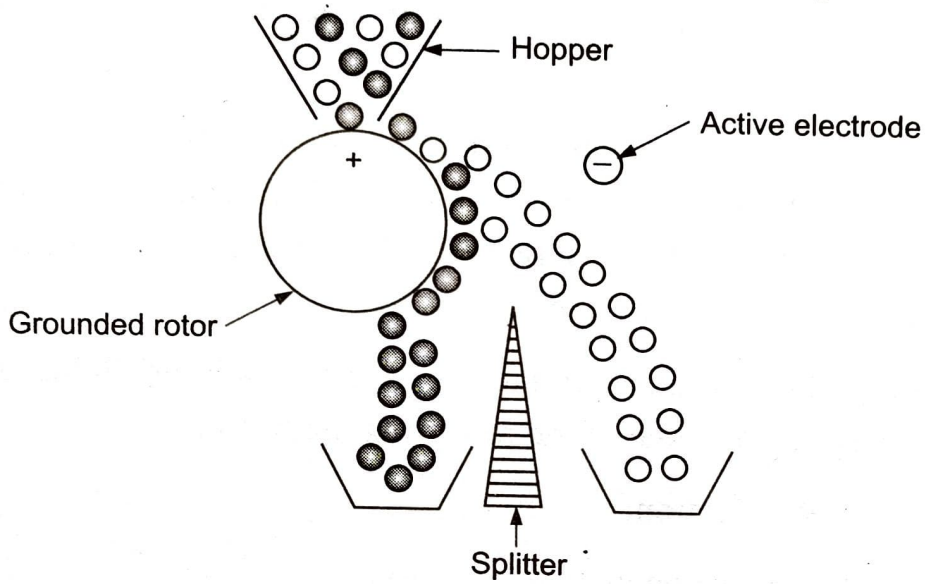


Fig. 4.10 : Electrostatic separator (separation by conductive induction)

Separation of Solid Particles based on Magnetic Properties

- Magnetic separation is a method of separating solid particles by means of a magnetic field. In this method, materials having different magnetic attractability are separated by passing them through a magnetic field. The difference in magnetic properties of different materials is responsible for such a separation.
- Solids are classified as (i) diamagnetic solids – which when placed in a magnetic field are repelled by it and (ii) paramagnetic solids – which when placed in a magnetic field are attracted by the magnetic field. Therefore, when a mixture of above solids is subjected to/is passed through a magnetic field, magnetic solids are attracted towards it and non-magnetic solids are repelled and collected in separate bins.
- Magnetic separators are employed for tramp-iron removal (in this case they are called eliminators) and concentration (concentrators).

  (i) Magnetic pulleys and (ii) Magnetic drums.
- Tramp-iron magnetic separators are used for the removal of small quantities of magnetic material - tramp iron from the charge/feed to a size reduction machine (e.g. crusher or pulveriser) in order to protect the size reduction machine. Iron coarser than 1/8" (3.125 mm) is usually termed as tramp iron.

Magnetic Head Pulley

- A magnetic pulley/magnetised pulley is used for the removal of tramp-iron from the products handled on a belt conveyor.
- Magnetic pulleys (either electromagnetic or permanent-magnetic) having a diameter upto 1500 mm and a width upto 1500 mm are available. The belt speed ranges from 53 m/min for a pulley of diameter of 300 mm to 150 m/min for a pulley of 1500 mm diameter.
- A magnetic pulley is incorporated in a belt conveyor (carrying the charge/feed to a machine/equipment) at the discharge end. As the material is conveyed over this pulley, the magnetically inert material/non-magnetic material drops-off the belt (or is discharged from the belt) in a normal manner, whereas the magnetic material adheres to the belt and falls off from the underside where the belt loses contact with the pulley (i.e., when the belt leaves the magnetic field of the pulley).
- The material to be separated must be supplied in the form of a thin sheet/layer in order to subject all the particles to a magnetic field of the same intensity (power is applied to the magnetic pulley).

