# VALUE ADDITION TO ORES THROUGH BENEFICIATION

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## INTRODUCTION

Mineral beneficiation is a process to separate the valuable minerals from the waste rock gangue. The difference of properties between the value minerals and the undesired minerals determine the method of separation. Recovery of metal values from the resources of low tenor is associated with generation of more and more quantities of waste and greater load on efficient management of these wastes and protection of environment. The mineral engineers are thus confronted with finding efficient, innovative and cost effective process and equipment for solving the problems faced by mineral industries.

Mineral processing involves a number of unit operations starting with the run of mine (ROM) ore as the initial raw material. Traditionally, the scope of mineral processing is limited to liberation of individual mineral phases and their separation from each other without altering the identity of any mineral constituents. Before separation of the individual minerals, an intimate knowledge of the mineralogical composition of the ore, their mode of association, complexity, texture and size are essential to know the optimum size of liberation. The study of mineralogy helps processing personnel in acquiring this knowledge. The liberation of valuable minerals from the gangue is accomplished by comminution i.e., the process of size reduction to the desired size. Actual separation is then effected by utilizing the difference in physical and other properties of value minerals and the gangue viz., size, shape, color, specific gravity, magnetic property, electrical conductivity, radioactivity, specific surface property like affinity or repulsion towards water etc.

## RELEVANCE OF MINERALOGY IN MINERAL PROCESSING

From mineral processing point of view, it is important to identify the ore and gangue minerals and their textural relationship. The mineralogical study helps in the modal distribution of ore and gangue which decides the grade of ore. Grain size of the minerals and their textural relationship helps in deciding the liberation size in mineral processing.

Mineral identification by optical microscopy, XRD, SEM, EPMA: For mineralogical characterization of the ores/rocks, optical microscopy is a valuable tool. The optical properties differ from mineral to mineral because their crystal structure is different and the chemical constituents of the mineral; also their relative positions in the crystal lattice sites differ. In complex systems advanced characterization techniques such as X-ray diffraction (XRD), Scanning Electron Microscopy (SEM) with micro-chemical analysis by WDS or EDS, and Electron Probe Micro-analysis (EPMA) are used. The latter techniques help in confirming the mineral phases which is very important. On the other hand, the textures and liberation characteristics are studied under optical microscopes.

Insufficient grinding may result in loss of valuable minerals in the tailings; over-grinding wastes energy and may produce slimes that are difficult to treat. The nature of the boundaries between intergrown particles will show whether or not the rupturing of larger particles during grinding is likely to occur at grain boundaries. Information regarding fractures, fissures, and porosity in the ore minerals is derived from the microscopic study.

***Study of Modal distribution :*** Modal distribution of minerals by microscopy with image analysis system or by grain counting helps in the statistical distribution of ore and gangue minerals which is directly related to the grade of ore. It also helps in the liberation studies. It can be extended to beneficiation products to find the efficiency of beneficiation

***Liberation study by microscopy :*** The liberation of ore and gangue is achieved by size reduction (through grinding). The statistical count of interlocked grains, 'ore minerals free of gangue' (liberated ore) and 'gangue minerals free of ore minerals' (liberarated gangue) gives the quantitative percentage of liberation [1]. This data is useful in deciding the extent of liberation required for a desired economy of comminution and beneficiation.

$$\text{Liberation (\%)} = \frac{100 \text{ X } \{(\text{No. of free ore minerals}) + (\text{No. of free gangue minerals})\}}{(\text{No. of free ore minerals + free gangue minerals + interlocked minerals})}$$

Table-1 : Associated ore and gangue minerals in various ore types.

