# MINERAL ENGINEERING & FUEL TECHNOLOGY

(MME-203)

$4^{th}$ Semester B. Tech

Dept. of Metallurgical and Materials Engineering

V.S.S.university of Technology , Burla

Sambalpur , odisha

| Person involved | Name | Designation And Email .id | Department |
|---|---|---|---|
| Course coordinator | Gautam Behera | Assistant professor gautamiitkgpian@gmail.com | MME |
| Course Co-coordinator | Dinesh ku mishra , | Assistant professor Dinesh.igit@gmail.com | MME |
| Course Co-coordinator | Avala Lava kumar | Assistant professor Lavakumar.vssut@gmail.com | MME |

## Goals of the subject

1-To impart knowledge about Mineral Processing [fundamental knowledge]

2-To teach you to “think” rather than “cook”

3-To encourage you to consider a career path in Mineral Processing

## Content

- Introduction to mineral processing(Engineering)
- Crushing and grinding
- Size separation methods
- Concentration methods
- Agglomeration techniques
- Fuel technology

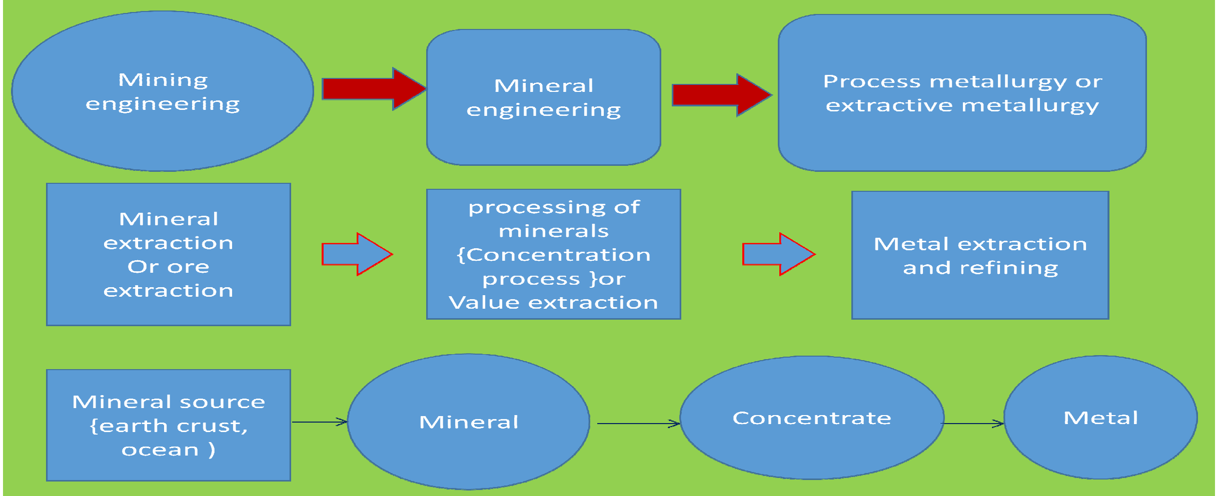
# MODULE -I

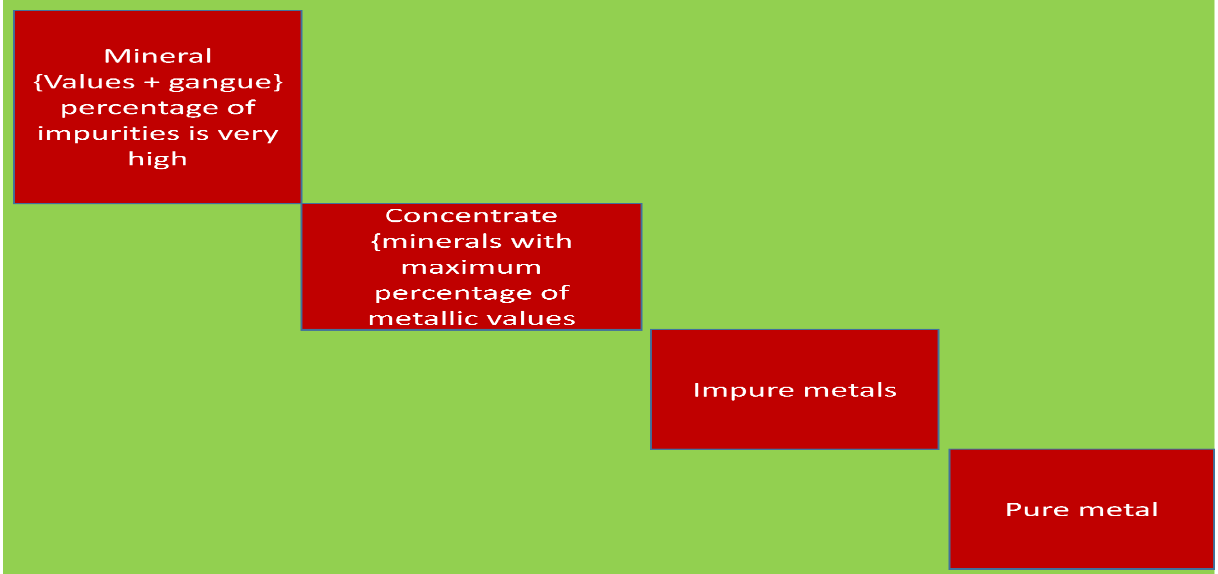
## Introduction to mineral and mineral Engineering

Mineral- a substance from which we get metal non metals or any valuables.

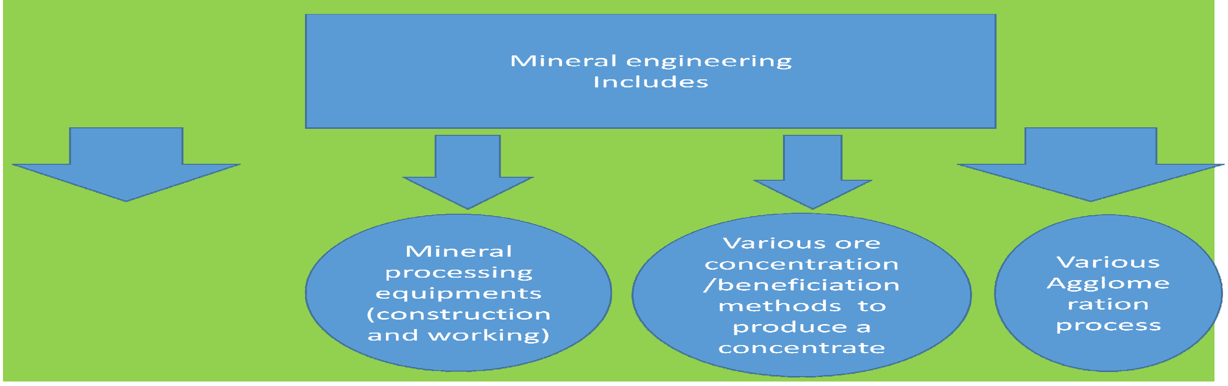
Mineral Engineering ( branch of mme which deals with study of minerals and its processing )where the minerals is being processed to get a concentrate from which metals are extracted .

Flow chat to show the relationship of mineral engineering with mining and extractive metallurgy engineering




Subject covers



Minerals definition

**MINERAL : Natural occur inorganic aggregate of metals and non metals .**

**Or Inorganic compound having a definite chemical composition and crystal structure (atomic structure). Or minerals are the forms in which metals are found in the earth crust and as sea bed deposit depend on their reactivity with their environment, particular with oxygen , sulphur, and co2.**

**Anything of economical value which is extracted from the earth.**

Characteristic of mineral

1-Minerals are homogeneous in physical and chemical composition.

2-Minerals shows isomorphism (atomic structure do not change )(with the same atomic structure but different chemical formulas)

ustal structure remains same) Example- olivine (Mg,Fe)2 SiO4 in different olivines the ratio of Mg /Fe atoms varies

3-Mineral also shows polymorphism (different crustal structure) same chemical composition but different physical properties.

Example – graphite and diamond

quartz, tridymite, cristobalite, stishovite and coesite--$SiO_2$---

quartz forms at low temperature and forms in the hexagonal system, cristobalite forms at a high temperature and forms in the tetragonal system,

tridymite is an intermediate temperature form which is orthorhombic---

coesite is stable at high pressures and is associated with meteor impact and is a monoclinic mineral---

stishovite is tetragonal and is thought to be associated with rocks from Mars

a. calcite and aragonite--$CaCO_3$---calcite is hexagonal and aragonite, orthorhombic

b. pyrite and marcasite--$FeS_2$---pyrite forms at a high temperature and is isometric

## Rock vs mineral

1-Chalk, clay, granite(igneous rock),coal are rocks there are not come under definition of minerals because they are not physically and chemically homogeneous.

2- rocks generally consists of variety of minerals.

## Mineral Vs Ore:

ORE definition - natural aggregates of minerals from which a metal or metallic compound can be extracted economically and profitable.

All ores can be minerals but all mineral cannot be an ore.

Ore: is mixture of extractable mineral and extraneous rocky materials described as gangue

## Physical properties of mineral

1-transperency

2-luster

3-color

4-specific gravity

5-hardness

6-cleavage

7-fracture

8-magnetic property

9-electric property

10-radiactive

11- optical property

Uses of some mineral.

1-diamond is used as an abrasive and cutting material.

2-garnet sand is used to make sand paper.

3-soft mineral like talk is used to make cosmetics powders.

A minimum metal content required for a deposit to qualify as an ore varies from metal to metal.

1. Many non ferrous ore contains only one per metals or some times less then it.
2. Gold can be recovered profitable from an ore containing 1 ppm level of metals

3. Iron containing less then 45 per in an ore is said to be low grade.
4. Every ton of material deposited have Contained value – depend upon metal content and current price of the contained metal.

## Ore types : on the basis of nature of valuable mineral

- 1-native ore – metal is present in native form
- 2-sulphide ore- metal is present in sulphide form
- 3-oxide ore- metal is in form of oxide
- 4-sulphate ore- metal is in form of sulphate
- 5- Silicate ore – metal is in form of silicate
- 6-carbonate ore- metal is in form of carbonate
- 7-hydrated form-
- 8-Hydroxide
- 9-complex ore- those ore which contains profitable amount of more than one valuable mineral.

## Ore types : on the basis of nature of their gangues.

1. Calcareous or basic – lime rich
2. Siliceous or acidic – silica rich

- Metal production from ore :
- To produce metals from ore the ore must be broken down by heat(pyro) , solvent(hydro) , electricity(electro) either alone .

## Mineral processing:

Mineral processing also called :

1-ore dressing

2-mineral dressing,

3- milling.

In case of mineral processing one of the main aim is to regulating the size of the ore.

We can define mineral processing as a process of physically separating the grains of valuable mineral from the gangue mineral, to produce an enriched portion or concentrate containing most of the valuable mineral and a discard or tailing containing predominantly the gangue mineral .

Advantages of mineral processing :

1-Processed minerals when processed by leaching or smelting the consumption of energy is less.

2- If an ore contain more than one valuable mineral objective of the mineral processing is to separate the minerals . or it help in separating impurities .

3-compared to chemical method of processing physical method consumes less amount of energy.

4-Mineral processing reduces not only reduces the smelters energy cost but also smelters metal loss due to less metal bearing slag.

Advantages

a) cheaper physical/chemical method of rejecting the waste material is substituted for the more expensive chemical/metallurgical methods such as smelting , refining,

b) Freight cost is saved since we don't have to transport the rejected materials.

c) In case of non metalliferrous ore such as graphite emery and precious stones , the mechanical methods can only work in separation /concentration

Flow sheet of mineral processing:


Principal operation in mineral processing:

Four kind of principal operation are there :

1-Comminution- size reduction process which involves crushing and grinding operation

2-sizing-Sizing is the separation of material or product into various fractions characterised by difference in size. Sizing can be performed by screening or classification. The latter depends on the settling velocity of particles in a fluid (air or water).

3-concentration-Concentration may be regarded as collection of valuable minerals in a small bulk. It is carried out by various means which mainly depend upon the mineral types and it characteristic

4-dewatering- after concentration the concentrate is in moist form or in a liquid pulp so it first dewatered before sending it to smelter or for shipment.

Two fundamental operation of mineral processing:

1-the release or liberation of the valuable mineral from the gangue minerals

2-concentration – separation of these valuable minerals from the gangue.

Release or liberation is accomplished by comminution process . this process involves

Crushing and grinding .

In comminution process we get a product which is a mixture of relatively clean particles of mineral and gangue.

