NATIONAL INSTITUTE OF TECHNOLOGY

JAMSHEDPUR

Metallurgical and Materials Engineering

SUBJECT: Principle of Extractive Metallurgy

COURSE CODE: MM1403

ASSIGNMENT

TOPIC: Classification, Dry and Wet Classifiers

GROUP MEMBERS

ANSHU KUMAR (2019UGMM006)

PRITHU JAYASWAL (2019UGMM036)

SATYAM SAURABH (2019UGMM090)

INTRODUCTION

Extractive metallurgy is a branch of metallurgical engineering wherein process and methods of extraction of metals from their natural mineral deposits are studied. Extractive metallurgy includes mineral processing, hydrometallurgy, pyrometallurgy, and electro metallurgy processes to separate commercially valuable metals from their ores. Mineral Processing plays a major role in extractive metallurgy.

In the field of extractive metallurgy, mineral processing, also known as ore dressing, is the process of mechanically separating the grains of ore minerals from the gangue minerals, to produce a concentrate (enriched portion) containing most of the ore minerals and a tailing (discard) containing the bulk of the gangue minerals or it is the process of separating commercially valuable minerals from their ores. Ore dressing is also called as beneficiation. It is a primary stage in the extraction of metal from ore in which as much gangue is removed and the ore is prepared for smelting, refining etc. It is also called as concentration of ores, washing of ores, reduction ores etc.

CLASSIFICATION

Classification is a method of separating mixtures of minerals into two or more products on the basis of the velocity with which the particles fall through a fluid medium. The carrying fluid can be liquid or a gas. In mineral processing, this fluid is usually water.

Classifiers are nearly always used to close the final stage of grinding and so strongly influence the performance of these circuits since the velocity of particles in a fluid medium is dependent not only on the size, but also on the specific gravity and shape of the particles, the principles of classification are also important in mineral separations utilizing gravity concentrators. In classifiers, use is made of the different rates of movement of particles of different sizes and densities suspended in a fluid and differentially affected by imposed forces such as gravity and centrifugal fields, by making suitable arrangements to collect the different fractions as they move to different regions.

Based on their separation principles, classifiers are classified into two major types.

- **Wet Classifiers**
- **Dry Classifiers**

Wet classification with hydro-cyclones using separation by centrifugal force typically covers the size range of 10 micrometers to 100 micrometers while wet classification with spiral classifiers using separation by gravity typical covers the size range of 100 micrometers to 1000 micrometers. Dry classification using separation centrifugal force typically covers the range of 5 micrometers to 150 micrometers.

PRINCIPLES OF CLASSIFICATION

1. **Force Balance**

When a solid particle falls freely in a vacuum, there is no resistance to the particle motion. Therefore, if it is subjected to a constant acceleration such as, gravity its velocity increases indefinitely independent of size and density.

In a viscous medium, such as air or water, there is resistance to this movement and this resistance increases with velocity. When equilibrium is reached between the gravitational force and the resistant force from the fluid, the body reaches its terminal velocity and therefore falls at a uniform rate.

The nature of the resistance, or drag force, depends on the velocity of the descent. Effectively, all resistance to motion is due to the shear forces, or the viscosity of the fluid, and is hence called *viscous resistance*. At high velocities the main resistance is due to the displacement of the fluid by the body with the viscous resistance being relatively small, this is known as *turbulent resistance*. Whether viscous or turbulent resistance dominates, the acceleration of particles in a fluid rapidly decreases and the terminal velocity is reached quickly.

A particle accelerates according to Newton's well- known equation i.e.

$$\sum \mathbf{F} = \mathbf{ma}$$

here mass is a combination of particle's size and density is a factor of the particle's acceleration.

The classification process involves the balancing of the accelerating (gravitational, centrifugal, etc.) and opposing (drag, etc.) forces acting upon particles, so that the resulting net force has a different direction for fine and coarse particles. Classifiers are designed and operated so that the absolute velocities, resulting from the total net force, cause particles to be carried into separable products.

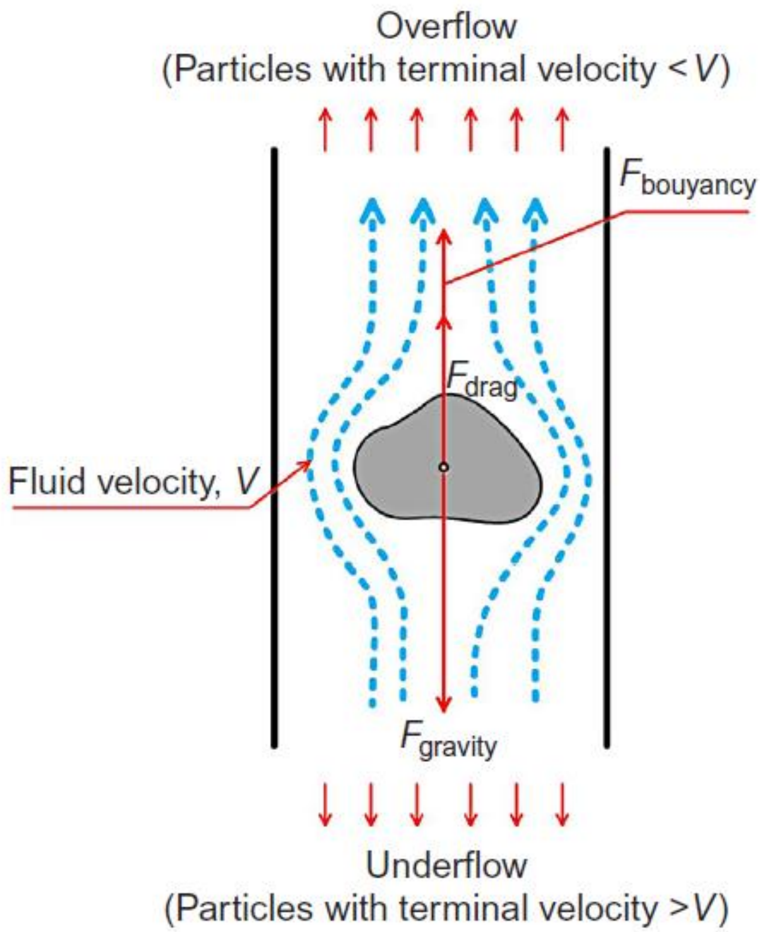


Fig: Balance of forces on a particle in sorting column

An example of a classifier is a *sorting column,* in which a fluid is rising at a uniform rate (as shown in fig). Particles introduced into the sorting column either sink or rise according to whether their terminal velocities, a result of the force, are greater or smaller than the upward velocity of the fluid. The sorting column therefore separates the feed into two products – an overflow consisting of particles with terminal velocities smaller than the velocity of the fluid and an underflow or spigot product containing particles with terminal velocities greater than the rising velocity.

2. ***Free Settling***

Free settling refers to the sinking of particles in a volume of fluid which is large with respect to the total volume of particles, hence particle - particle contact is negligible. For well dispersed pulps, free settling dominates when the percentage by weight of solids is less than about 15%.