| Ore-type | Ore minerals | Common gangue minerals |
|---|---|---|
| Iron ore | Martite, Hematite, magnetite, goethite | Quartz, jasper, kaoline, gibbsite, shale |
| Bauxite | Gibbsite, diaspore, boehmite | Goethite, kaoline, Ilmenite, zircon, anatase |
| Manganese | Psilomelane, pyrolusite, cryptomelane, manganite, wad | Quartz, feldspar, apatite, clay, micaceous mineral, pyroxene, barite, hematite, goethite |
| Limestone | Calcite, aragonite, dolomite | Quartz, chlorite, shale |
| Beach sand | Ilmenite, zircon, garnet, monazite, xenotime, Sillimanite | Quartz, amphibole, pyroxene, olivine, tourmaline |
| Copper (hydrothermal and porphyry type) | Chalcopyrite, chalcocite, covellite, Bornite, cuprite, malachite, azuriteTrace: U, Mo, Au | Phyllite, schist, quartz schist, chlorite, biotite, dolomite, shale, chert, quartz, feldspar |
| Lead-zinc (hydrothermal deposit) | Galena, sphalerite, cerrusite, Anglesite, hemimorphiteTrace: Ag, Au, Cd, In, Cu, Sb | Chlorite, biotite, dolomite, shale, quartz, feldspar, Barite, Pyrite, pyrrhotite, arsenopyrite, chalcopyrite, argentite |
| Chromite (magmatic deposit) | Chromitite $FeCr2O4$, Trace: Ni | Magnetite, dunite, pyroxene, plagioclase, olivine, pyroxene |
| Gold | Arseno-pyrite, native gold | Amphibole, chlorite, dolomite, shale, chert, quartz, feldspar, pyrite, chalcopyrite |

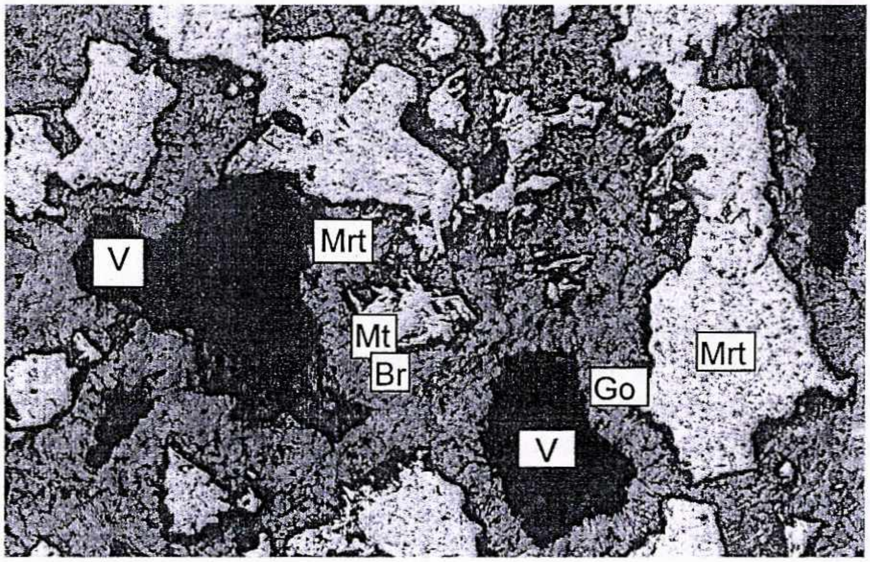


**Fig.1 :** Martite (Mrt) and microplaty hematite around which goethite (Go) is deposited in the voids (V). The longer edge of photo equals to 0.6mm.

## COMMINUTION

The process of size reduction is known as comminution. In mineral processing parlance, comminution in coarse range is known as crushing and in fine range it is called grinding. Generally, crushing is carried out in two stages, namely, primary and secondary crushing. Jaw and Gyratory type crushers are used mostly for primary crushing. Jaw crushers produce a reduction ratio of 4:1 to 9:1 while gyratory crushers produce a larger range of 3:1 to 10:1. After the primary crushing units, the secondary crushers are employed to achieve further reduction in size. Examples of secondary crushers are cone crusher, impact crusher and roll crusher. Cone crushers produce reduction ratios in the range 5:1 to 8:1. Very high reduction ratios, 20:1 to 40:1, can be achieved using hammer type impact crushers. However, roll crushers can attain ratios only in the range 2:1 to 4:1 [2].