- Maximum energy is consumed in grinding process which accounts 50 per of the concentrator energy consumption.
- Key to good mineral processing : grinding is the key to good mineral processing because it provides efficient separation of valuables mineral from gangue.
- Production of very fine untreatable smile particles which may be lost into the tailing

Disadvantage of fine grinding is :

- Energy cost increases

- In order to produce clean concentrate with less contamination of gangue mineral, fine grinding is essential.

## Requirement of efficient mineral processing:

Requirement of efficient mineral processing:

An intimate knowledge of mineralogical assembly of ore is required .

And knowledge on ore texture is required

Here texture refers to the size, dissemination(distribution) , association and shape of the minerals within the ore.

## Comminution

Main objective of the comminution process is to release or liberation of the valuable mineral particles from the associated gangue mineral as the coarsest possible particles size.

Or we can say The primary purpose of comminution is the unlocking of values in the ore

But this is not achieved during comminution which leads to the increase in cost of processing and subsequent separation stage becomes hard.

Comminution : is nothing but it is a size reduction process .

It is carried out may be wet condition or dry condition which depends upon required size of material.

(ii) Comminution involves crushing and grinding operation

(III)- in case of crushing it is always carried out in dry condition but for grinding it is carried out on may be dry or wet.

(IV) The extent of comminution depend upon mineralogical characteristic .

(v)-The extent ‘of comminution is regulated by the particle size required for the subsequent concentration operation.

Middlings : the particles of the locked mineral and gangue which are produced by crusihing operation called midlings.

Midlings are further processed by comminution to achieved liberation .

Degree of liberation : refers to the percentage of mineral occurring as a free particles in the ore in relation to the total content.

This can be high if there is weak boundaries between gangue and mineral. Which generally observed in case of ore composed mainly of rock forming mineral.

Sedimentary minerals . generally bond between the gangue and mineral is strong due to which during crushing it produces maximum middling’s and low degree of liberation

New approach to increases the degree of liberation involves directing the breaking stresses at the mineral crystal boundaries, so that the rock can be broken without the breaking of mineral grain.

Advantage of wet grinding

- Lower power consumption per tonne of material

- Higher capacity per unit mill volume
- Makes possible the use of wet screening or classification for close product control
- Elimination of the dust problem
- Makes possible use of simple handling and transport methods such as pump, pipe , and launder

## Sampling

Sampling definition :is the mean where by a small amount of material is taken from the main bulk in such a manner that it is representative of the large amount.

This sampling must be accurate because great responsibility rest on a very small sample.

Objective of sampling: is to estimate grades and contents of sampling unit in an unbiased manner

and with an acceptable and affordable degree of precision.

1-Sampling ideally should be carried out before the material is subjected to losses in the mill.

That means it must be carried out on run of mines ore entering the primary crusher stage.

But the problem is that here in this stage accurate sampling cannot be done due two  main factors one is different size of particles, and inhomogeneity of material.

Sampling is the removal from a given lot of material a portion that is representative of the whole yet of convenient size for analysis.

It is done either by hand or by machine.

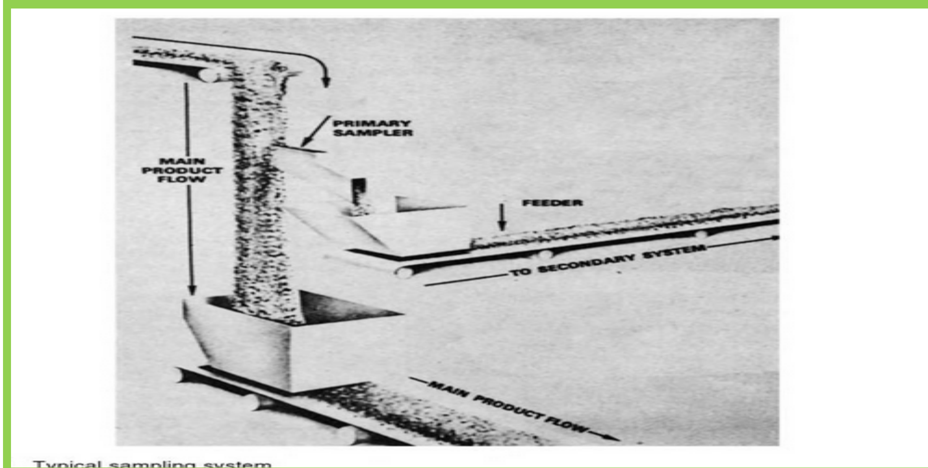
## How sampling is done

Hand sampling is usually expensive, slow, and inaccurate, so that it is generally applied only where the material is not suitable for machine sampling (slimy ore, for example) or where machinery is eithe Many different sampling devices are available, including shovels, pipe samplers, and automatic machine samplers. For these sampling machines to provide an accurate representation of the whole lot, the quantity of a single sample, the total number of samples, and the kind of samples taken are of decisive importance. A number of mathematical sampling models have been devised in order to arrive at the appropriate criteria for sampling.

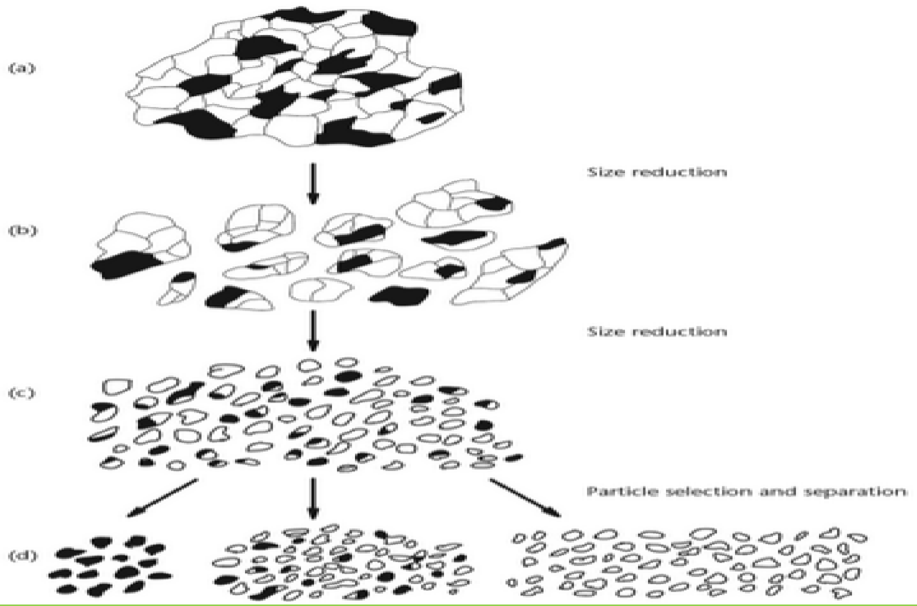
## Analysis

After one or more samples are taken from an amount of ore passing through a material stream such as a conveyor belt, the samples are reduced to quantities suitable for further analysis. Analytical methods include chemical, mineralogical, and particle size.

## Typical sampling  system




This above dig is size reduction, separation and selection of minerals form rocks,




Cross section through a typical ore particle

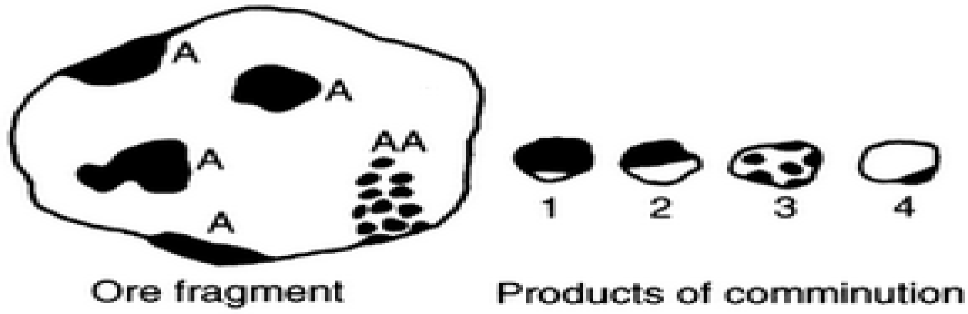



**Figure 1.6** Cross-sections of ore particles

Product of comminution

Here region A represent valuable mineral

Where as AA represents rich in valuable mineral but is higly intergrown with the gangue mineral . During comminution a range of fragments are produced ranging from fully liberated mineral and gangue particles.Here from the figure we can see

Type 1- is rich in mineral and are classified as concentrate since as they have an acceptable degree of locking with the gangue , which limits the concentrate grade.

Type 4- is tailing since small amount of mineral presents reduces the recovery of mineral into the concentrate.

Types 2, 3- are middling's degree of regrinding needed to promote economic liberation of mineral from particle 3 would be greater than in 2.

## Types of Separation of usefully values from impurities in a mineral

1- physical separation- comminution process where we apply force to break the minerals so as to separate the values from gangue particles,

Which form there stuffs

(I)-concentrate(main valuable mineral)

(II)-middling's(contains mineral as well as impurities

(III)-tailings (mainly impurities)

2- chemical separation- leaching process.in which we use chemicals which selectively attack the values without affecting the impurities (gangue)

In mineral processing physical process of separation is very important which has been discussed earlier

## Characteristic of comminution products

1- surface area increases due to comminution since as the size reduces the surface area increases .

2-size of the comminution products are not uniform . There may be range from bigger to smaller fines.

3- generally ratio of dia of bigger to smaller particles in comminution product is 104

4- to characterise the size of needle shape and plate like shape particles two dimension is considered .

## Energy and power requirement for size reduction

1--total use full work done in comminution is equal to amount of new surface generated in comminution multiplied with specific surface energy of solid .

2-- but the actual energy need for this is 100 to 1000 times higher then these values

This means efficiency based on surface energy is

Varies from 0.1 to 1 percent

Remaining  energy is wasted in

1-the elastic deformation of solid particle before fracture. This stored energy get dissipated in form of sound and heat.

2-the elastic deformation of the equipment

3-friction between solid particles and also between the particles and the equipment wall

### These energy loss manifest in form of

(A)- heat

(B)-sound

( c )- vibration

Due to generation of large amount of heat the equipments and the product may damage(if it is heat sensitive)so cooling is required.

Reduction ratio , that is the ratio of the initial particle size to the final particle size.

Crushing efficiency : It is defined as the ratio of surface energy created by crushing during crushing to the energy absorbed by the solid .

Denoted by $\eta_c$

## Laws of reduction

Rittingers law – work(energy) required in crushing is proportional to the new surface created .

Or minium energy required is the surface energy of the new surface created.

This crushing efficiency is constant and for a given machine and material , is independent of the sizes of the feed and product .

rittinger law can be written as

$$P/m = k_r [1/D_{sb} - 1/D_{sa}]$$

Where

p is the power required

M is the feed rate to crusher

$D_{sb}$ average particle dia before crushing

$D_{sa}$ average particle dia after crushing

$K_r$ rittinger constant or coefficient

which assumes that the energy consumed is proportional to the newly generated surface area

assumed that the energy required for size reduction is directly proportional, not to the change in length dimension, but rather, to the change in surface area

## Kicks law

The work required for crushing a given mass of material is constant for the same reduction ratio , that is the ratio of the initial particle size to the final particle size.

P/M = Kk   ln Dsa/Dsb

Where Kk  is the kicks constant of coefficient

## Bond law

The work required to form particles of size dp from large feed is proportional to the square root of the surface to volume ratio of the product

$$\frac{P}{\dot{m}} = \frac{K_b}{\sqrt{D_p}}$$

where $K_b$ is a constant that depends on the type of machine and on the material being crushed.

## Size reduction equipment

Size reduction equipments are classified into 4 types

1- crushers – crusher do the heavy work of breaking large pieces of solid material into small lumps .

2-grinders-grinders reduce crushed  feed to powder

3-ultra fine grinders-

4-cutting machine – gives particles of definite size and shape , 2 to 10 mm in length

Types 1-crushers  types

(A) Jaw crushers

(B) Gyratory crusher

(C) Crushing rolls

2-grinder types

(A) Hammer mills

(B) Rolling compression mills(bowl mills, roller mills)

(C) Attrition mills

(D) Tumbling mills(rod mills, ball mills, tube mills )

of crusher and grinders

## Characteristic action of size reduction equipment

Each machine have its own way to reduce the size

1- crushers-compression

2-grinders-impact and attrition some times combined with compression

3-ultra fine grinders-attrition

4-cutters- cutting action

## Mechanism of breaking

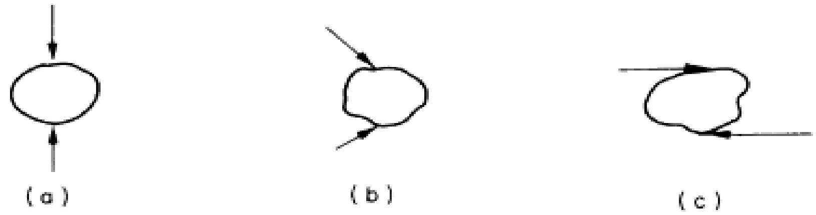



FIG. 7.1. Mechanisms of breakage: (a) impact or compression, (b) chipping, (c) abrasion.