Consider a spherical particle of diameter d and density ρ_f falling under gravity in a viscous fluid of density ρ_s under free-settling conditions, that is, ideally in a fluid of infinite size. The particle is acted upon by three forces: **a gravitational force** acting downward (taken as positive direction), an upward **buoyant force** due to the displaced fluid and a **drag force** D acting upward.
The equation of motion of the particle is therefore:

$$\sum F = ma$$

$$F_{Gravity} - F_{Buoyancy} - F_{Drag} = m\frac{dx}{dt}$$

$$mg - m'g - D = m\frac{dx}{dt}$$

where m is the mass of the particle, m' the mass of the displaced fluid, x the particle velocity, and g the acceleration due to gravity. When terminal velocity is reached, acceleration (dx/dt) is equal to zero and hence

$$D = g\,(m - m')$$

Therefore, using the volume and density of a sphere:

$$D = \left(\frac{\pi}{6}\right) g\, d^3\, (\rho_s - \rho_f) \quad \text{--------- (i)}$$

Stokes assumed that the drag force on a spherical particle was entirely due to viscous resistance and deduced the expression:

$$\boldsymbol{D = 3\pi d\eta v}$$

Here η is the fluid viscosity and v is the terminal velocity. Equating above two equation we get terminal velocity;

$$v = \frac{g\, d^2\, (\rho_s - \rho_f)}{18\eta}$$

This expression is known as <u>Stokes' law</u>.

Newton assumed that the drag force was entirely due to turbulent resistance and deduced;

$$D = 0.055\, \pi\, d^2 v^2\, \rho_f$$

Equating this with equation (i) give;

$$v = \sqrt{\frac{3\, g\, d(\rho_s - \rho_f)}{\rho_f}} \;;$$

This is the <u>Newton's Law for Turbulent Resistance.</u>

The range for which Stokes' law and Newton's law are valid is determined by the dimensionless Reynolds number. For Reynolds number below 1, Stokes' law is applicable and for Reynolds number over 1000 Newton's law is applicable. But there is an intermediate range of Reynolds number which corresponds to the range in which most wet classification is performed in which neither law fits experimental data. For these intermediate particles' sizes:

Stokes' law can be simplified to

$$v = k_1\, d^2\, (\rho_s - \rho_f)$$

And Newton's law can be simplified to

$$v = k_2\sqrt{d(\rho_s - \rho_{f})}$$

Where k_1 and k_2 are constants and $(\rho_s - \rho_f)$ is known as the effective density of a particle of densityρ_s in a fluid of densityρ_f.

Effect of density on Separation Efficiency

The aforementioned laws show that the terminal velocity of a particle in a particular fluid is a function of the particle size and density. It can be concluded that

***1**. If two particles have the same density, then the particle with the larger diameter has the higher terminal velocity.*

***2**. If two particles have the same diameter, then the heavier (higher density) particle has the higher terminal velocity.*

Most industrial classification devices will contain particles with varying densities, particles will not be classified based on size alone. Consider two mineral particles of densities ρ_a and ρ_b and diameters d_a and d_b respectively, falling in a fluid of density ρ_f at exactly the same settling rate (terminal velocity).

Hence, from Stokes' law for fine particles:

$$\frac{d_a}{d_b} = \left(\frac{\rho_b - \rho_f}{\rho_a - \rho_f}\right)^{1/2}$$

This expression is known as ***<u>the free – settling ratio</u>*** of the two minerals, that is, the ratio of particle size required for the two minerals to fall at equal rates.

Similarly, from ***Newton's law*** the free settling ratio of large particles is:

$$\frac{d_a}{d_b} = \frac{\rho_b - \rho_f}{\rho_a - \rho_f}$$

<u>The general expression for free-settling ratio can be deduced from above two equations as:</u>

$$\frac{d_a}{d_b} = \left(\frac{\rho_b - \rho_f}{\rho_a - \rho_f}\right)^n$$

Where n = 0.5 for small particles obeying Stokes' law and n = 1 for large particles obeying Newton's law. The value of n lies in the range of 0.5 – 1 for particles in the intermediate size range of 50 µm to 0.5 cm.

3. <u>Hindered Settling</u>

As the proportion of solids in the pulp increases above 15%, which is common in almost all mineral classification units, the effect of particle-particle contact becomes more apparent and the falling rate of the particles begins to decrease. The system begins to behave as a heavy liquid whose density is that of the pulp rather than that of the carrier liquid; hindered-settling conditions now prevail. Because of the high density and viscosity of the slurry through which a particle must fall, in a separation by hindered settling *the resistance to fall is mainly due to the turbulence created* and a modified form of Newton's law can be used to determine the approximate falling rate of the particles, in which ρ_p is the pulp density:

$$v = \boldsymbol{k_2\sqrt{d(\rho_s - \rho_p)}}$$

When considering **hindered settling**, the lower the density of the particle, the greater is the effect of the reduction of the effective density $(\rho_s - \rho_p)$. This then leads to a greater reduction in falling velocity. Similarly, the larger the particle, the greater is the reduction in falling rate as the pulp density increases. This is important in classifier design; in effect, hindered-settling reduces the effect of size, while increasing the effect of density on classification.

The *hindered- settling ratio* can be derived from terminal velocity of hindered settling:

$$\boldsymbol{\frac{d_a}{d_b} = \frac{\rho_b - \rho_p}{\rho_a - \rho_p}}$$

The hindered-settling ratio is always greater than the free-settling ratio, and the denser the pulp, the greater is the ratio of the diameter of equal settling particles.
Hindered-settling classifiers are used to increase the effect of density on the separation, whereas free-settling classifiers use relatively dilute suspensions to increase the effect of size on the separation.

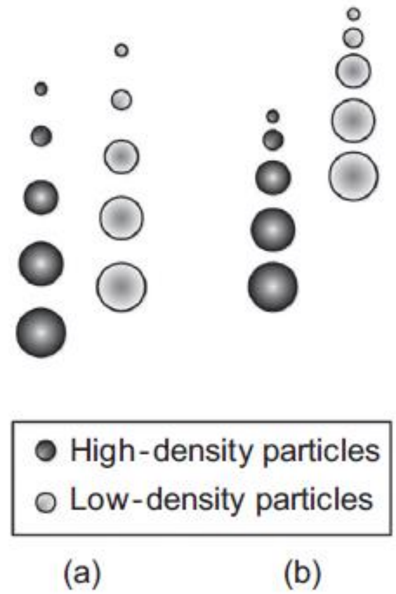


Fig: Classification by: (a) free settling and (b) hindered settling

As the pulp density increases, a point is reached where each mineral particle is covered only with a thin film of water. This condition is known as a ***quicksand***, and because of surface tension, the mixture is a perfect suspension and does not tend to separate. The solids are in a condition of ***full teeter***, which means that each grain is free to move, but is unable to do so without colliding with other grains and as a result stays in place. The mass acts as a viscous liquid and can be penetrated by solids with a higher specific gravity than that of the mass, which will then move at a velocity impeded by the viscosity the mass.