The relationship between comminution energy absorbed per unit mass and the representative size is defined by a differential equation:

$$dE/dd_p = -kd_p^{-n} \tag{1}$$

where, E is the energy absorbed and n is an exponent whose various values have been suggested by different workers. The above equation can be solved with the initial condition that E=0 when dp=dpi (product size = parent size) to get (for n ?1) [3]:

$$E = \frac{k}{n-1}[\frac{1}{d_p^{n-1}} - \frac{1}{d_{pi}^{n-1}}] \tag{2}$$

Thus, when n = 1 (Kick's Equation):

$$E = k\ln\frac{d_{pi}}{d_p} \tag{3}$$

When n = 1.5 (Bond's Equation):

$$E = 2k[\frac{1}{d_p^{1/2}} - \frac{1}{d_{pi}^{1/2}}] \quad (4)$$

When n = 2 (Rittinger's Equation):

$$E = k[\frac{1}{d_p} - \frac{1}{d_{pi}}] \quad (5)$$

The work index of a material is calculated using Equation (4), that indicates the ease or difficulty of comminution in terms of energy requirement.

Grinding machines in the mineral industry are of tumbling mill type and are of various kinds such as ball, rod, pebble, autogeneous, semi-autogeneous, etc. Grinding action is induced by relative motion between the particles of media - the rods, balls or pebbles and the particles themselves. High compression roll mill and fluid energy mills are recent developments in comminution technology. Cascading and cataracting are two types of motion generating from the tumbling motion of the mill. When the particles move along the inner surface of the mill shell, lifted up, loses contact with the surface and travel downward in a trajectory through the empty space inside the mill resulting in an impact on contact with the inner surface again, the motion is called cataracting. This motion produces fewer amounts of fines.

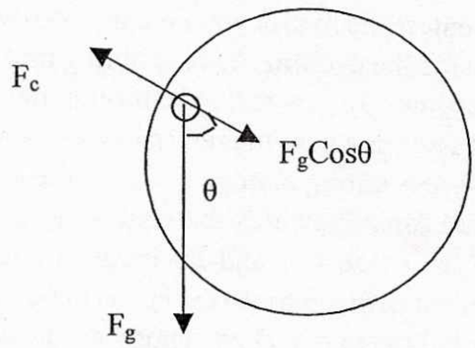


**Fig. 2 :** Forces on a media particle in a tumbling mill

When a media particle is moved up the two forces acting on it are the centrifugal force Fc and the gravitational force $F_g$. Balancing them in the radial direction and simplifying,

$$\omega = [\frac{2g}{D_m}]^{1/2} \quad (6)$$

where ω is the angular speed and Dm is the mill diameter. Expressing angular speed in revolutions per minute,

$$N_c = \frac{42.3}{D_m^{1/2}} \quad (7)$$

This is the critical speed of the mill beyond which the media particles will remain centrifuged at the wall resulting in no impact or grinding action. Thus, the mill must be operated below the critical speed.

In industrial practice, most comminution operations are closed circuit except primary crushing. A comminution circuit is said to be closed when it operates in series with a size classifier and the coarse fraction of the classifier is re-circulated back into the comminution unit. A secondary crusher with a vibrating screen and a ball mill/rod mill with a hydrocyclone are most common closed circuit comminution operations in mineral processing plant practice.

## CLASSIFICATION

Classification is a method of separating of minerals into two or more products on the basis of size. Classifiers consist essentially of sorting column in which a fluid is rising at a uniform rate. Particles introduced into the sorting column either sink or rise according to whether their terminal velocities are greater or less than the upward velocity of the fluid. The sorting column separates the feed into two products - an overflow consisting of particles with terminal velocities less than the velocity of the fluid and an underflow of particles with terminal velocities greater than the rising velocity [4]. Hydrocyclones are most popular type of classifiers in the industry.