## Crushing

1. Crushing is the first stage in the comminution process main aim is liberation of the valuables minerals from gangue.
2. Size of the ore from run of mines may be 1.5 m but by crushing the size is reduced to 10-20 cm
3. Dry operation is done in 2 to 3 stage.
4. Secondary crushing produce size of 0.5 to 2cm
5. In crushing a washing sage is included sticky ore containing clay which may lead to chocking
6. Vibrating screens are of secondary crushing sometimes placed ahead of secondary crusher to remove under size materials or scalp the feed and thereby increasing the capacity of the secondary crushing unit.
7. Crushing may be open or closed depending upon the product size
8. Slow speed M/C for coarse reduction of large quantity of solid.
9. operates by compression and can break large lumps of very hard material
10. Tooth roll crusher – used to crush soft materials like coal

# Working of the jaw crusher

Feed is inserted between two jaws set to form a V open at top

One jaw is fixed and is vertical called anvil jaw and other is movable which reciprocate in a horizontal plane called swiniging jaw this jaw makes an angle of 20 to 30 degree with the anvil jaw

Swining jaw is driven by an ecentric due to which it applies a greater compressive force to feed to cut between the jaw.

Face of the jaws are slightely bulge d or flat they may carry horizontal grooves .
Large lumps cut between the upper part of the jaw s are broken ,drop into the narrow space below , and are recrushed the next time the jaws closed

After sufficient reduction they drop out from the bottom . And the jaw open and close nearly 250-400 times per minute

# Functional diagram of blake jaw crusher

MINERAL PROCESSING TECHNOLOGY

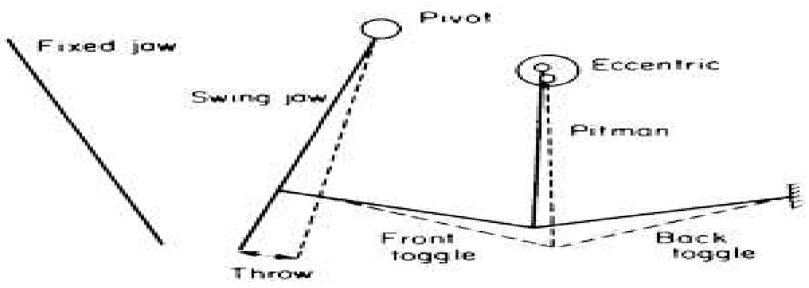
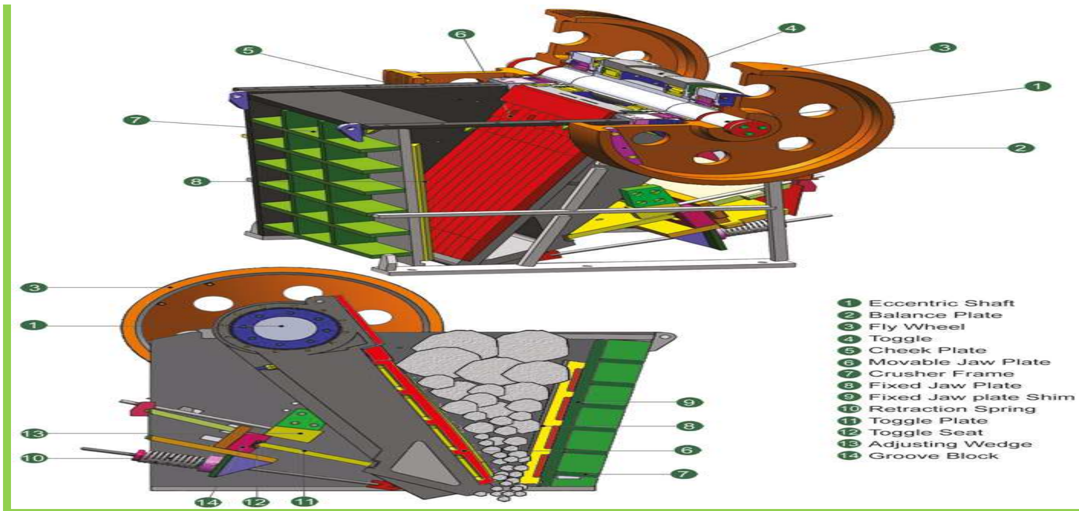



FIG. 6.4. Blake jaw crusher (functional diagram).

# Blake jaw crusher




## Blake jaw crusher construction

1- Common type of jaw crusher

2-ecentric drives a pitman which is connected to two toggle

3- here one toggle is connected with frame and other with swinging jaw .

4-the pivot point is at the top of the movable jaw or above the top of the jaw on the centre line of the jaw opening.

5-the greatest amount of motion is at the bottom of the v which means that there is little tendency for a crusher of this kind to choke.

6- feed size is 1.8-2.4 m .

7-It crush 1000tons /h

8-Maximum product size of 250 mm

9-angle between the jaw is less than 26 degree

10 lower end of the swinging jaw is concave and fixed jaw is convex this allow more gradual reduction at the end prevents paking

11-speed of jaw crusher lies 100-350 rev /,mint

## Types of blake jaw crusher

2 types of blake jaw crusher are there

1- single toggle

2- double toggled

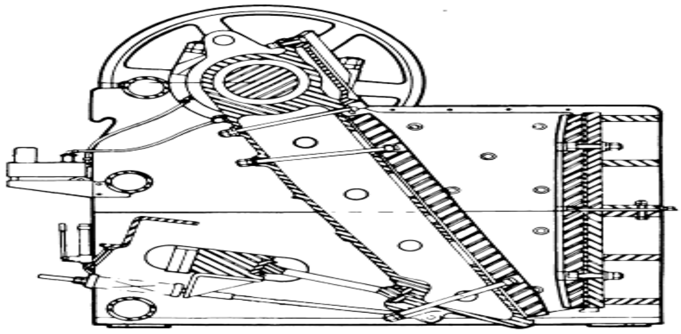


FIG. 6.6. Cross-section of single-toggle jaw crusher.

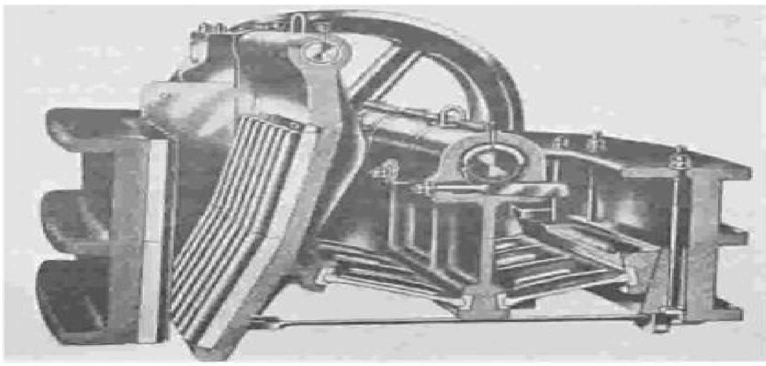


FIG. 6.5. Cross-section through double-toggle crusher.

## Dodge jaw crusher

1-moving jaw is pivoted at the bottom

2-the minimum moment is thus at the bottom and more uniform product is open .

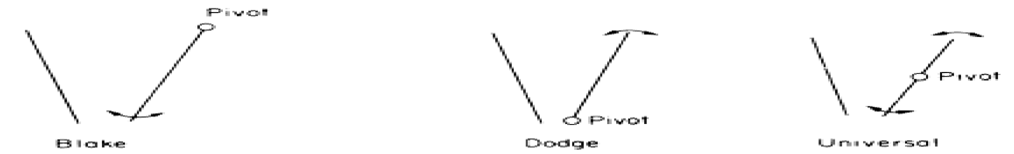
3-this is prone to choking so this is rarely used crusher

4-the larger opening at the top enables it to take

Very large feed and to effect a large size to high fluctuating stress that are produced in the member of the machine

Blake vs dodge vs universal crusher

| **Crusher** | **Blake** | **Dodge** | **Universal** |
|---|---|---|---|
| Pivoting | At the top | At the bottom | Intermediate position |
| Receiving area | Fixed | Variable | Variable |
| Discharging area | Variable | Fixed | Variable |
| Application or use | Heavy duty crushing (industrial use ) | Laboratory as it chock very easily | Industry |




| | |
|---|---|
| Main frame | Mild steel welded together |
| Main jaws | Cast steel fitted with replacable liner |
| Replacable liner (bolted to the jaw so that thy can easily replaced<br>0 | Mn steel or Ni hard or ni-cr alloyed cast iron |

| | |
|---|---|
| Cheek plates to protect the main frame from wear | Hard alloy steel |

## Gyratory crusher

1-The name gyratory crusher comes from the fact that while the spindle is revolving around the axis of the frame generating a conical surface, at the same time it rotates about own axis due to frictional drag.

2-a gyratory crusher may be looked upon as a jaw crusher with circular jaws between which material is being crushed at same point at all times

3-A conical crushing head gyrates inside a funnel –shaped casing , open at the top of the machine .

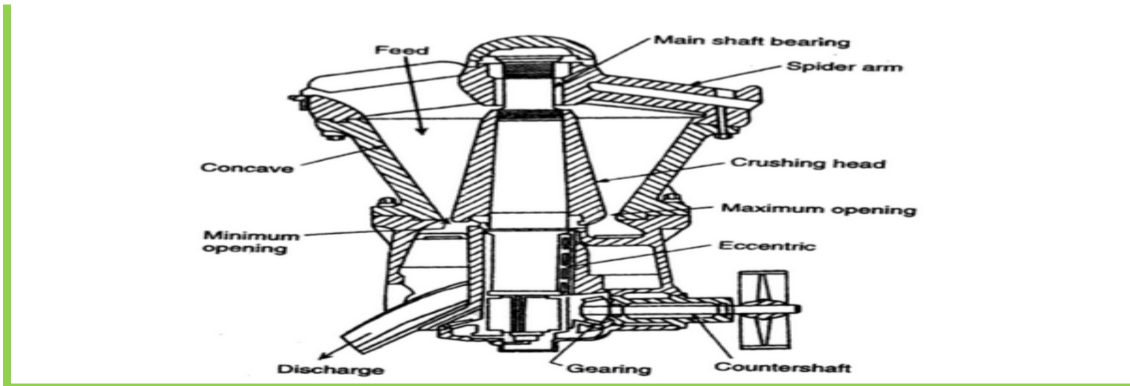
4-an eccentric drives the bottom end of the shaft .

At any point on the periphery of the casing ,therefore the bottom of the crushing head moved towards and then away from the stationary wall

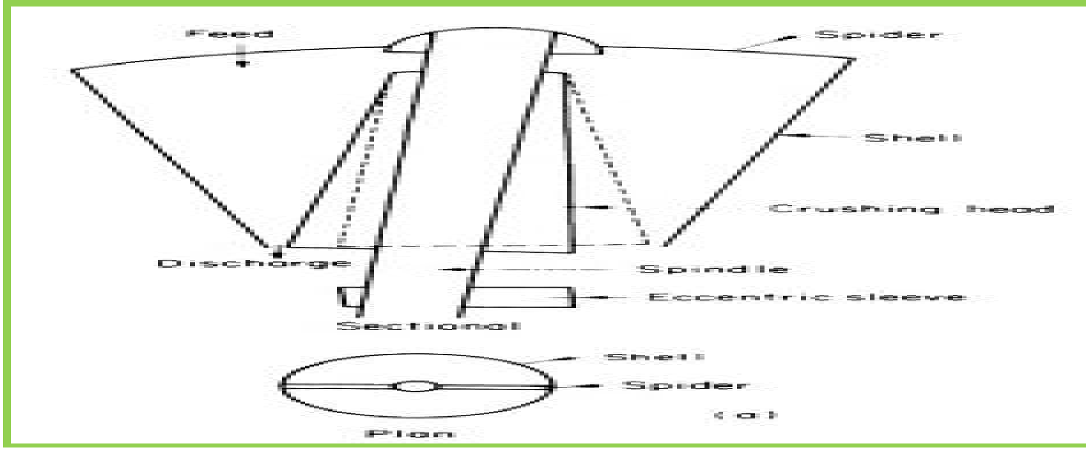
5-side caught in the V shaped space between the head and the casing are broken and rebroken until they pass out the bottom.