WET CLASSIFIERS

Wet classifiers are based on the principle that separation of coarse particles from fine particles is by **liquid fluidization**.

The coarse particles move faster than fine particles at equal density and high-density particles move faster than low density particles at equal size.

Basically they work according to the principle that the particles are suspended in water which has a slight upward movement relative to the particles. Particles below a certain size and density are carried away with the water-flow, whereas the coarser and heavier particles settle.

Further movement of the particle in the fluid can be either free movement or hindered movement. If a particle has no interference from other particles it moves faster than a particle surrounded by other particles due to increased density and viscosity of the slurry. This is called free and hindered movement respectively.

***Different types of Wet Classifiers*:**

1. Gravitational Classifier

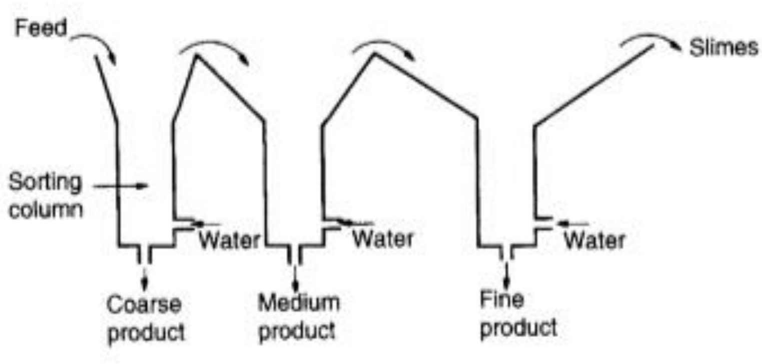
- **(i)** Hydraulic Classifiers
- **(ii)** Sedimentation or Horizontal Current Classifiers
  - **(a)** Settling Cone Classifiers
  - **(b)** Mechanical Classifiers
    - **(1)** Rake Classifiers
    - **(2)** Spiral Classifiers

2. Hydro cyclone Classifier

Hydraulic Classifiers

The principle of the gravitational hydraulic classifiers is that a vertical rising current of water is used to classify particles by gravity. A vertical current is established by an incoming feed of water and the finer particles follow the overflow

These are characterized by the use of water additional to that of the feed pulp, introduced so that its direction of flow opposes that of the settling particles. They normally consist of a series of sorting columns through each of which a vertical current of water is rising and particles are settling out. The rising currents are graded from a relatively high velocity in the first sorting column, to a relatively low velocity in the last, so that a series of spigot products can be obtained, with the coarser, denser particles in the first spigot and the fine particles in the latter spigots. Very fine slimes overflow the final sorting column of the classifier. The size of each successive vessel is increased, partly because the amount of liquid to be handled includes all the water used for classifying in the previous vessels and partly because it is desired to reduce, in stages, the surface velocity of the fluid flowing from one vessel to the next.



Principle of hydraulic classifier

Sedimentation or Horizontal Current Classifiers

If the fluid movement is horizontal and forms an angle with the particle trajectory, the classification is called sedimentation or horizontal current classifiers.

Settling Cone Classifier (Non-Mechanical Classifier):

As the simplest form of classifier, there is a little attempt to do more than separate the solids from the liquid, and as such they are sometimes used as dewatering units in small scale operations.

They are often used in the aggregate industry to de-slime coarse sand products.

The pulp is fed into the tank as a distributed stream at F, with the spigot discharge S initially closed. When the tank is full, overflow of water and slimes commences, and a bed of settled sand builds up until it reaches the level shown. If the spigot valve is now opened and sand discharge maintained at a rate equal to that of the input, classification by horizontal current action takes place radially across zone D from the feed cylinder B to the overflow lip. The main difficulty in operation of such a device is the balancing of the sand discharge and deposition; it is virtually impossible to maintain a regular discharge of sand through an open pipe under the influence of gravity.

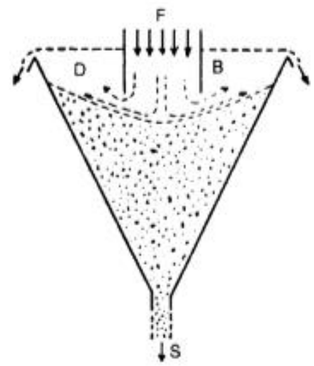
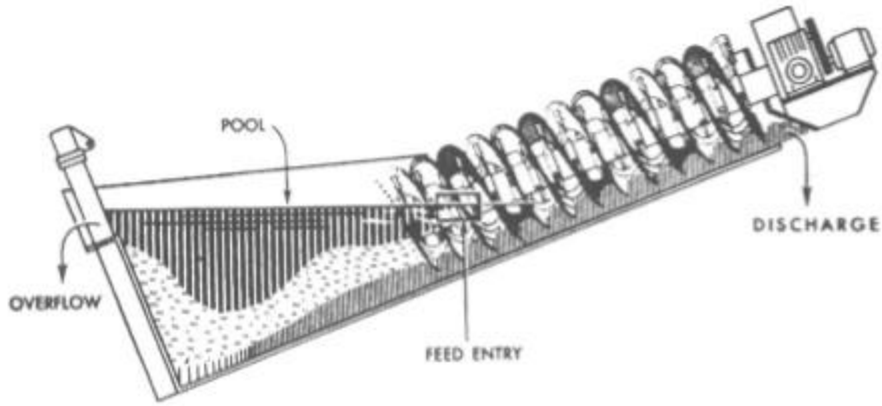


Figure 9.8 Settling cone operation

MECHANICAL CLASSIFIER

Several forms of classifier exist in which the material of lower settling velocity is carried away in a liquid overflow, and the material of higher settling velocity is deposited on the bottom of the equipment and is dragged upwards against the flow of liquid by some mechanical means.

The pulp feed is introduced into the inclined trough and forms a settling pool in which particles of high falling velocity quickly fall to the bottom of the trough. Above this coarse sand is a quick-sand zone where essentially hindered settling takes place. The depth and shape of this zone depends on the classifier action and on the feed pulp density. Above the quick-sand is a zone of essentially free settling material, comprising a stream of pulp flowing horizontally across the top of the quicksand zone from the feed inlet to the overflow weir, where the fines are removed. The settled sands are conveyed up the inclined trough by mechanical rakes or by a helical screw. The conveying mechanism also serves to keep fine particles in suspension in the pool by gentle agitation and when the sands leave the pool they are slowly turned over by the raking action, thus releasing entrained slimes and water, increasing the efficiency of the separation. Washing sprays are often directed on the emergent sands to wash the released slimes back into the pool.



Principle of mechanical classifier

Rake Classifier

Rake classifier is a mechanical classifier consists of a rectangular tank with a sloping/inclined bottom. The tank is provided with movable rakes. The feed in the form of a suspension is introduced continuously near the middle of the tank. The lower end of the tank has a weir overflow from which the fines that are not settled leave with the overflow liquid. The heavy materials sink to the bottom of the tank. The rakes scrap the settled solids upwards along the bottom of the tank to the top of the tank.