***Hydrocyclones :*** These are continuously operating classifying devices that utilise centrifugal forces to accelerate the settling rate of particles. It is one of the most important devices used in the mineral industry. Hydrocyclones operate under pressure. The feed, a mixture of water and solids, enters the hydrocyclone tangentially through the inlet, which forces the mixture to spin inside the cyclone. This spinning motion generates centrifugal forces causing the air to disengage quickly and exit through the vortex finder. The liquid passes down into the conical section where the reduction in diameter accelerates the fluid thus generating centrifugal forces strong enough to cause the solids to separate from the liquid. The larger particles are forced towards the wall because of greater mass and then travel down the length of the conical section and discharge through the underflow opening. The finer particles do not get centrifuged towards the periphery due to their smaller mass and hence accompany the liquid to the overflow. Thus a separation of larger size particles from smaller size ones are achieved.

The commonest method of representing cyclone efficiency is by a performance curve or partition curve as shown in the Figure 4. This relates the weight fraction or percentage of material in each size in the feed that reports to the apex or underflow to the particle size. The cut point is usually referred as the $d_{50}$. The sharpness of the cut depends on the slope of the central section of the partition curve; the closer to vertical is the slope, the higher is the efficiency. The slope of the curve can be expressed by taking the points at which 75% and 25% of the feed particles report to the underflow. These are the $d_{75}$ and $d_{25}$ sizes, respectively. The efficiency of separation or the so called imperfection I, is then given by

$$I = (d_{75} - d_{25}) / 2d_{50} \qquad (8)$$

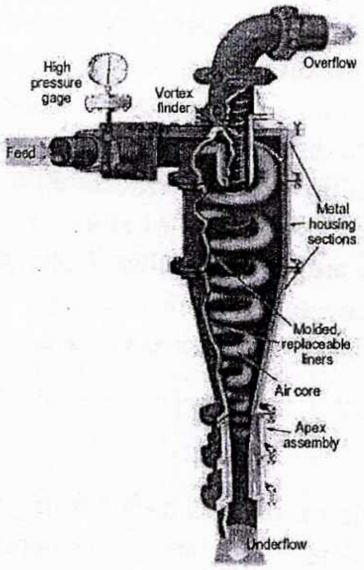


**Fig. 3 :** A hydrocyclone classifier

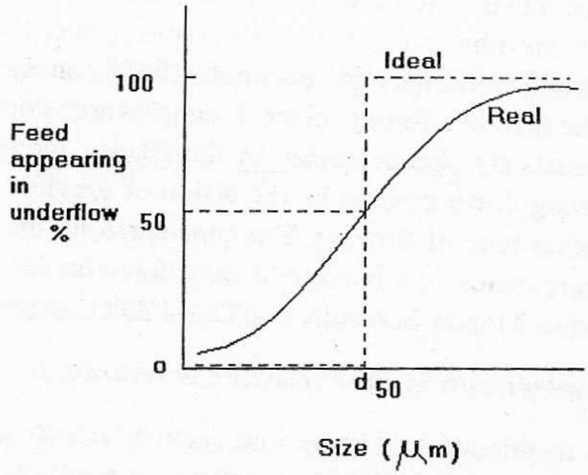


**Fig. 4 :** Performance curve of a hydrocyclone

## GRAVITY CONCENTRATION

Gravity concentration process exploits the differences in densities of minerals to bring about a separation. It finds diverse applications in the treatment of coal, beach sands, iron, gold, diamonds platinum, barite, fluorspar, tin, tungsten ores etc. The gravity separation processes are comparatively cheaper and environment friendly.

Gravity separation of two minerals with different specific gravity is carried out by the relative movement in response to force of gravity and one or more other forces. Normally one of the forces is resistance to motion by a fluid, usually water. The Concentration Criteria (CC) which gives an idea of the amenability of separation of two minerals, can be expressed by [5]

$$CC = \frac{(d_H - d_F)}{(d_L - d_F)} \tag{9}$$

where, $d_H$, $d_F$ and $d_L$ are sp. gr. of the heavy mineral, fluid and light mineral, respectively. When the quotient is greater than 2.5 (whether positive or negative), gravity separation is relatively easy. Below 1.25, generally, gravity concentration is not feasible.