6- the crushing head is free to rotate on the shaft and turns slowly because of friction with the material being crushed .

## Gyratory crusher




Functional dig of gyratory crusher




Jaw crusher vs gyratory crusher

Application of the crusher is based on two main factor

1- capacity

2- maximum size it can handle

When crusher gap is more imp rather than capacity jaw is used and vice versa

| **Prime requirement** | **Jaw** | **Gyratory** |
|---|---|---|

| | | |
|---|---|---|
| Capacity | | Yes |
| Maximum size of ore handling | Yes | |
| Capital and maintenance cost | Less | High |
| Installation cost | High | Low |
| Foundation | Rugged | |
| Feeding | Expensive feeder | Self feeding |
| Type of material being crushed | Clayed n plastic | Hard n abbrasive |

Cone crusher (secondary crusher)
and modified gyratory crusher

CRUSHERS

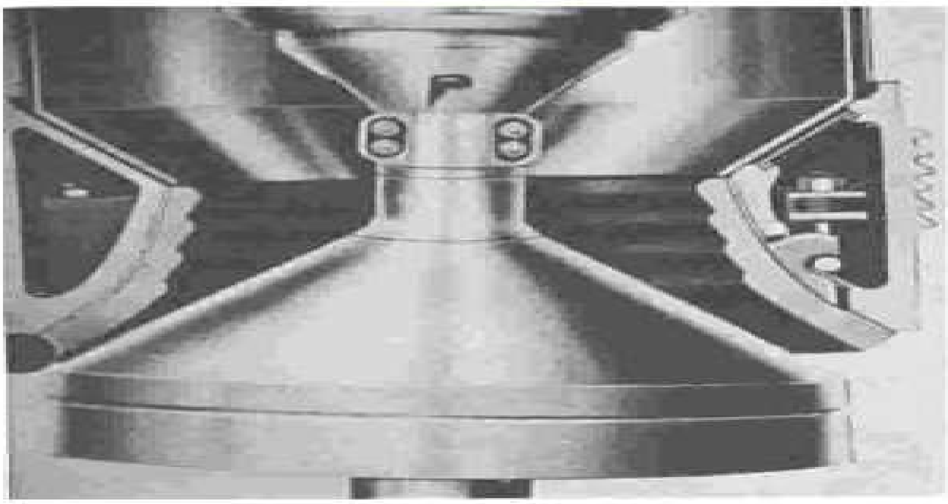


FIG. 6.12. Standard cone crusher.

## Gyratory vs cone crusher

1-shorter spindle of the cone crusher is not suspended as in the gyratory , but is supported in a curved , universal bearing below the gyratory head or cone.

2- capacity of cone crusher is higher than gyratory

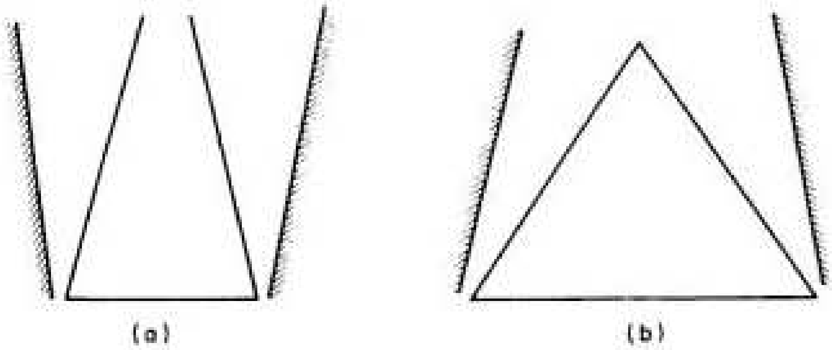


FIG. 6.11. Head and shell shapes of (a) gyratory, and (b) cone crushers.

## Roll crusher

1- roll crushers are now a days replaced by cone crushers in many mills but still some mills used it.

2-they are mostly used for sticky , friable , frozen and less abrasive feed as lime stone, coal, chalk, gypsum, phosphate, and soft iron ore .

3- advantage over gyratory and jaw crusher is that it will not choke near the discharge end when crushing friable rock with a large proportion of maximum size pieces in the feed.

4- function of roll crusher is very simple .

Construction and working :

1-it consist of two rolls(horizontal cylinders which revolved toward each other

2- the set is determined by shims which cause the spring loaded roll to be held back from the solidly mounted roll .

3-the crushing process in roll crusher is one of single pressure where as in jaw and gyratory it is a repeated pressure.

4- some roll crushers are made up of one rotating cylinder which revolved towards a fixed plate others use 3, 4, 6, cylinders

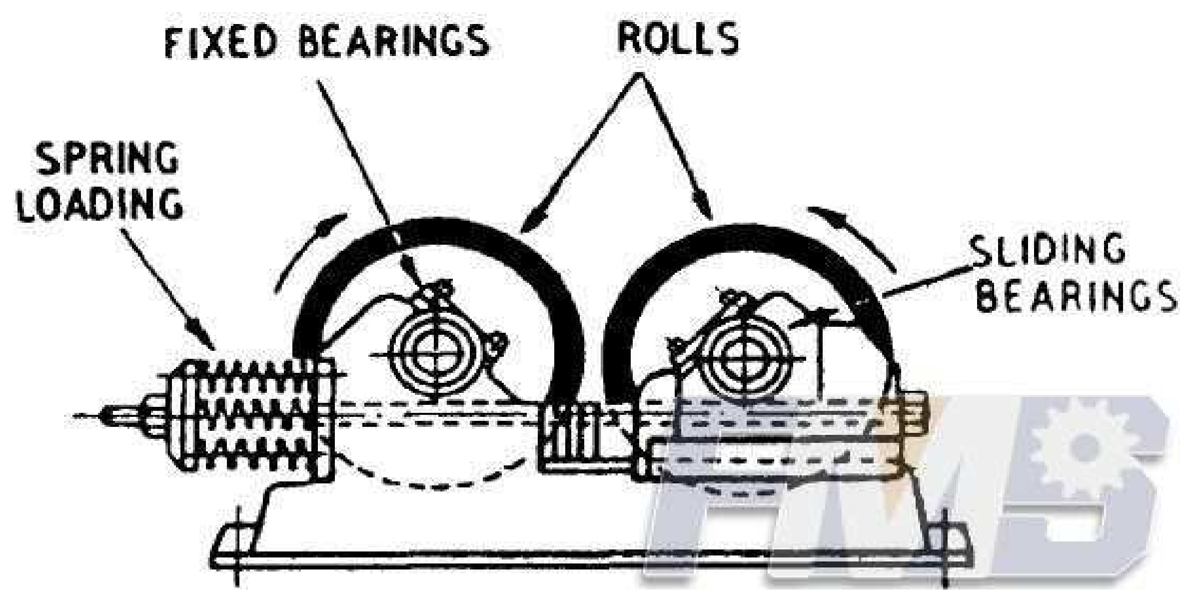
5- diameter and speed of the roll varies from crusher to crusher

6- the rolls may be grear driven , but this limits the distance adjustment between the rolls , but where as Modern rolls are driven by v belt from separate motors

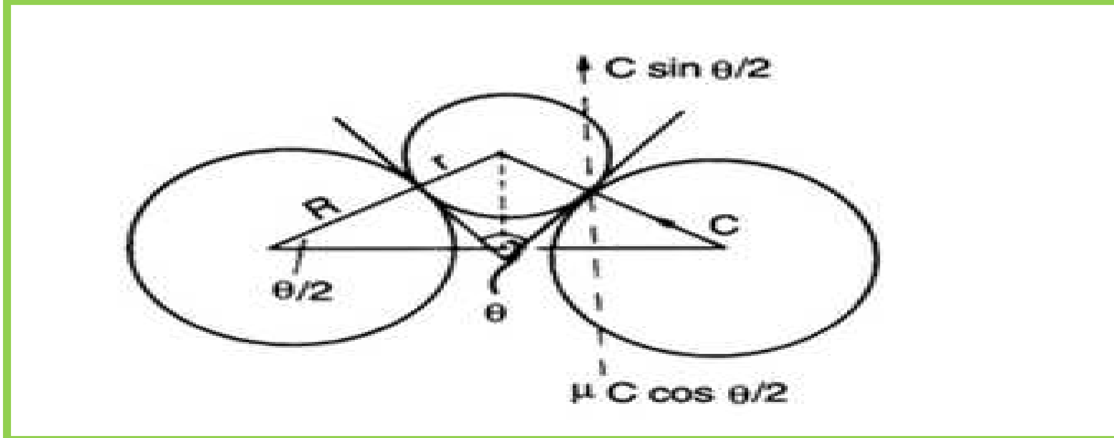
Multi roll machine may use rolls in pair or in set of three .

Disadvantages of roll crusher:

In order for reasonable reduction ratios to be archived very large rolls are required in relation to the size of the feed particle they there fore have the highest capital cost of all crusher



Force on a particle in a crushing roll




Radius of the particle= r

Radius of the rolls =R

Gap between the rolls= 2a

Coefficient of friction between the particle and the roll = μ

Angels formed by the tangent to the roll surface at their point of contact with the particle (angle of nip)=θ

Compressive force exhausted by the rolls acting from the roll centre through the particle centre =c

Then the particle to be just gripped by the rolls

Equating vertically

$C \sin \theta/2 = \mu c \cos (\theta/2)$

$\mu = \tan \theta/2$

The value of the coefficient of friction between a particle and moving roll can be calculated from the equation

$$\mu_k = \left[\frac{1+1.12\nu}{1+6\nu}\right]\mu$$

## Flow sheet of crushing plant

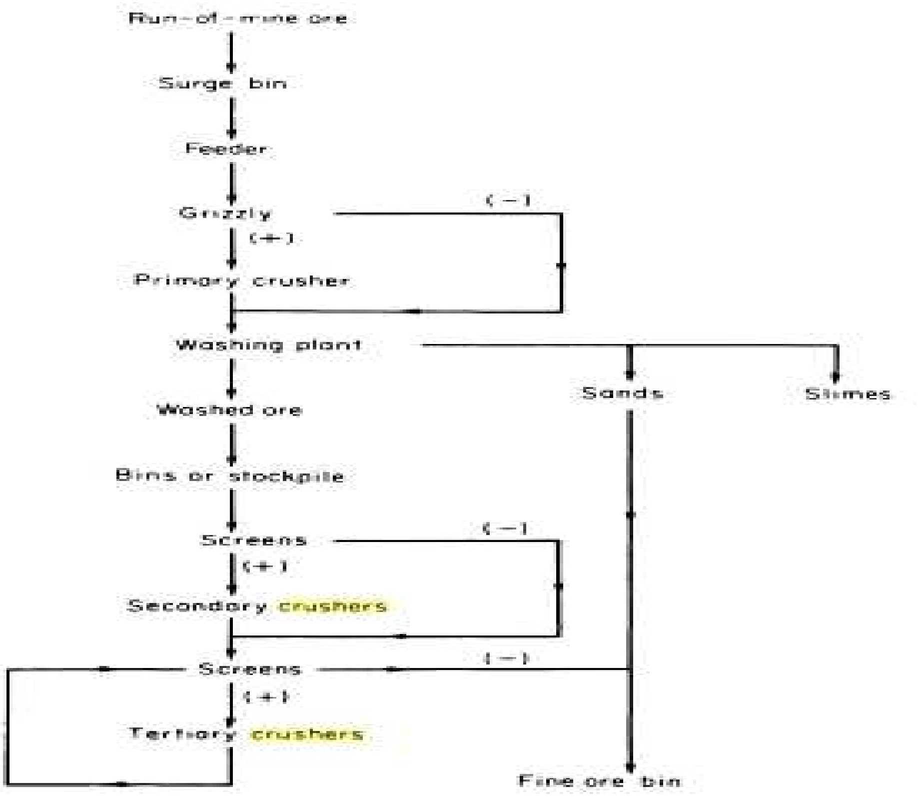
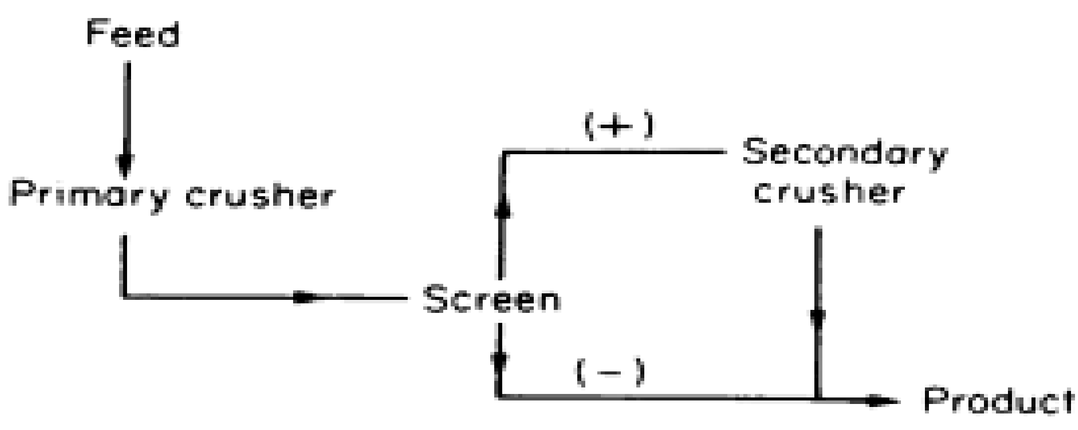