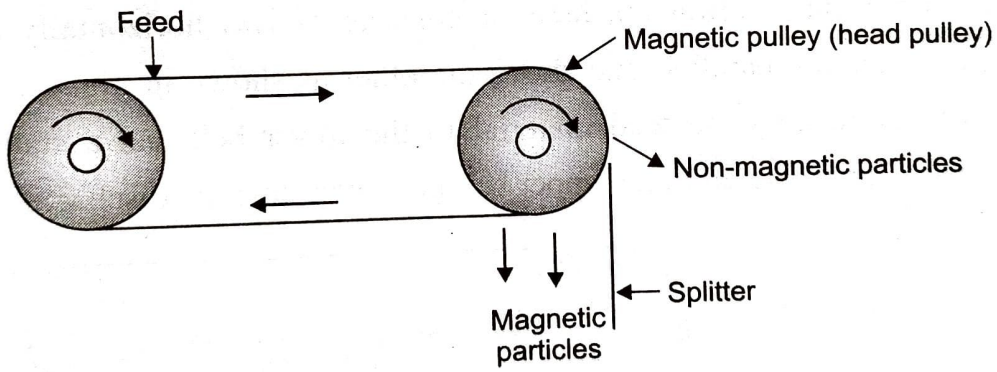


Fig. 4.11 : Magnetic head pulley

Magnetic Drum Separator

- A magnetic drum separator (Fig. 4.12) consists of a rotating drum incorporating stationary magnet assembly. The magnet arc covers approximately 165 degrees towards the discharge side of the drum. The feed is admitted at the top and is allowed to fall on the rotating drum. The non-magnetic material is discharged in the normal manner, while the magnetic material adheres to the drum and falls off the underside when the drum loses the contact of the magnet assembly.

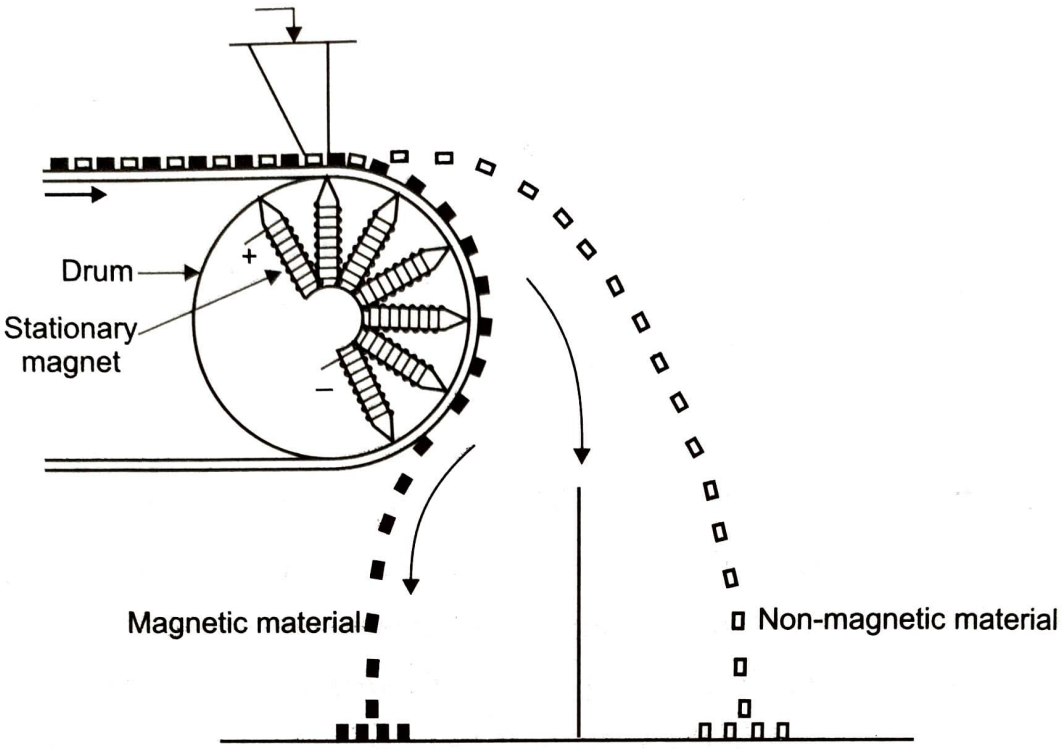


Fig. 4.12 : Magnetic drum separator

Ball-Norton Type Separator (Magnetic separators as concentrators)

- A typical concentrator used for separating magnetic ores from the associated mineral matter is the Ball-Norton machine. It consists of two horizontally staggered belt conveyors running parallel, one above the other as shown in Fig. 4.13. A hopper is provided for feeding the feed material to the lower belt and a stationary magnet assembly is incorporated in the upper belt conveyor near the discharge end.