Besides the specific gravity, the motion of a particle in fluid also depends on its size. The efficiency of gravity concentration increases with an increase in particle size. The particle movement should be governed by the Newton's Law

$$v = \left[ 3gd \frac{(D_s - D_f)}{D_f} \right]^{1/2} \tag{10}$$

where, v = terminal velocity of the particle, $D_s$ = density of the solid, $D_f$ = density of the fluid, and d = diameter of the particle.

There is no single mechanism for the operation of a particular gravity separator. Generally a combination of two or more mechanisms is helpful in explaining the behavior of any separator.

Purely density based methodology employs a fluid with the apparent density in between those of the minerals to be separated. Hence due to difference in the buoyancy, one mineral floats while the other sinks. The most common example is the heavy medium separation. In the case of stratification, the minerals are stratified by an intermittent fluidization caused by the pulsation of the fluid in a vertical plane. Examples are various types of jigs used for concentration. The minerals are also separated by the relative movement through a stream of slurry which is flowing down a plane by the action of gravity. Examples are sluice, Richert Cone etc. In another type of flowing film concentrators, the various constituents are separated by the superposition of a horizontal shear force on the flowing film. Examples are Shaking table, Bartles-Mozley Separator and Cross Belt Concentrator.

***Developments in Fine Gravity Concentration***

As mentioned in the previous section, gravity concentration processes suffer from serious limitations in treating fine particles (typically below 50 micron) efficiently. In recent times because of their simple design and less maintenance problems, water only cyclones are gaining popularity. The equipment is similar to conventional cyclone except that it has got a large angle lower conical section. This helps in suppressing the classification and leads to separation based on the difference in the specific gravity of the suspended particles. The equipment has been used for coal preparation but there exists scope for extending its application to lead-zinc, cassiterite, placer deposits of gold etc.

The application of centrifugal forces to heavy media separation, in the D.M.S. Cyclone, Dynawhirlpool and the Triflow separator, has increased the range of particle sizes that can be treated down to 200 microns. The recent fine gravity centrifugal separators like Knelson concentrator, Kelsey jig and Multi-Gravity separator (MGS) can treat particles further in the finer size range.

## MAGNETIC SEPARATION

This is one of the concentration processes that utilize the differences in magnetic susceptibilities of various minerals present in the ore body. The magnetic fraction may be valuable or gangue depending upon its use in a particular flow sheet or process e.g., separation of magnetite (magnetic) from quartz (non-magnetic), separation of tin bearing mineral cassiterite (non-magnetic) from magnetite (magnetic) impurity etc.

If M is the intensity of magnetization and H is the field strength then the magnetic susceptibility ($\chi$) is defined by $\chi = M/H$. The most commonly tabulated value of magnetic susceptibility is the specific susceptibility ($\chi_s$) which is defined as the ratio of specific magnetization ($M_s$) to the magnetizing field, $\chi_s = M_s/H$.

**Table 2 :** Magnetic susceptibilities of common minerals

| Mineral | Specific susceptibility ($10^{-8}$ m$^3$/kg) | Mineral | Specific susceptibility ($10^{-8}$ m$^3$/kg) |
|---|---|---|---|
| Calcite | -0.3 to -1.4 | Pyrrhotite | 10 to 30,000 |
| Quartz, Feldspar, | -0.5 to -0.6 | Hematite | 10 to 760 |
| Magnesite | -2 | Ilmenite | 46 to 80,000 |
| Kaolinite | -0.5 to -2.0 | Magnetite | 20,000 |
| Halite, Gypsum, | 120 to 2900 | Dolomite | to110,000 |
| Anhydride | 5 to 13 | Sandstones, Shales | -1 to -41 |
| Serpentinite | 5 to 52 | Limestone | 0 to 1200 |
| Illite, Montmorillonite | 26 to 280 | Serpentine | 110 to 630 |
| Biotite | 0.6 to 10 | Clay | 10 to 15 |
| Goethite | 1 to 100 | Coal | 1.9 |
| Chalchopyrite | | | |
| Pyrite | | | |