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. Rake classifiers are also used for close circuit grinding.

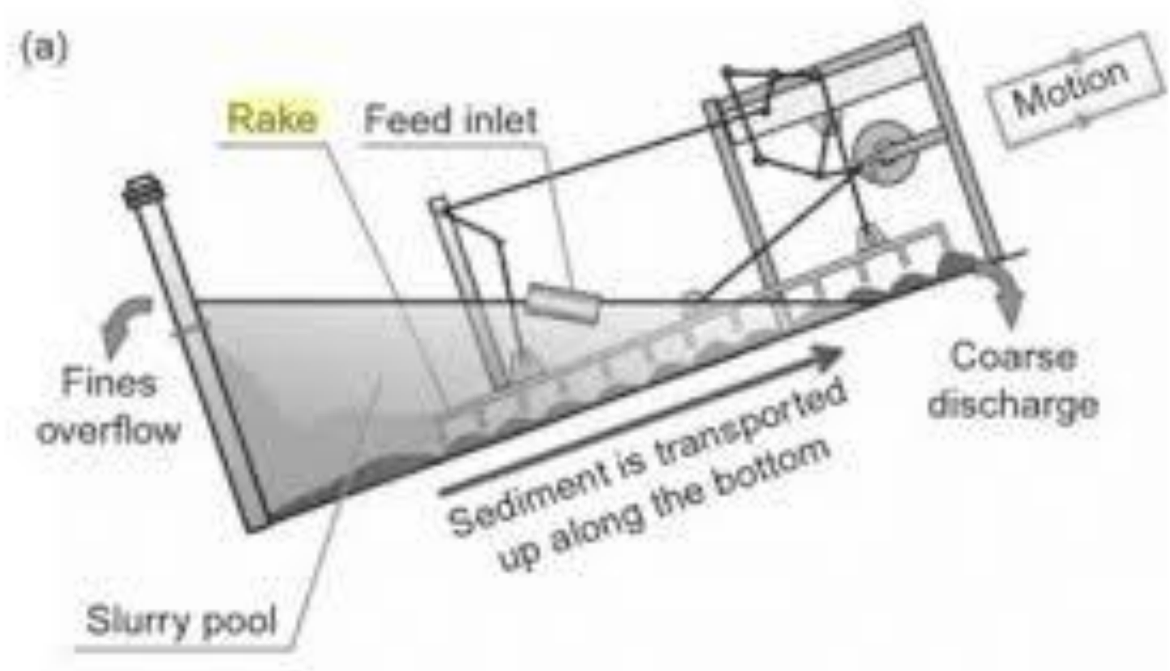
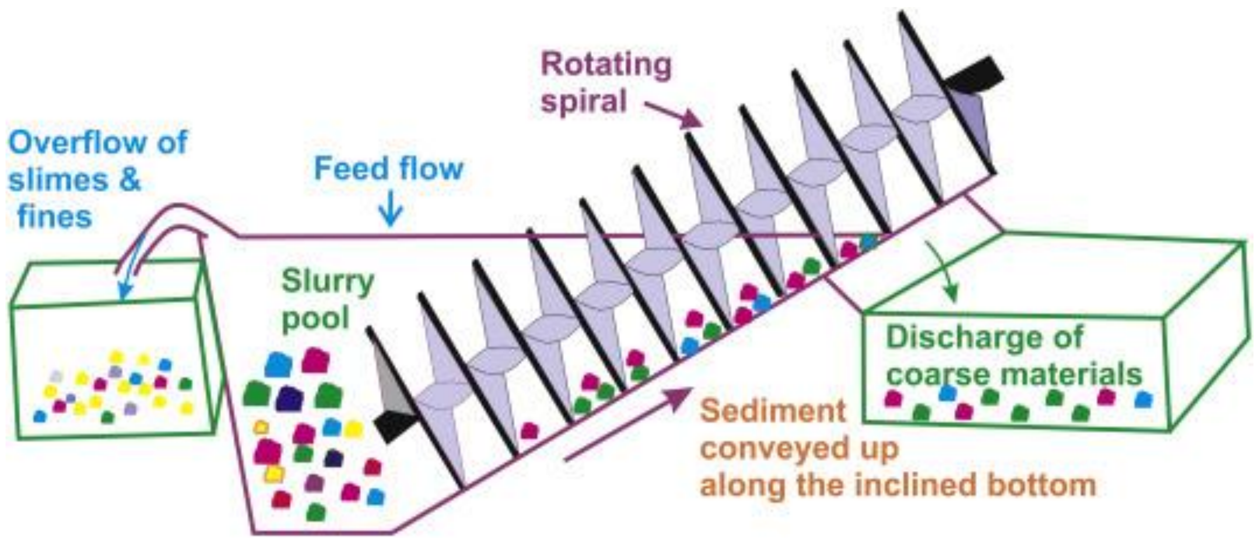


Fig: Rake Classifier

Spiral Classifier

The spiral classifier is also a mechanical classifier. It is also called as helical classifier. It uses a continuously revolving spiral to move the sands up the slope. They can be operated at steeper slopes than the rake classifier, in which the sands tend to slip back when the rakes are removed. Steeper slopes aid the drainage of sands, giving a cleaner, drier product. Agitation in the pool is less than in the rake classifier which is important in separations of very fine material. The spiral conveys or 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 at the bottom and the spiral conveyor moves the settled particles upwards along the floor of the trough (The spiral rotates in the clockwise direction from the top end, and then the sediments will move upwards).



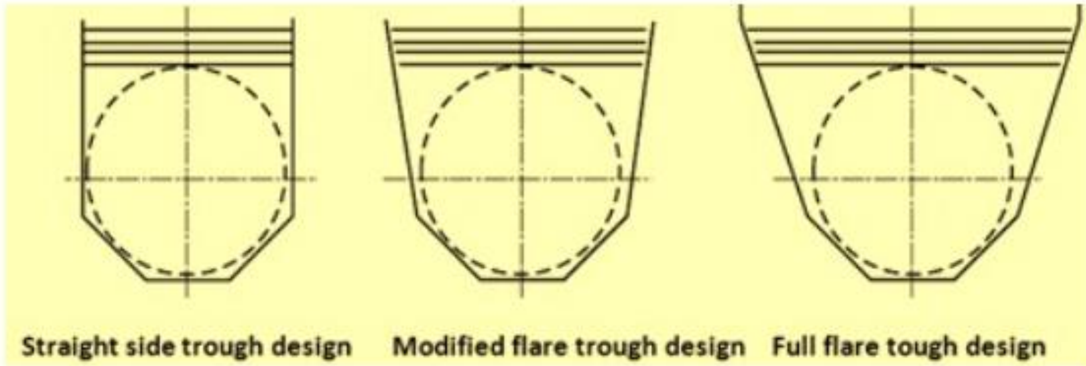
SPIRAL CLASSIFIER

Spiral Classifier Nomenclature:

SC 90 ST- 1 means 90cm spiral diameter, straight tank and 1 pitch.