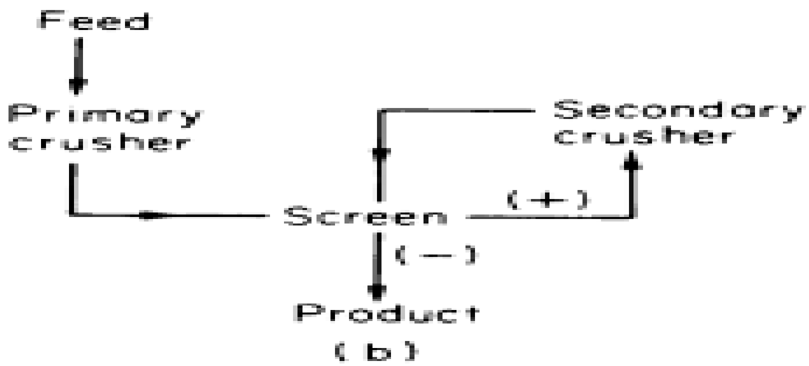

FIG. 6.1. Basic crushing plant flowsheet.

## Open circuit crushing




(a)

## Close circuit crushing




## Grinding

1. Last stage of comminution process
2. By impact and abrasion force the reduction in size of particles occurs
3. It is carried out in a mills called tumbling mills (which is a rotating cylindrical steel vessel.
4. The tumbling mills consist of crushed ore and grinding medium 10 to 300 micrometer  (steel ball, roads, rocks, or ore it self.)
5. Here the particles with size 5- 250 mm will reduced to
6. Correct grinding is sometimes said to be key to good mineral processing
7. Consequence of under grinding :

- (I)result in a product which is too coarse with a degree of liberation too low for economic separation.
- (II) poor recovery and enrichment ration will be achieved in the concentration stage

Conseque It reduces the size of comminution product (gangue , minerals ) below the size required for more efficient separation,

Much expensive energy is wasted in this process.

1. Grinding is usually performed wet , rarely dry grinding is carried out.
2. Mill charge consists of water , ore, and grinding media when it is rotated they get mixed
3. Most of kinetic energy of tumbling load is dissipated as heat , noise and other losses only a small fraction of energy is utilised for breaking the ore.
4. Control of the product size is governed by

type of medium used

the speed of the rotation of the mill

nature of the ore feed

and type of circuit used

13-gridninng process is a continuous process where material is charged from st0rage bins from one end and it comes out from other end after a particular dwell timence of overgrinding :

Ball mill

1-In a ball mill or pebble mill most of the reduction is done by impact as the ball or pebbles drop from near the top of the shell.

2-in a large ball mill the shell might be 3 mm in diameter and 4.25 m long .

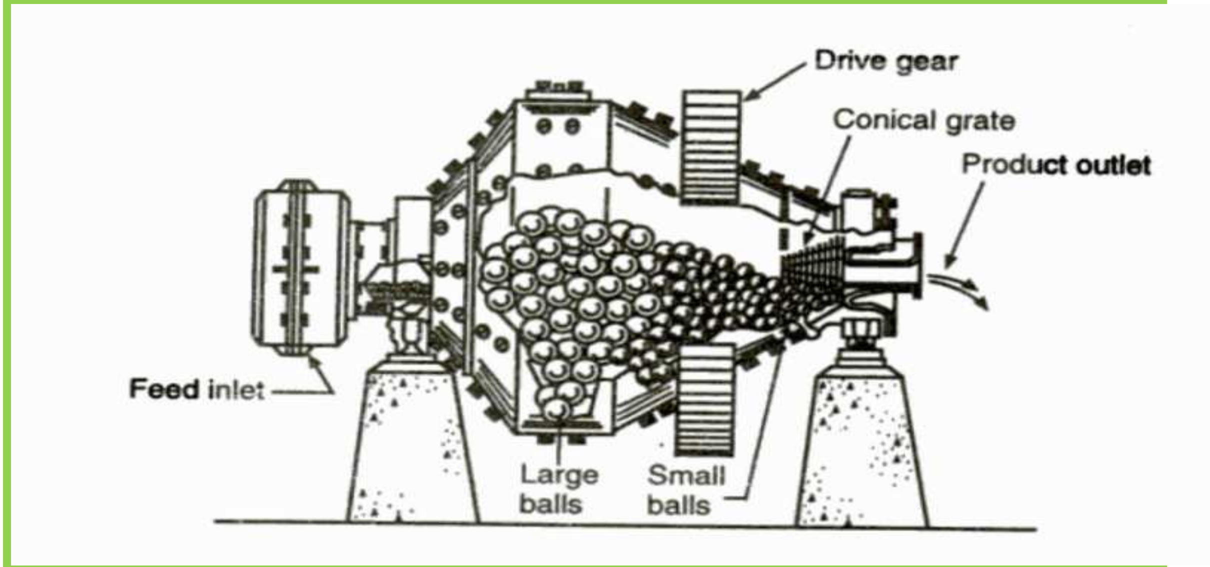
3- the ball are 25 to 125 mm in diameter

4-the pebbles are 150-170mm in size

5-a tube mills is a continuous mill with a long cylindrical shell ,in which material is ground  for2 to 5 times as long as the shorter ball mills.

6- tube mills are excellent for grinding to very fine powders in a single pass where the amount of energy consumed is not of primary importance  by putting slotted transverse partitions in a tube mill converts into a compartment mill. One compartment may contains large balls, another small ball and a third pebbles .

Conical ball mill




Motion of the charge in a tumbling mill :

1. distinctive features of the tumbling mill is its grinding media which are losse crushing bodies which are large , hard and heavy in relation to the ore particle , but small in relation to the volume of the mill and which occupy slightly less than half the volume of the volume.

2. due to rotation motion of mill the grinding medium is lifted along the rising side of the mill until a position of dynamic equilibrium is reached ,after that the grinding medium with the ore particles cascade and cataract down the free surface of the other bodies , about the dead zone where there is a little moments occurs , down to the toe of the mill charge.
3. Here the nature of the product with the wear on the shell lining is governed by the speed of the mill.

Grinding parameter in a ball mill

1- feeding arrangement

2-partciles size of the feed

3-gridning media -material , size ,quality

4-mill size , its speed and power consumption

5- solid liquid ratio and circulating load in a close circuit .

Phenomenon inside ball mill

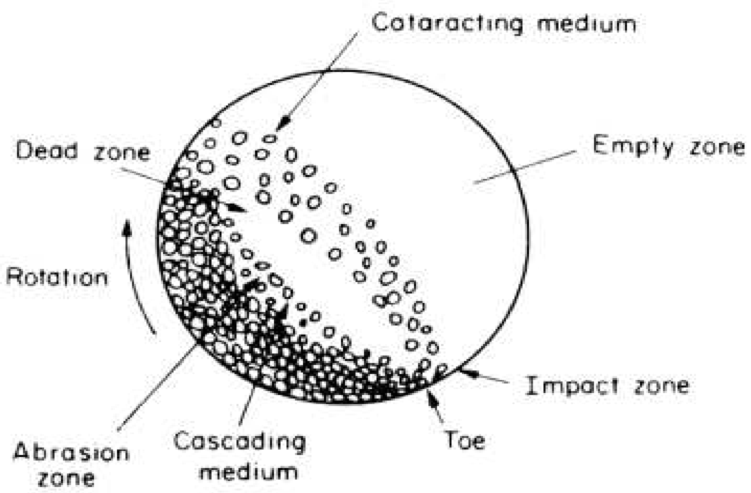


FIG. 7.2. Motion of charge in a tumbling mill.

Working of ball mill

1-When the ball mill is rotated the ball are picked up by the mill wall and carried nearly to the top(this is due to centrifugal force which keep the ball in contact with the wall and with each other during upward moment), where they break contact with the wall and fall to the bottom to be picked up again.

2- while in contact with the wall the ball do some grinding by sleeping and rolling over each other. But most of the grinding occurs at the zone impact , where the free falling balls strike the bottom of the mill.

3-if the speed is too high , how ever the ball are carried over and the mill is said to be centrifuging . The speed at which centrifuging occurs is called the critical speed.

During centrifuging no grinding or very little grinding occurs , so operating speed must be less than the critical .

The critical speed of ball mill is given by

$$n_c = \frac{1}{2\pi}\sqrt{\frac{g}{R-r}}$$

where,

$R$ = Radius of Ball mill;
$r$ = Radius of ball
$n_c$ = Critical speed of ball mill

Tumbling mill is run at 65 to 80 per of the critical speed , with low value of wet grinding in viscous condition

Application of ball mill :

Grinding coal , pigments, feldspar feed size of 2 inch .

The efficiency of the grinding increases with hold up in the mill until the void between the balls are filled

## Rod mill


## Theory of rod mill

1-similar to ball mill but difference is that they use rods for grinding rather than ball(grinding media).

2-the rod grind the ore by tumbling in side that mill. The length to dia ratio of rod is 1.4 to 1.6\

3-rod mill operates at lower speed than ball mill as they rotate not cascade .

4-For an equivalent grind a rod mill uses less steel than ball mill because of the lower speed and better contact between the ore and the rod.

5-rod mill requires more attention since it is important that the rod stay essentially parallel to one another if rod becomes misaligned, grinding action is lost and rod tanges occura

Max rod length is limited by 6.1 m .

Its carries 35-65 per rod by volume

## Open circuit and close circuit operation

Open circuit : the mill is said to be working on open circuit when the feed is broken into particles of satisfactory size by passing it once through the mill , when no attempt is made to return over size particle to machine for further reduction .

Disadvantage of open circuit : this process may requires excess amount of power for much energy is wasted in regrinding particle that are already fine enough

For example if a 50 mess product is required it is obviously waste full to continue grinding 100- 200 mesh material . Due to this reason close circuit is introduced to make the process economical

## Close circuit

To make the process economical close circuit is introduced where partially ground material is removed from the mill and pass it through a size reduction device . The undersized becomes the product and over sized is returned to be reground . The separation device is sometimes inside mill as in ultra fine grinder or as in more common it is out side the mill .

So we can say close circuit operation is that where a separator is used to separate the over and under sized particle and these over sized particle is returned to the mill once again .

For coarse particles the separation device is screen or grizzly , for fine powders it is some form of classifiers .

## Feed control

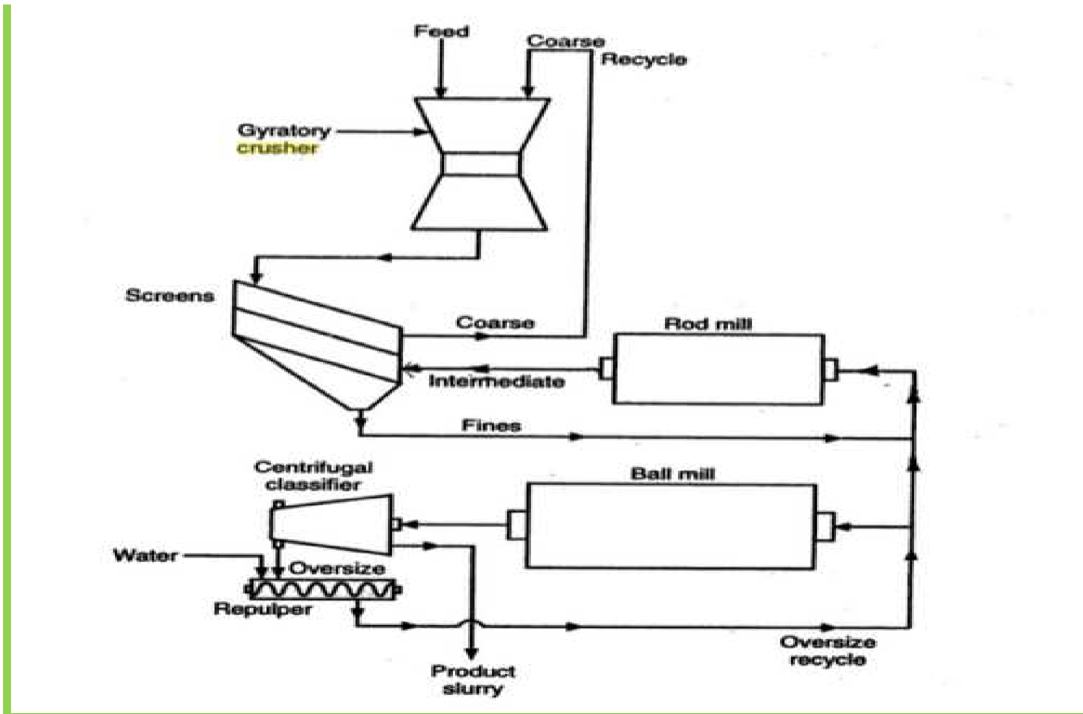
1- particles size should not be very large so that they cannot be broken by mils. They must be of appropriate size

2- effectiveness of many intermediate crusher and grinder is reduced if the particles size are very fine.