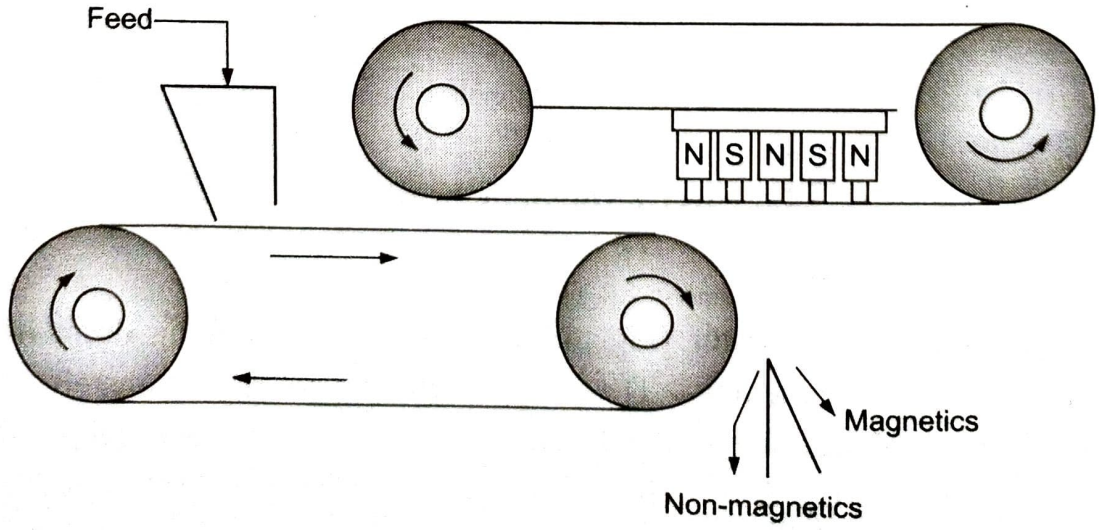


Fig. 4.13 : Ball-Norton magnetic separator

- The material to be separated is fed to the lower belt in the form of a thin sheet and is conveyed under the second belt where it is subjected to a magnetic field. The non-magnetic material is discharged in the normal manner, whereas the magnetic material adheres to the lower side of the upper belt and thus carried some distance away from the discharge point of non-magnetic materials. It ultimately drops-off the belt in a separate compartment when it leaves the magnetic field, i.e., when the belt loses the contact of the magnet assembly. In this way the magnetic material is separated from the non-magnetic material.

Important Points

- *Classification is a method of separating solid particles into fractions based upon/according to their terminal falling/settling velocities.*
- Classification devices include gravity settling tank, cone classifier, rake classifier, double cone classifier and spiral classifier.
- A cyclone/cyclone separator is essentially a settling chamber in which the gravitational separating force is replaced by a much stronger centrifugal separating force (to increase the settling rate).
- A **jig** is a mechanical device used for the separation of materials of different specific gravities by pulsating a stream of liquid (usually water) flowing through a bed of materials resting on a screen.
- Jigging is a method of separating materials of different specific gravities by the pulsation of a stream of liquid (water) flowing through a bed of materials resting on a screen.
- Flotation refers to *an operation in which one solid is separated from another by floating one of them at or on the liquid surface.*
- Separation by froth flotation depends on differences in the surface properties of the materials treated.
- Electrostatic separation depends on differences in the electrical properties of the materials treated.
- Magnetic separation is a method of separating solid particles by means of a magnetic field. The difference in magnetic properties of different materials is responsible for such a separation.

Practice Questions

1. Define magnetic separation.
2. Define classification/wet classification.
3. Define electrostatic separation.
4. Draw a neat sketch of jig and explain its construction.
5. Draw a neat sketch of Drum separator for magnetic separation.
6. State the principle of froth flotation.
7. Explain in brief the construction and working of Ball-Norton magnetic separator.
8. Explain in brief rake classifier with a neat sketch.
9. Draw a neat sketch of cyclone used for dust collection.

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