Spiral can be of single pitch or double pitch. Single pitch spirals consist of one continuous spiral ribbon. The double pitch spiral has twice the raking capacity of a single pitch assembly and consists of two duplicate spiral ribbons.

AN IMPORTANT DESIGN FEATURE



TANK OPTIONS

Hydro Cyclone Classifier

This is a continuously operating classifying device that utilizes centrifugal force to accelerate the settling rate of particles in which classification is done according to size of solids (mass).

It has replaced mechanical classifiers in many applications, its advantages being simplicity and high capacity relative to its size.

A typical hydro cyclone consists of a conically shaped vessel, open at its apex, or underflow, joined to a cylindrical section, which has a tangential feed inlet. The top of the cylindrical section is closed with a plate through which passes an axially mounted overflow pipe. The pipe is extended into the body of the cyclone by a short, removable section known as the vortex finder, which prevents short-circuiting of feed directly into the overflow.

The feed is introduced under pressure through the tangential entry which imparts a swirling motion to the pulp. This generates a vortex in the cyclone, with a low-pressure zone along the vertical axis. An air core develops along the axis, normally connected to the atmosphere through the apex opening, but in part created by dissolved air coming out of solution in the zone of low pressure.

The classical theory of hydro cyclone action is that particles within the flow pattern are subjected to two opposing forces - an outward centrifugal force and an inwardly acting drag. The centrifugal force developed accelerates the settling rate of the particles thereby separating particles according to size, shape, and specific gravity. Faster settling particles move to the wall of the cyclone, where the velocity is lowest, and migrate to the apex opening. Due to the action of the drag force, the slower-settling particles move towards the zone of low pressure along the axis and are carried upward through the vortex-finder to the overflow.

The existence of an outer region of downward flow and an inner region of upward flow implies a position at which there is no vertical velocity. This applies throughout the greater part of the cyclone body, and an envelope of zero vertical velocity should exist throughout the body of the cyclone. Particles thrown outside the envelope of zero vertical velocity by the greater centrifugal force exit via the underflow, while particles swept to the center by the greater drag force leave in the overflow. Particles lying on the envelope of zero velocity are acted upon by equal centrifugal and drag forces and have an equal chance of reporting either to the underflow or overflow.

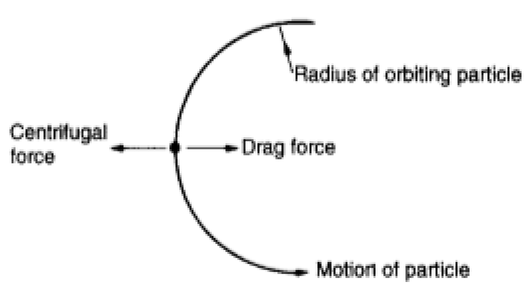


Figure 9.14 Forces acting on an orbiting particle in the hydrocyclone

Although the hydro cyclone by nature is a size controlling machine the number of applications in mineral are many such as

(i) classification in grinding circuits

(ii) dewatering and thickening

(iii) desliming and washing

(iv) enrichment of heavy minerals (dense media separation), and others.

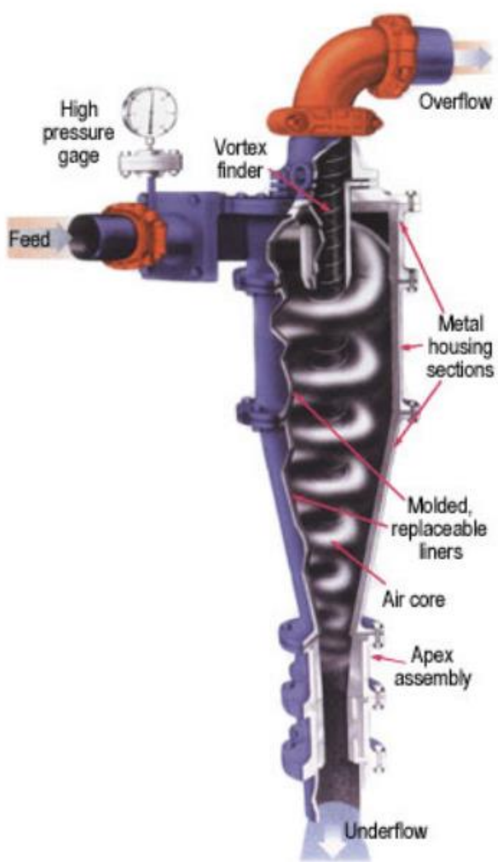


Fig: Hydro Cyclone Classifier

DRY CLASSIFIERS

Dry classifiers are based on the principle that separation is by air fluidization. Air classification is a process of separating categories of materials by way of differences in their respective aerodynamic characteristics. The aerodynamic characteristic of a particular material is primarily a function of the size, geometry, and density of the particles. The process consists of the interaction of a moving stream of air, material particles, and the gravitational force within a confined volume. In the interaction, the drag force and the gravitational force are exerted in different directions upon the material particles. The result is that material particles that have a large drag-to weight ratio are suspended in the air stream, whereas components that have a small ratio tend to settle out of the air stream. The suspended fraction conventionally is referred to as the **'air classified light fraction'** and the settled fraction is termed **'air-classified heavy fraction'**. The confined volume in which the separation takes place is called an **'air classifier'.**

The density of a material is not the only characteristic of a particle that affects the air classification process. Moisture affects the separation as a result of its influence on the density of a material particle. Air classifiers may be one of a number of designs. The three principal groups of designs are horizontal, inclined, and vertical. All three require appropriate dust collection, blower, separator, and control facilities.

AIR CLASSIFIER TYPES

(i) Static Air Classifier

1. Gravitational Classifier

2. Gravitational Inertial Classifier

3. Centrifugal Classifier

(ii) Dynamic Air Classifier

Static Air Classifier

Static air classifiers achieve accurate separations from 12 mesh size (1.4 mm) to 20 (micrometer). The static air classifiers are designed to achieve extremely accurate separations even though they contain no moving elements in the airstream. This is achieved through airflow design and use of recirculating, secondary airflow on finer separations to scrub the coarse product before it is discharged. The recirculating airflow is adjustable so the amount of undersize retained is also adjustable. This provides fine tuning of the end products so exact product specifications can be achieved. The design of the recirculating systems mean that adjustments can be done during production and results are instant.

The static design of these classifiers offers excellent wear characteristics through the use of ceramic linings whose lifetimes are measured in years, low maintenance requirements and low power consumption.

Gravitational Classifier

The gravitational classifiers are designed for coarser separations in the range of 12 mesh size (1.4 mm) to 100 mesh size (150 micrometers). The feed material is spread over the width of the classifier and drops as a continuous feed curtain through the top of the classifier. Low velocity air enters the classifier through the front inlet and is drawn through the feed curtain which is dropping in front of the angled vanes on the air outlet.