3-some solids requires pre compressing and chilling which enhanced it tendency  to ground

4- feed control must be in control limit other wise it leads to chocking and erractic variation of load.

## Flow sheet of closed circuit grinding



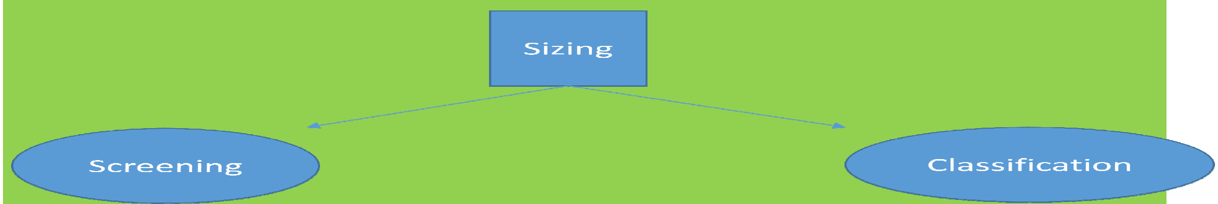

## Size separation

Separation of comminution products on basis of size is called sizing .

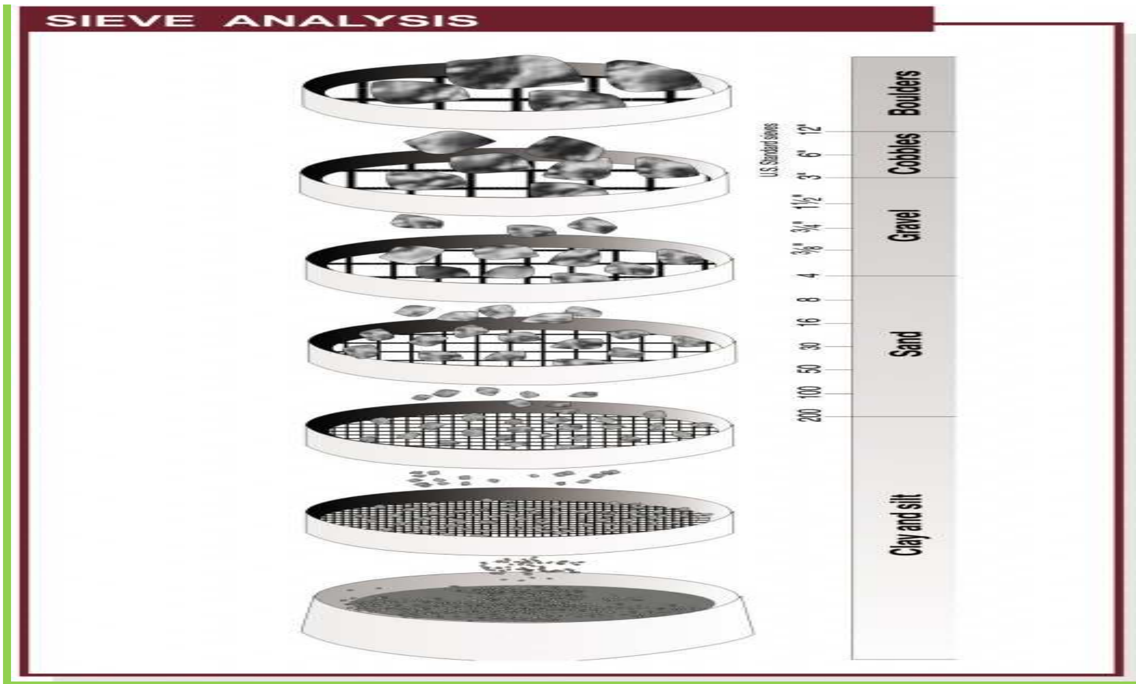
Importance of sizing :

1-to carry out further processing or for selling

2-to gauge(estimate the amount or level) the effectiveness of crushing and grinding operation also to taken up to control size reduction process.




## Sieving process



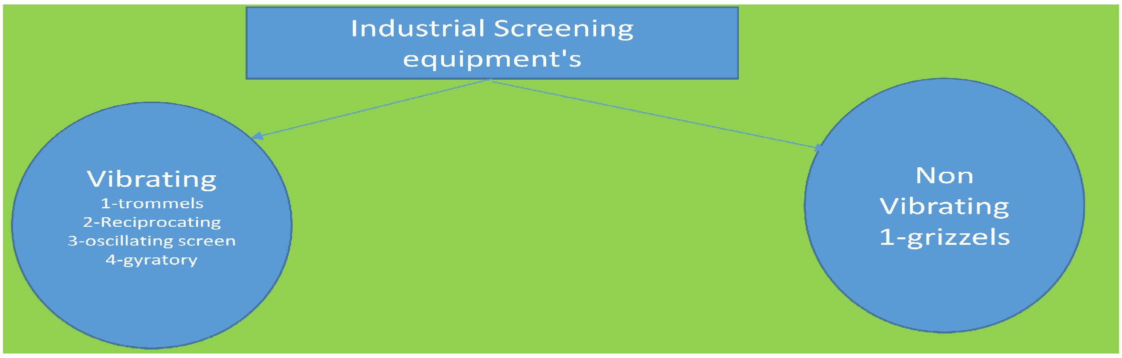

## Concept of mesh

The mesh number system is a measure of how many openings there are per linear inch in a screen. Sizes vary by a factor of $\sqrt{2}$. This can easily be determined as screens are made from wires of standard diameters, however, opening sizes can vary slightly due to wear and distortion.

As the mesh number increases the no of opening increases per liner inch , where as the size of the opening decreases.

## Screening

- Screen are attached with all types of crushing units at feed and discharge end
- Screening: it is carried out by passing the comminution products over a surface provided with opening of desired size.
- Screening equipment may be stationary or moving bar punched metal plate or woven wire mess.




1-grizzels (non vibrating )stationary screen

- -Screening large size particles more than 25 mm (used for primary screening).
- -consists of simple parallel heavy wear resistance manganese steel bars or rails separated by required space at the ends
- -these bar may be laid horizontally or inclined
- -usually cross section of the bar is trapezoidal with wide base upward to prevent clogging or weeding of particles

2-vibrating screen:

- -used for treating large tonnage of material
- -vibrating moting(shaking motion) is imparted by means of cam , eccentric unbalanced fly wheel, or electromagnetic mass.
- -it may be single doubled, or triple decked to obtain different size of particle from single feed
- - these screens can be used upto 35 mess
- - amplitude is usually 6-8mm
- - angle is around 20-30 degree for dry and 5-10 degree for wet

- -rpm is varied below 1200 -1800.

4-oscillating screen :

- a-these are characterized by relatively low speed in the range of 300- 400 rpm in plane ,essentially parallel to screen

b-the riddle is a screen driven in a oscillating path by an eccentric or other mechanism attached to it

5-Reciprocating screen :

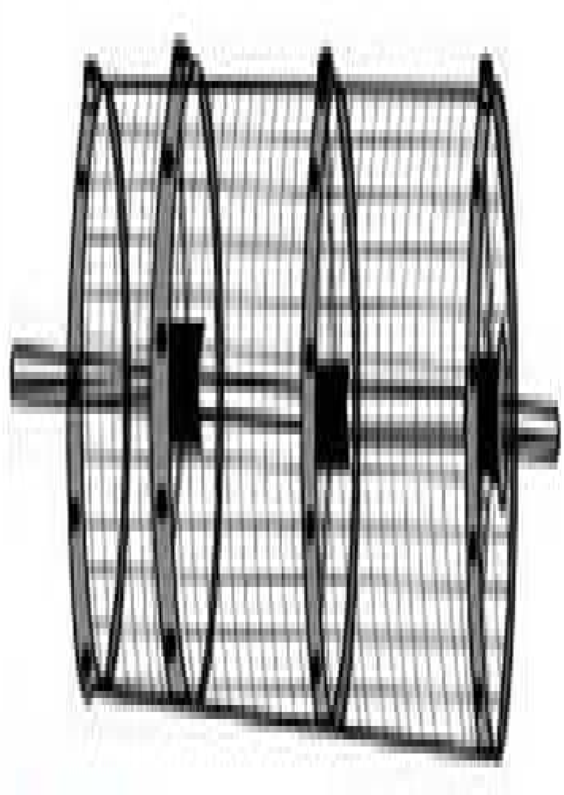
- a-these are driven by an eccentric under the screen at the feed end
- b-the motion varies from gyratory (up to 50 mm dia ) at feed end to a reciprocating motion at the discharge end the inclination is about 5 degree

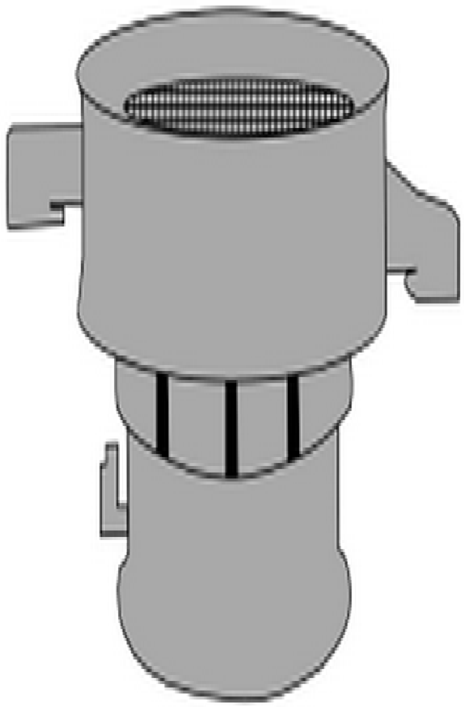
6-trommels ( vibrating screen)

- a-there are revolving screen or drum separator type consist of a screen in the form cylindrical or conical in shape rotated about its axis
- b-the material is feed at one end of the screen , the undersized materials falls through the screening surface while the oversize is conveyed by rotating motion down the incline to the discharge end .
- c-it can handle both dry or wet feed
- d- it can separate several size feed by using a series of screen from coarset t finest.
- e- cheap and most suitable for washing of coal and iron ore

7-gyratory screen :

- a-contains removable and replicable circular decks or trays for different size products .
- b- it works  both  gyratory and vertical motion  to the screen decks

| | |
|---|---|
| grizzle<br> | Tromme<br> |
| Vibrating screen | Gyratory screen |



factors affecting screening performance :

- 1-size
- 2-shape
- 3-orientation
- 4-feed rate
- 4-Angle of discharge
- 5-Percent opening area
- 6-Type of vibration
- 7-Moisture content
- 8-Feed material

Limitation of screening :

- There is a limitation of screen process since very fine particles (size is also very similar)cannot be sorted effectively into two or more products .
- Sorting (separation can only be possible on the basis of velocity with which the grain falls through a fluid medium.