In general, minerals can be classified in two broad categories, according to whether they are attracted or repelled by a magnetic field. Diamagnetic minerals are made up exclusively of diamagnetic ions and are repelled along the lines of magnetic forces to a point where the field intensity is smaller. The forces involved here are very small and diamagnetic minerals cannot be concentrated magnetically. Paramagnetism in minerals generally arises from ions with unpaired electron spins, most commonly of the first transition series [6]. They are attracted along the lines of magnetic force to points of greater field intensity. Paramagnetic minerals can be concentrated in high intensity magnetic separators. Ferromagnetism is a special case of paramagnetism, involving very high forces. In a few minerals e.g., Fe, Ni, Co, Mn, Cr, Ce, Ti and Pt group metals, the interaction between the spins cause spins on adjacent atoms in the minerals to become aligned parallel to each other. They can be separated in low intensity magnetic separators.

Concentration is achieved by simultaneously applying to all particles in an ore a magnetic force that acts on magnetic particles and a second force or combination of forces which acts in a different direction and affects both magnetic and non-magnetic particles. The most commonly applied nonmagnetic forces are gravitational, centrifugal and fluid drag. A magnetic separator is generally classified as low intensity if its maximum field intensity is less than about 2000 gauss (H= $1.6 \times 10^5$ A/m, B=0.20 T). Low intensity magnetic separators (LIMS) are used to treat ferromagnetic and highly paramagnetic minerals such as iron and magnetite. High intensity magnetic separators (HIMS) generally have field strengths of 10 to 20 kilogauss. These separators are used to treat weakly magnetic minerals, such as hematite. Magnetic separators are commonly classified into two broad groups, namely, wet and dry based on their usage. Magnetic Pulleys, Magnetic Drums, Induced Roll Magnetic Separator, Cross-belt High Intensity Magnetic Separators, High Intensity Wet Magnetic Separators are some of the common types of magnetic separators used in mineral processing.

## ELECTROSTATIC SEPERATION

Electrostatic separation is a unit operation where electrical conductivity property of mineral surface is used selectively to separate out desirable mineral from other undesirable minerals. Electrostatic forces are generated by the action of an electric field on a charged particle. So, in any electrostatic separation process one needs a source of electrical potential to generate the electric field and a process by which the individual particles are charged electrically [7]. This technique has the following advantages:

1. The electrostatic forces work on the particles to be separated only; they do not affect the medium in which the particles are located
2. The electrostatic forces may be arranged to work in combination with other forces such as gravitational or centrifugal forces
3. The electrostatic separation forces are independent of the substrate of the material on which the surface electric charge is generated. They are determined solely by the product of electric field and charge.

However, the process is associated with the limitation of maximum mass that it can effectively work upon. Also, the size of the material to be separated should be very small which leads to the increase of comminution cost.

Drum type electrostatic separator: This equipment consists of a rotating drum made of mild steel or some other conducting material, which is earthed through its support bearings as shown below in the Figure 5. An electrode assembly, comprising of a brass tube in front of which is supported a length of fine wire, and is supplied with a fully rectified DC supply of up to 50 kV, usually of negative polarity. The voltage supplied to the assembly should be such that ionisation of the air takes place. This can often be seen as a visible corona discharge. When ionisation occurs, the minerals receive a spray discharge of electricity, which gives the poor conductors a high surface charge, causing them to be attracted to and pinned to the rotor surface. The particles of relatively high conductivity do not become charged as rapidly since the charge rapidly dissipates through the particles to the earthed rotor. These particles of higher conductivity follow a path, when leaving the rotor, approximating to the one, which they would assume if there were no charging effects at all.

A combination of pinning and lifting effects can be created by using a static electrode large enough to preclude corona discharge, following the electrode. The conducting particles, which are flung from the rotor, are attracted to this static electrode and the compound process produces a very wide and distinct separation between the conducting and non-conducting particles.

Plate type electrostatic separator: A plate or screen type electrostatic separator is also used for separation. This type of equipment mainly consists of an oval type, high voltage electrode, which induces the electric field. The material is fed through a sloping, grounded plate under gravity. The electrostatic field is effectively shorted through the conducting particles, which are lifted towards the charged electrode in order to decrease the energy of the system.