The air stream enters the feed curtain perpendicularly and draws the finer particles from the curtain of material. The air current then draws the particles up almost vertical through the vane rack. Gravitational classifiers are suitable for close grinding circuits, de-dusting of coarser feeds, reducing a high feed loading rate to a finer classifier and it can also be used as a density separator if the specific gravity difference of the product to waste ratio is greater than 5. Power requirements are extremely low; most energy lost is due to the change of direction of the air stream as it is exhausted through the vanes.

Operating Principles of Gravitational Classifier:

Feed material is dropped in a continuous feed curtain and enters the classifier at the top of the unit (1). Low velocity air enters the classifier at inlet (2) and is forced through the feed curtain (3) which is dropping in front of the air outlet (4) provided with widely spaced vanes (5). The air stream enters the feed curtain perpendicularly, but is changed to an almost parallel, but reverse, direction to the feed curtain as it passes through the vane. Each particle entering the classifier has a gravitational force (F_g) proportional to its mass, which in turn is proportional to the cube of its diameter. The particle is also subjected to a drag force (F_d) proportional to the square of its diameter, created by the air flow through the feed curtain. As the particle is influenced by the drag force (F_d) and changes direction, it is subjected to a small, centrifugal force (F_c) proportional to its mass, directly opposing drag force (F_d). Under set conditions, the resultant force (R), acting on a particular particle diameter (K) referred to as the cut point, will be of a magnitude and direction such that the particle will either be swept through the vanes by the air stream or impinge on the vanes, throwing it back into the feed curtain. The resultant force (r) on particles larger than (K) is in a direction at small variance with the gravitational force (F_g). These particles will either impinge on the vanes and be knocked out or will fall directly into the coarse discharge outlet. (6) Smaller particles will have a resultant force (R) almost parallel to the drag force (F_d), permitting them to be swept through the vanes and collected by a filter.

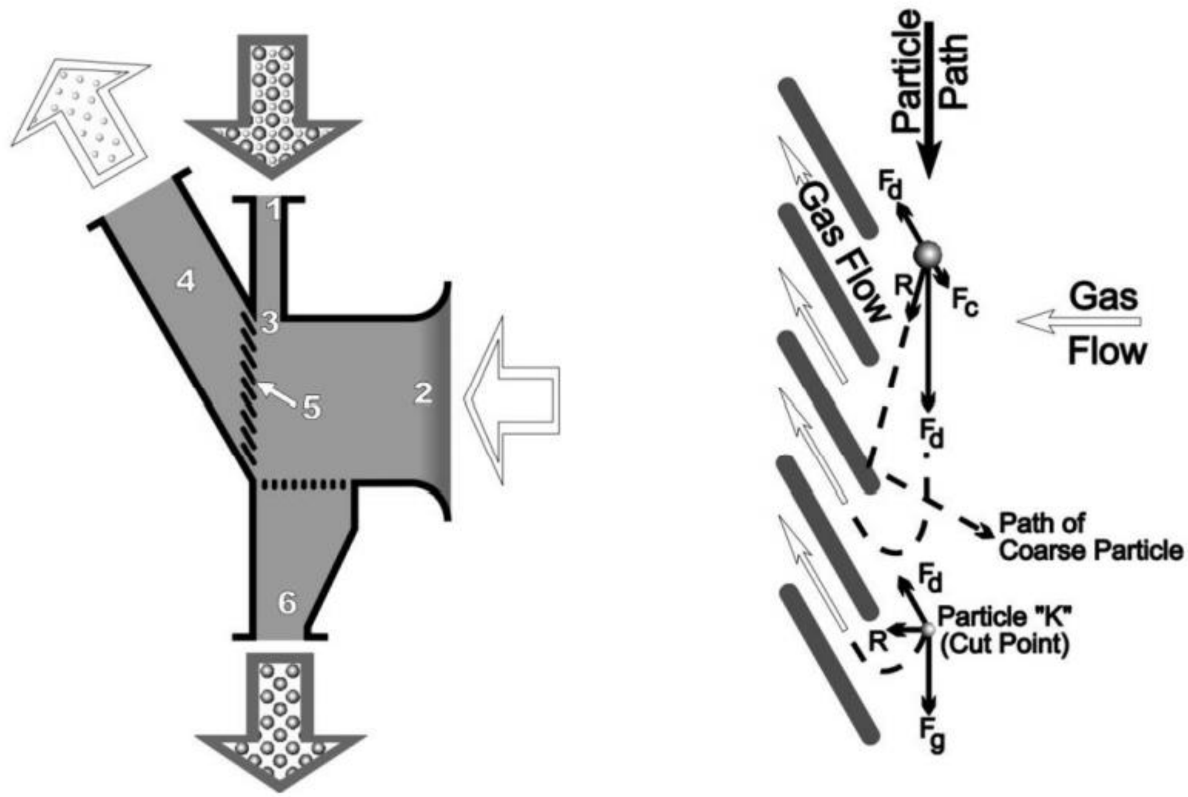


Fig: Operating Principles of Gravitational classifier

Gravitational Inertial Classifier

Gravitational inertial classifiers combine gravitational, inertial, centrifugal and aerodynamic forces to achieve separations from 50 mesh size (300 micrometer) to 230 mesh size (63 micrometer). The feed material is spread over the width of the classifier and drops as a continuous feed curtain through the top of the classifier. The primary air also enters the top of the classifier in a downward direction with the feed. The air is drawn through the feed curtain and then through a 120-degree change in direction and exits through the vanes carrying undersize particles with it. The coarser particles that are not drawn away drop down to where a secondary air flow is drawn into the classifier. The coarse particle curtain is scrubbed by this secondary air with the finer fraction being drawn by the secondary airflow back into the primary feed curtain. By making simple adjustments to the secondary air damper the end products can be modified. As there are no moving parts within the material flow stream significantly reduces maintenance requirements. Use of ceramic lining throughout the classifier gives impressive wear resistance.

Operating Principles of Gravitational Inertial Classifier

Air or gas-entrained feed material enters the classifier primary air inlet (1). Mechanically fed material is introduced at point (1A).

The curtain of feed material drops in front of the air outlet (2) which is provided with widely-spaced vanes (3) almost reversing the air flow introduced through the primary air inlet (1). Prior to passing through the vanes, the friction of the relatively high velocity causes the particles to flow in a counterclockwise current (eddy) (5) in the chamber (4).The eddy is reinforced by air entering through the secondary air inlet (6) located just above the coarse discharge outlet (7).

Each particle entering the classifier has a gravitational force (F_g) proportional to its mass, which is in turn proportional to the cube of its diameter. As the particle is introduced into the classifier primary air stream, it is further subjected to an inertial force (F_i) also proportional to its mass.