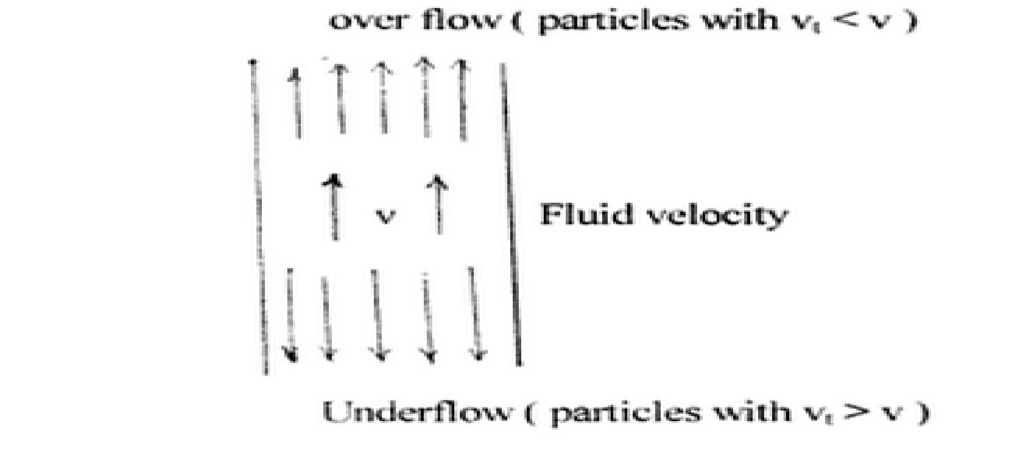
## Classification

classification can be defined as:

the method of separation or concentration by difference in the settling rate due to variation of particle size shape and density in a fluid medium is know as classification.

- Fluid medium :here fluid medium is water but in modified condition such as rising at uniform rate , changing density , addition of suitable reagent , and passing air bubble .
- Classifier consists of a sorting column in which a fluid rises at uniform rate ,particles introduced into the shorting column sink and report as underflow if their terminal velocity are greater than the velocity of water , and in other hand if their terminal velocity is less than upward velocity of the fluid , it rises and report as over flow.

## Sorting column




Hydraulic classifier

Working principle- difference in the settling rate of particles of feed pulp against the rising water current .

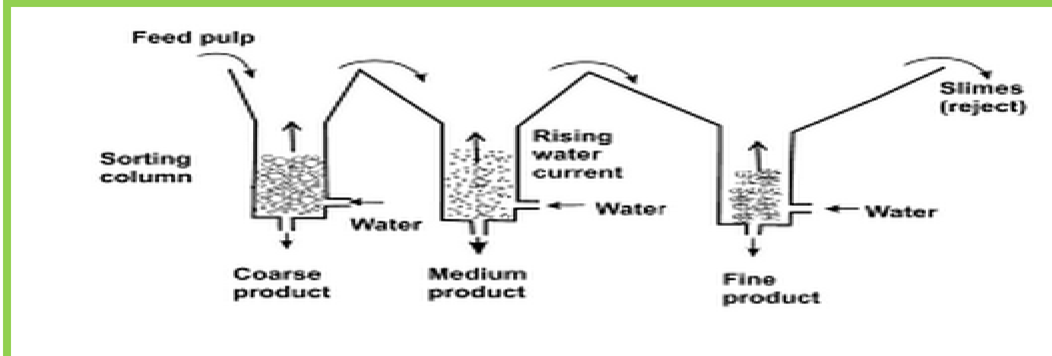
2-Unit is simple in design

3-consist of series of conical sorting columns

4-The columns in series are successively larger in size with relatively lower current velocity.

5-The relative rate of settling against the varying up flow current in each of the conical pocket accumulates coarser particle in the first to finest in the last

Hydraulic cyclone

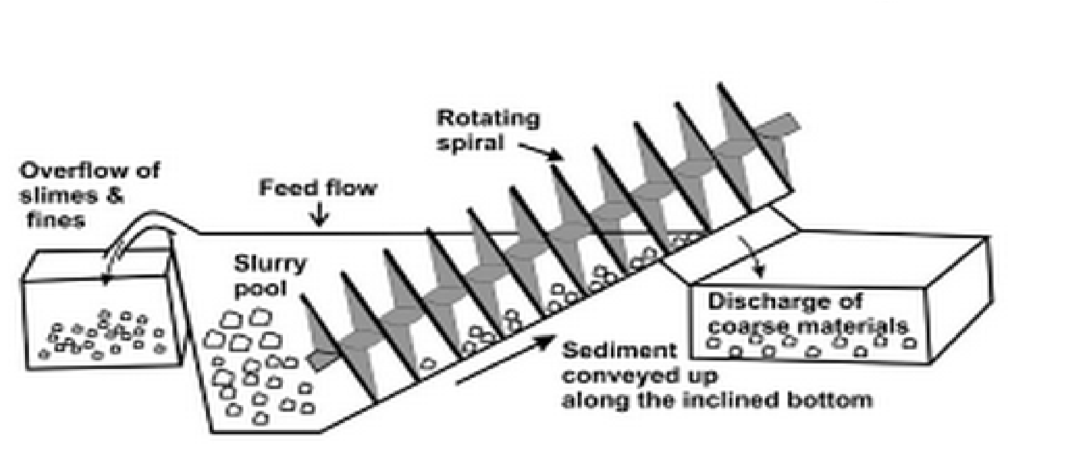



Spiral and rake classifier 1-mechanically driven devices

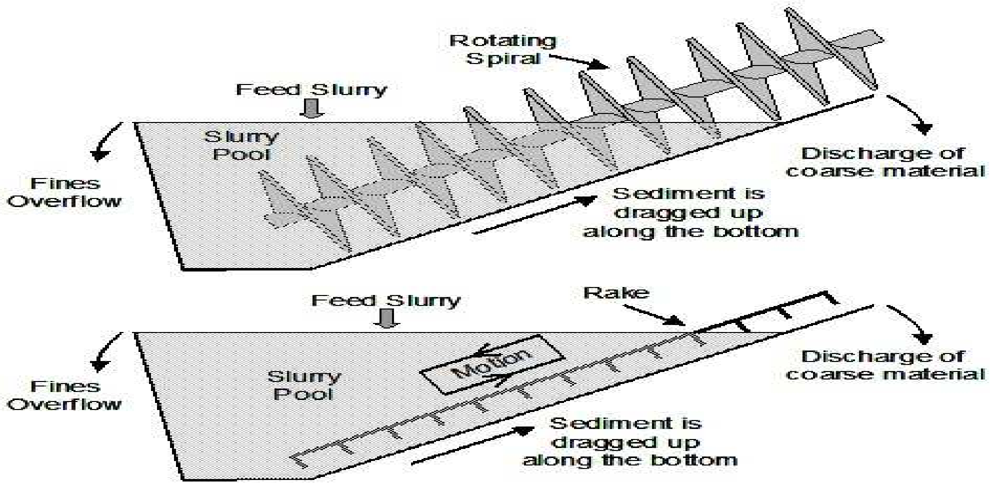
- The unit drag coarser sandy sediments from the settled feed pulp by a continuously revolving spiral along the bottom of an inclined surface to a high discharge point on one end of the settling tank the fines over flow at the other end .

- Rake classifier is a variation in the mechanism of shifting the coarser component .the rake dip into the feed pulp ,move in an eccentric motion along an inclined plane for a short distance then lift it up and go back to the starting point to repeat the operation
- Spiral classifier are prefer over rake  as the material does not slides backward.

Spiral



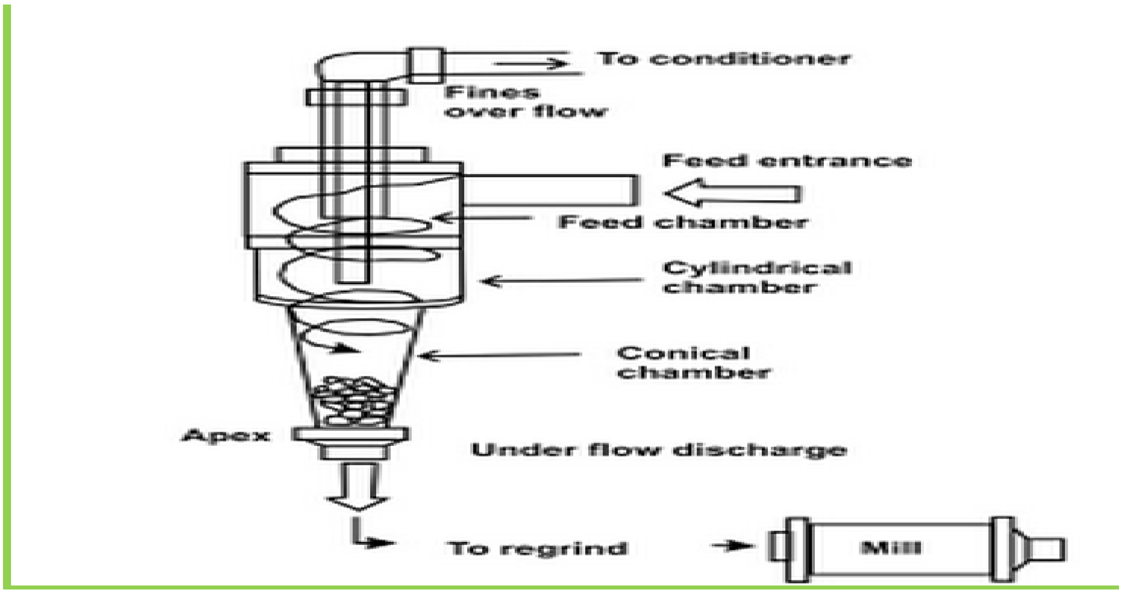

Spiral vs rake classifier



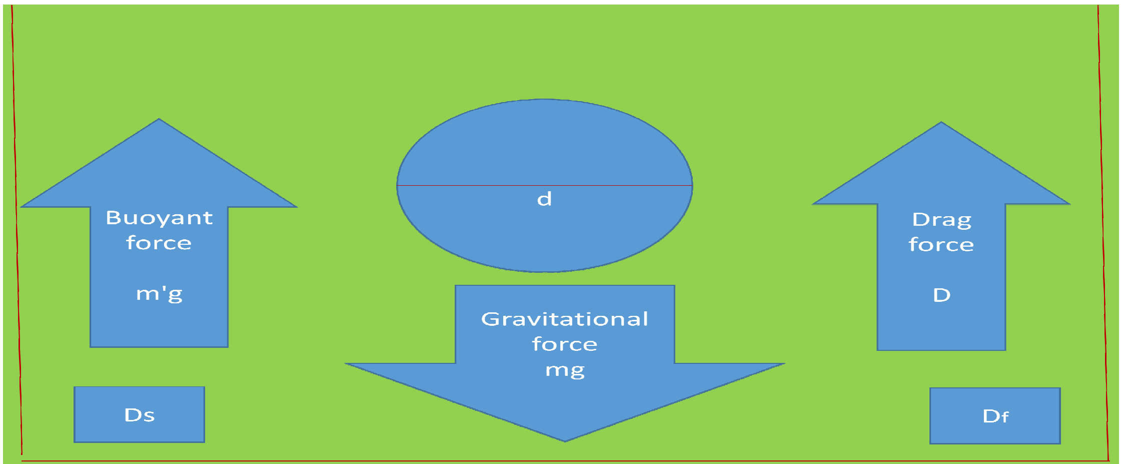

## Hydro cyclone

- Most imp and widely used classifier for base metals
- It is generally installed in close circuit between grinding and conditioning path for flotation of complex base metal ore.
- It consist of cylindrical section at the top connected to the feed chamber for continuous inflow of the pulp and an over flow pipe .
- The unit continues downward as a conical shape vessel and open at its apex to underflow of the coarser material .
- The feed is pulped under pressure through the tangential entry which imparts a spinning motion to the pulp .
- The separation mechanism works on this centrifugal force to accelerate the settling of the particles. The velocity of the slurry increases as it flows a downward centrifugal path from the inlet area to the narrow apex end
- The larger and denser particles migrates nearest to the wall of the cone the finer of lighter particles migrates

toward s the centre axis of the cone and reverse its axial direction




## Stocks law and terminal velocity(settling velocity)




Consider a spherical particle of dia d and density Ds falling under gravity in a viscous fluid of density Df under free settling conditions, ideally in a fluid of infinite extent. The particle is acted by three force

1- a gravitational force acting acting downwards

2-an upward buoyant force due to the displaced fluid

3-a drag force d acting upwards

d- diameter of spherical particle

Ds- density of solid

Df- density of fluid

M'-mass of the displaced liquid

M- mass of the particle

X- partial velocity

Equation of motion of particle is given by

Gravitational force – buoyant force – drag force = m dx/dt

mg - m'g – D = M dx/dt

At terminal velocity that is when upward force is equal to downward (x tend to 0)

That is dx/dt = 0

g(m-m') – D = m . Zero

g(m-m) – D = 0

D = g (m – m')

We know that density = mass/volume

So mass is equal to density x volume

D = g (Ds.v – Df .v)

D = gv (Ds – Df )

$= g [ 4/3 \pi (d/2)3 ] ( Ds – Df )$

$= g1/6 \pi d3 ( Ds – Df )$

Stocks assumed that the drag force on the a sphere particle to be entirely due to viscous resistance and deduced the expression.