Electrostatic separation is used successfully for beneficiation of wide range of minerals including beneficiation of coal, beach sand, etc.

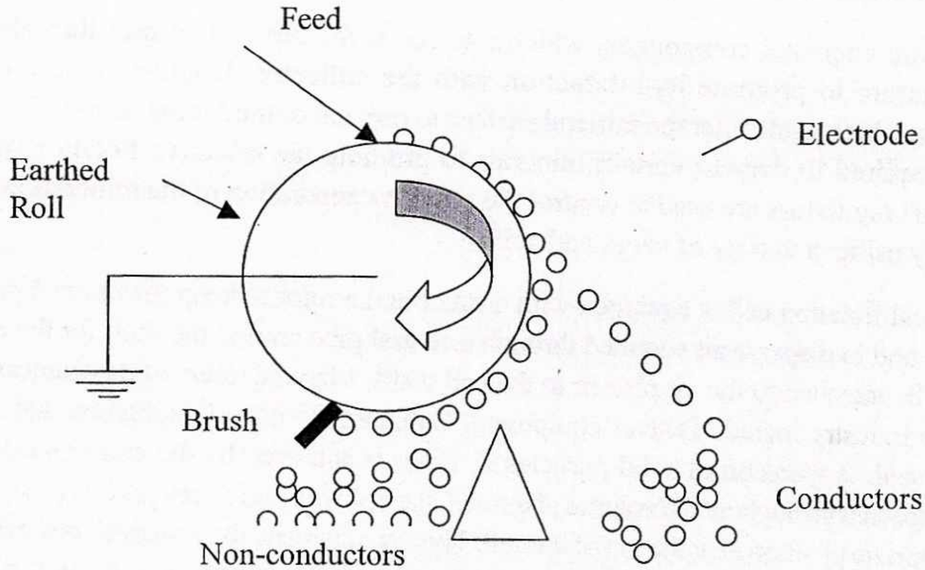


**Fig. 5 :** Principle of Electrostatic Separation

## FLOTATION

Froth flotation is a process used to separate minerals, suspended in liquids, by selectively attaching them to gas bubbles. Hence, in flotation we have a three-phase system.

***Principles of flotation:***

Froth flotation utilizes the differences in physico-chemical surface properties of various minerals. After treatment with reagents, such differences in surface properties between the minerals within the flotation pulp become apparent. For flotation to take place, an air bubble must be able to attach itself to a particle and lift it to the water surface. The process can be applied to relatively fine particles. In flotation, the mineral is usually transferred to the froth leaving the gangue in the tailing in direct flotation and in the reverse flotation the gangue is separated into the float fraction leaving the concentrate in the pulp [8]. Very few minerals are naturally hydrophobic and the hydrophobic conditions could be achieved by using chemical reagents. Diamonds are naturally hydrophobic and this property is made use of in grease tabling to recover diamonds.

The reagents employed in flotation are generally interfacial surface tension modifiers, surface chemistry modifiers, and/or flocculants. Usually these are classified as collectors, frothers and modulating agents.

Collectors are reagents that are absorbed on the mineral surfaces to render water repellent property of the surface. Usually, very small quantities of collectors are used in flotation ranging from 0.2 to about 1.0 kg per ton of material processed. Frothers are heteropolar, surface-active organic reagents capable of being adsorbed on the air-water interface and reduce the surface tension to form a stable air-bubble. The alcohols containing hydroxyl group are most common. Pine oil, cresylic acid, MIBC are widely used frothers.

Activators are chemical compounds, which interact at the mineral surface thus altering its chemical nature to promote its interaction with the collector. Depressants are chemical compounds, which again alter the mineral surface to prevent or hinder the action of collectors. They are required to depress certain minerals to promote the selective flotation of desired minerals. pH regulators are used to control the selective separation of the minerals and can be achieved by using a variety of bases and acids.