Because the air stream flows in a downward direction, the inertial and gravitational forces (F_i) and (F_g) complement each other. As it passes through the vanes, the air stream changes direction, exerting a drag force (F_d) proportional to the diameter of the particle and approximately opposite in direction to the gravitational and inertial forces. As the particle is influenced by the drag force (F_d) and changes direction, it is subjected to a centrifugal force (F_c) proportional to its mass, which directly opposes the drag force (F_d).

Under design condition, the resultant force (R) acting on a particular particle diameter (K) (cut point) is of a magnitude and direction to cause the particle to either be swept through the vanes or be thrown back into the feed curtain. The resultant force (R) on particles larger than (K) is in a direction at small variance with the gravitational-inertial forces. The Review report on dry and wet classification of filler materials for concrete 19 particles will either impinge on the vanes and be knocked out or fall directly into the coarse discharge (7).

The eddy current (5) flowing downward, parallel to the place formed by the vanes, provides a moving wall containing the curtain of feed material in the classifying zone without the detrimental frictional drag effects of a solid wall.

The particles not swept through the vanes fall onto an inclined baffle plate (8) located at the bottom of the air outlet (2) directly beneath the primary air inlet (1). The coarse product is scrubbed by the secondary air as it slides off into the coarse discharge outlet. Secondary air flow dislodges any fines adhering to coarser particles. They join the stray fine particles entrained by the eddy current and are returned to the classifier inlet point (9) and reintroduced into the classifying zone (10).

The cut point is controlled by the air velocity through the vanes, which determines the magnitude of drag force (F_d) and the primary air inlet velocity which determines inertial force (F_i). Varying cut point requirements are met by regulating the inlet velocity while keeping the total air volume, i.e., vane velocity, constant.

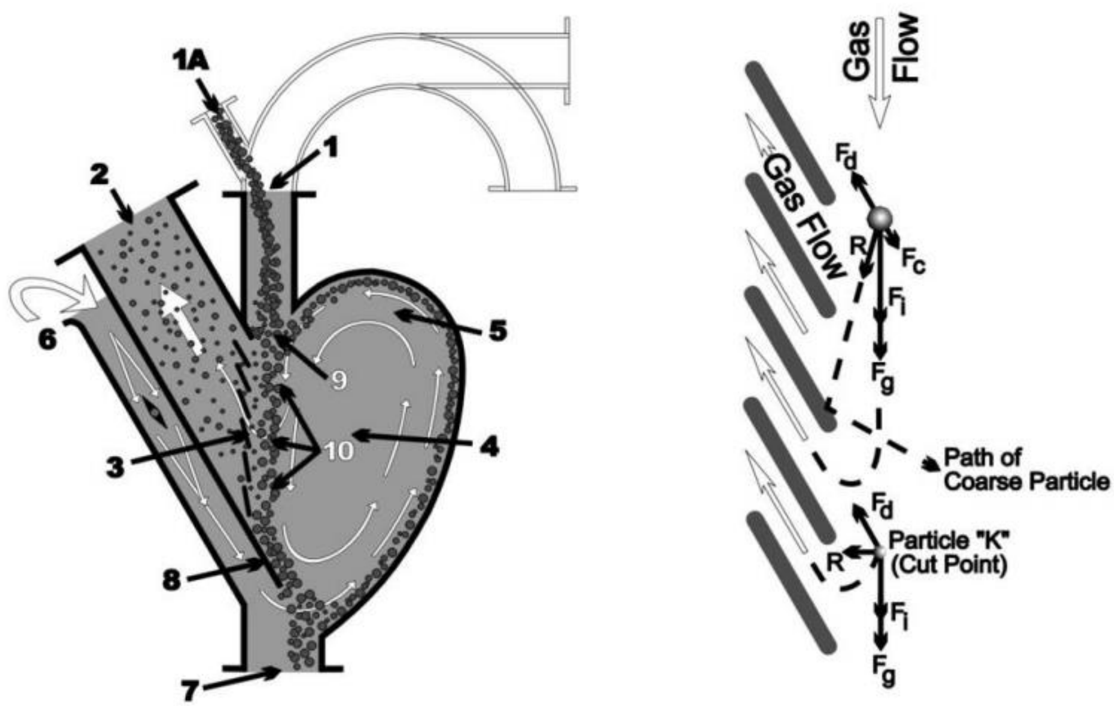


Fig: Operating Principles of Gravitational Inertial Classifier

Centrifugal Classifier

The centrifugal classifier utilizes centrifugal forces in a similar way to cyclones to induce fine particle separation. The classifier is capable of separations in the range of 140 mesh size (100 micrometer) to 800 mesh size (15 micrometer). The classifier has widespread acceptance in industrial minerals, cement and fly ash applications. It has high degree of separation accuracy and exceptionally low maintenance requirements. The classifier is used in conjunction with a dust collector and system fan. Systems can have an open or closed loop dependent on application and numerous dust collector and silo storage options.

Operating Principles of Centrifugal Classifier

Feed material and gas (usually air) enter the classifier inlet (1). The connecting duct for pneumatically conveyed material can be positioned from a vertical to a horizontal position to suit layout requirements (see dashed outline Figure). Air inlet velocity is approximately 20 meters per second, dependent upon feed material physical characteristics and cut point. Conveying velocity may be higher for pneumatically fed, open air systems, the classifier inlet is flared and the feed dropped directly into the air stream.

The sharp bend (2) behind the inlet separates feed material from the air stream by centrifugal action. The resultant "clean" air stream passes behind a baffle plate (3) against which the feed material is sliding. The air stream then crosses the curtain of feed material (4) producing an intense scrubbing action which separates fine particles from the tailings, breaks up agglomerates and subjects all particles to an equal drag force.

Gravitational force immediately precipitates any very large particles to the bottom of the classifier. Intermediate and finer particles flow with the air stream in a spiral path around the exhaust orifice (5) and are classified. The baffle plates (3, 6), the classifier outer casing (7), and side plates (8) form a flat, cylindrical classifying chamber (9) through which the air stream spirals inwardly in a two-dimensional flow.

Each particle is subjected to centrifugal force (F_c) proportional to the cube of its diameter, causing the particle to move towards the periphery of the chamber. Concurrently, the air stream is exerting a drag force (F_d) directly proportional to the diameter of the particle. Under design conditions, the centrifugal force (F_c) equals the drag force (F_d) of a particular particle diameter (K) (cut point). These two opposing forces which are in equilibrium only at cut point separate feed particles into two groups. Centrifugal force (F_c) $c$auses particles larger than cut point (greater mass) to be propelled outwardly, impinging on the peripheral walls; their velocity is slowed; gravity causes them to settle to the bottom of the classifier.

Drag force (F_d) causes particles smaller than cut point (lower mass) to be swept inwardly and discharged with the air stream through the orifice (5) where they are collected by a cyclone.

To obtain sharp separation, forces acting on cut point particle (K) must be in equilibrium through the classifying chamber assuring that every introduced particle is subjected to the same separation influence. The centrifugal classifier uniquely meets this requirement with its patented method of introducing feed material and air flow into the classifying chamber to form a controlled vortex with a constant velocity profile. Appropriate classifying chamber proportions and specialized orifice design eliminate detrimental frictional drag effect from the chamber side walls (8) without moving parts

Centrifugal classifiers separate at any desired cut point from 15 to 100 microns. The cut point is controlled by the vortex flow path steepness, the tangential velocity (V_t) and the absolute dimensions of the classifying chamber. The flow path is controlled by the ratio of exhaust orifice diameter to the classifying chamber diameter and the amount of secondary air introduced at the bottom of the unit (11). Customers' varying cut point requirements are met by regulating secondary air flow.

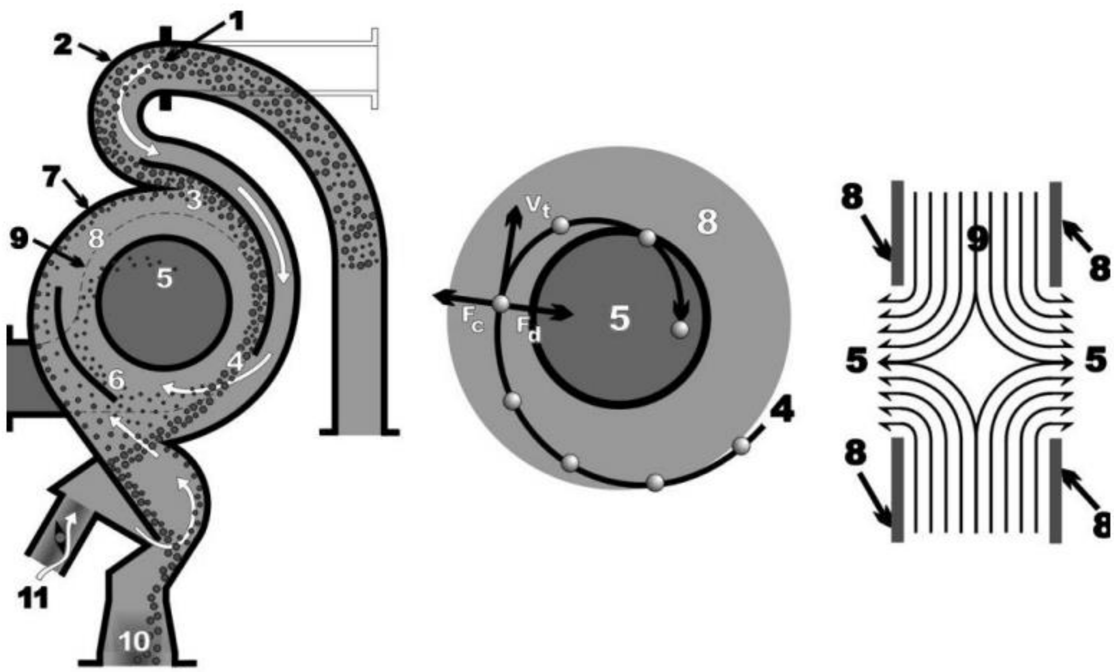


Fig: Operating Principles of Centrifugal Classifier

Dynamic Air Classifier

The dynamic air classifiers are built to suit a range of applications and systems and have been often installed on air swept mills circuits. The rotating vane air classifier separates dry, solid, homogenous particles by size. It utilizes a rotating vane to separate dry solid particles by size for separations for 35 mesh size (500 micrometer) to 325 mesh size (45 micrometer). This classifier can be integrated into a conventional closed or open dry grinding circuit. It can also be utilized in a classification only system complete with cyclone, fan, dust collector and rotary air locks. The classifier, in which the rotary type is the dominating solution for the aggregate industry, all have in common mechanical, rotating or moving parts in the air stream.

The main advantage with the dynamic rotor type air classifiers is that it has no need for a separate fan and filter assembly. This lowers the investment cost and reduces the machine assembly footprint and makes the system easier to transport in a mobile configuration.

The main disadvantage is increased wear cost because the fan blades are moving inside the dust laden air stream inside the classifying chamber. The fan blades will be exposed to relatively high abrasion and wear during operation. In non-abrasive rock types like limestone this is normally not critical but with abrasive rock types like granite or gneiss the wear very often becomes much more significant. The wear on the fan blades will also lead to changes in the aerodynamics inside the classifier and as a result the cut point will change. With this the properties of the manufactured sand will also change and consequently the properties of concrete or asphalt made with this sand.

Operating Principles:

A dynamic air classifier is based on a centrifugal-crossflow separation zone with an internal aerodynamic cycle. Usually an air vortex in the center of a chamber separates the coarser and finer particles. The centrifugal force drags the coarsest particles out to the chamber walls and down while the finer particles are forced to the middle of the chamber and up together with the air, (see Figure). For aggregate purposes the classifiers should have ceramic liners to reduce the wear.

Still there is a challenge that e.g. granitic rocks easily wear the inner walls of the machine.

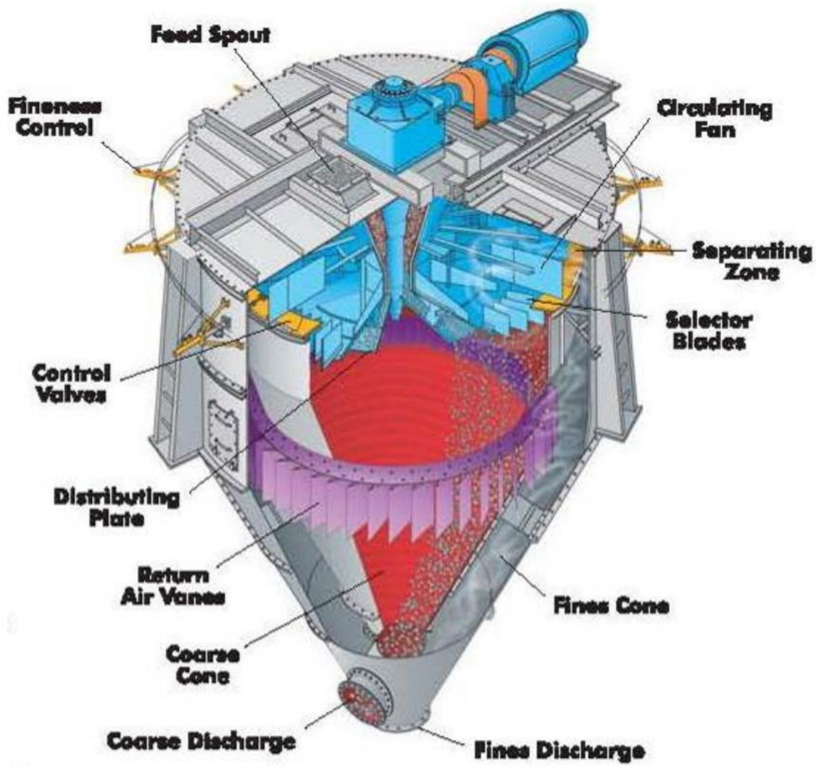


Fig: The Principle of Dynamic Rotatory Air Classifier

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