A mechanical flotation cell is equipped with a stator and a rotor to keep the mineral particles in suspension and to disperse air supplied through a central pipe around the shaft for the rotor. The stator may be attached to the air pipe or to the cell walls. Manufacturers of mechanical flotation cells in the industry include Denver equipment, Galigher, Wemco, Outokumpu and Sala. In a pneumatic cell, suspension of solid particles in water is achieved by the compressed air being suitably dispersed throughout the volume of the cell. It employs a perforated grid (or pipes) arranged in an appropriate position near the top of the cell. This arrangement allows a thick bed of froth to be formed. The flotation pulp, appropriately prepared and ready for separation, is fed with a minimum of agitation on top of this bed of froth. Feed along with air is introduced in a cyclone cell through a cyclone feeder, under pressure. These are known as air-sparged hydrocyclones.

**Operating guidelines in flotation machine**

1. Peripheral speed affecting amount of air drawn.
2. Pulp density affecting volume of air and power consumption.
3. Pulp feed point below impeller may create choking.
4. Pulp level affects turbulence and aeration.
5. Frother quantity may affect bubble size and air intake.
6. Impeller and stator position affects air intake and specific power consumption.
7. Mechanism of removal of froth affects the quality of froth.
8. Improper removal of chamber product affects efficiency and quality.

Oleo flotation and oil agglomeration are also prevalent in coal industry. Electro-flotation is a recent development in the recovery of ultra fines. Scope of electro-flotation has also been extended to the field of effluent treatment.

## AGGLOMERATION

Often concentrates are produced from mineral processing plants in fine particulate form and as such those can not be utilized for metal extraction unless they are bound into some compacted or lumpy form called 'agglomerates' suitable for handling and feeding into furnaces. Some of the common agglomeration techniques are discussed below.

***Pelletisation :*** This consists of two distinct operations, namely, forming the ball shaped pellets at atmospheric temperature and then firing them at a temperature below the softening temperature. Iron ore fines and concentrates are ground to suitable fineness generally 50-70% below 50 microns and mixed with some quantity of moisture and a suitable binder e.g., bentonite, lime etc and the mixture rolled in either a horizontal drum or an inclined disc. At this stage, the spheres known as green balls or pellets have adequate strength to withstand handling to the firing stage. Pellet firing, called induration, is normally carried out using either a gas or oil. Initially, shaft kilns were used but later, horizontal traveling grates, or a combination of horizontal traveling grates and rotary kilns, were developed for this purpose. During induration, not only the crystal structure is changed but also other bonds appear by reactions between slag forming constituents - both between each other and with iron oxides. In another pelletisation process, called 'Cold bonded pelletisation', binders like calcium hydroxide or cement is added during green ball formation. They are indurated by using steam under high pressure in an autoclave or keeping the green pellets under moist condition over a long period of time to complete the setting process.

***Sintering :*** The sintering process consists, in essence, of mixing iron ore fines, moisture, other fine iron bearing recycling material like mill scale, flue dust etc., fluxing material e.g. lime, limestone, dolomite, quartz etc. and solid fuel, normally coke breeze, and loading the mix on to a permeable grate. The upper surface is ignited by oil or gas burners and air is sucked downwards through the grate. After a short ignition period, heating of the top surface is discontinued and a narrow combustion zone moves downwards through the bed, each layer in turn being heated to 1200-1500°C. In advance of the combustion zone, water is evaporated and volatile compounds are driven off. In the combustion zone, bonding takes place between the grains and a strong agglomerate is formed. Most of the heat in the gases leaving the combustion zone is absorbed by drying, calcining and pre-heating the lower layers in the bed. When the combustion zone has reached the base of the sinter mix the process is complete, and the sinter cake is tripped from the grate and roughly broken up. After screening, the undersize is recycled and the oversize is cooled and sent to the blast furnaces. The sintering of non-ferrous ore fines is sometimes carried out in the reverse direction. A thin layer of mix is first charged on to the grate and ignited, mix is then added to bring the bed up to the full height and air is blown upwards through the bed. The process is complete when combustion at the bed top has been completed. This process is referred to as up-draught sintering, in contradiction to the normal down draught sintering.

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