$D= 3 \pi d \eta V$

Here

$\eta$ = fluid velocity

V= terminal velocity

$3 \pi d \eta V = \pi/6 g d3 (Ds – Df)$

$V = g d 2 (Ds – Df) / 18 \eta$

This expression is called stokes law

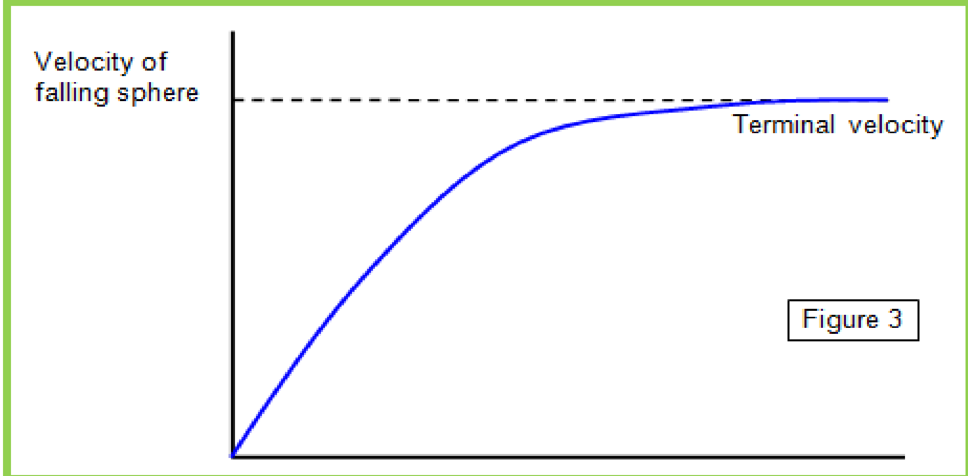
Newton assumed that the drag force was entirely due to turbulent resistance and deduced

$D= 0.55 \pi d 2 \ v 2 Df$

$0.55 \pi d 2 \ v 2 Df = \pi/6 g d3 (Ds – Df)$

$V = (3gd (Ds-Df)/Df)1/2$

This is newton's law of turbulent resistance



Stokes' law makes the following assumptions for the behaviour of a particle in a fluid:

1-Laminar Flow

2-Spherical particles

3-Homogeneous (uniform in composition) material

4-Smooth surfaces

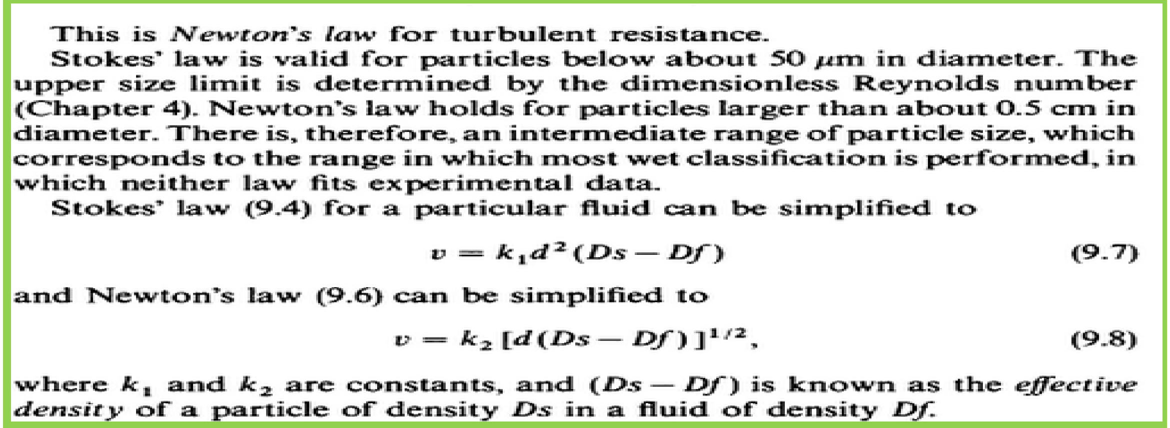
5-Particles do not interfere with each other.

Stokes law vs newton's law

Stockes law is valid for particles of size below about 50micrometer in dia.

The upper size limit is determined by dimensionless reylond number .

Newtons law is valid for particles of size greater than 0.5 cm in dia



This is *Newton's law* for turbulent resistance.

Stokes' law is valid for particles below about 50 $\mu$m in diameter. The upper size limit is determined by the dimensionless Reynolds number (Chapter 4). Newton's law holds for particles larger than about 0.5 cm in diameter. There is, therefore, an intermediate range of particle size, which corresponds to the range in which most wet classification is performed, in which neither law fits experimental data.

Stokes' law (9.4) for a particular fluid can be simplified to

$$v = k_1 d^2 (Ds - Df) \tag{9.7}$$

and Newton's law (9.6) can be simplified to

$$v = k_2 [d(Ds - Df)]^{1/2}, \tag{9.8}$$

where $k_1$ and $k_2$ are constants, and $(Ds - Df)$ is known as the *effective density* of a particle of density $Ds$ in a fluid of density $Df$.

Both laws shows that the terminal velocity of the particles in a particular fluid is a function only on the particles size and density

It can be seen that :

1- if the two particles have the same density then the particle with the larger dia has the high terminal velocity .

2- if the two particle have the same dia then the heavier particle has the higher terminal velocity

# MODULE-II

## Concentration

Concentration means enrichment of ore.

Here after seizing the particles are sent for concentration where the gangue (tailings) are separated from the valuable minerals, producing a concentrate and tailings.

| **Physical Methods to concentrate ores** | **principle** |
|---|---|
| **1.Sorting** | Is done by hand now a days done by machines Based on optical microscopy and other properties |
| **2.gravity concentration** | Based on difference in density among the minerals . different mineral have different hydraulic properties so they have differential moments in water.<br><br>Here in dense medium separating particles sink or |

| | |
|---|---|
| | floats in a dense liquid , or an artificial dense medium .<br><br>Specially carried out for iron ore , caol diamond ore processing. |
| **3.froth flotation** | Based on the different surface properties of the mineral .some mineral are attracted to water and some are oil(froth)air bubbles .<br><br>Here a pulp is used and many reagents are used in this process the valuables minerals are attached to air bubbles (froth) and rise up and get separated from gangue. |
| **4.Magnetic separation** | Based on the difference in magnetic properties of the mineral.<br><br>Some minerals are highly magnetic in nature they get attracted by low intensity magnetic field where as some minerals are less magnetic called diamagnetic so they get attached only by high intensity magnetic field. |

| | |
|---|---|
| | Mainly used for iron and tin ore , beneficiation.<br>In case of tin it is used to separate wolframite and hematite . |
| **5. electrostatic separation** | Based on electrical conductivity properties of minerals .<br>High tension separation can be used to separate from conducting minerals from non-conducting minerals. |

Gravity separation or gravity concentration:

1-separation of mineral by virtue of specific gravity.

2-Oldest one of mineral processing is hand sorting after that gravity method was introduces

3-Earlier days it was most dominating way to do mineral processing but due to development of other process like froth flotation, magnetic separation and leaching it was decline.

4-Mainly used for iron ore separation and coal separation:

Gravity concentration has a lower installed cost per tonne of through put that froth flotation for any given job and lower installed power requirement.

Gc do not use any costly reagents like ff.

Gc is somewhat environmental friendly process than that of ff.

Advancement in gc method:

1- High capacity

2- High efficiency

3- Inexpensive and simple equipment than older

gc method used to treat various minerals examples are _

Minerals Recovered by Gravity Concentration

| | | |
|---|---|---|
| Coal | Barite | Gold |
| Uranium | Fluorite | Silver |
| | Andalusite | Platinum |
| Iron Ore | Cassiterite | |
| Minerals Sands | Wolframite | Diamonds |
| Chromite | Scheelite | |
| Manganese | Tantalite | Sulphides |

## Principles of gravity concentration:

Gravity concentration can be defined as separation of two or more minerals, usually of different specific gravity, by their relative moment in response to the force of gravity and one or more other force, one of which is the resistance to motion by a viscous fluid such as water.

Factors affecting relative moments of particles:

1- weight

2- size

3- Shape

4- Specific gravity

Generally if two mineral are having all thing is same except one then it is easy to separate both.

Concentration criteria

(cc): provides idea of amenability of separation of two minerals.

It is defined as specific gravity of the heavy species minus density of the suspending fluid , divided by the specific gravity of the light species minus the density of the suspending fluid

Mathematically :

Sp. Gravity of heavy mineral – Sp. gravity of fluid /Sp gravity of light mineral – Sp gravity of fluid

Concentration criterion guide for gravity separation [1].

| Concentration criterion | Suitability to gravity separation |
|---|---|
| $CC > 2.5$ | easy down to 75 µm |
| $1.75 < CC < 2.5$ | possible down to 150 µm |
| $1.5 < CC < 1.75$ | possible down to 1.7 mm |
| $1.25 < CC < 1.5$ | possible down to 6.35 mm |
| $CC < 1.25$ | impossible at any size |

- Advantages of gravity separation are :

1. a low installed cost per tonne of throughput than flotation
2. lower installed power requirement
3. does not use expensive reagent

4. Environment impact is less as compared to flotation as it doesn't involves organic chemicals.

Gravity separation operation:

1- Jigging - in this process the bed of ore particle is vertically expanded or contract by help of fluid .

2- Shaking concentrators: employs a horizontal motion to the solid fluid stream to effetely fluidised the particle causing segregation of light and heavy particles.

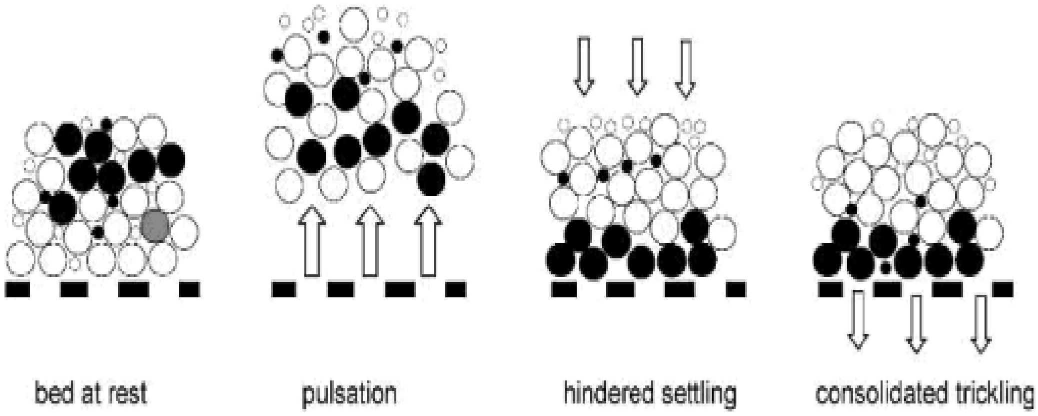
3- Flowing film concentrator: initiate particle separation by a layer of slurry flowing down an inclined surface under influence of gravity.

Some of the oldest knows concentrator

Jigs process

in a jig it consists of a perforated bed with a bed of different size particles . Stratification occurs due to expansion and contraction of the bed due to pulsation of fluid upward through the bed , this pulsation is done in acyclic manner (50-300 cycles per min ) due to this heavier particles and lighter particles get stratified .

Jigging operation (Expansion and contraction of bed due to jig action)




It is a special form of hindered settling resulting in stratification of particles into layers of different density followed by removal of different layer.

This stratification is achieved by repeatedly affording an oppournity to a very thick suspension of mixed particles to settle for a short time.

Principle of jigging:

Three factors responsible for stratification of particles during jigging are

1- Hinder settling

2-differentaial acceleration at the beginning of the fall

3- Consolidation trickling at the end of the fall

Jigging vs classification

1- In jigging the solid fluid mixture is very thick and it approximates to a closed packed bed of solid with interstitial fluid flowing through the particle rather than the fluid carrying the solid particle with it as in case of classifier

Jigging cycle :

It consist of pulsion and suction in case of pulsion the fluid moved upward through the bed of particles ,the bed expanded (fluidised ) and in suction the fluid return back downwards .

A complete cycle of of one suction and one pulsion is know as jigging cycle

Most jigs used pulsion and suction both but in some jigs only pulsion is used.

Jigs types

1- hand jigs – consist of rope pulley  and perforated cylindrical vessel . Here the jigs is vertically moved in water medium to carry out jigging process.

For laboratory purpose

2- mechanical jigs – shallow open tank containing a screen bottom on which ore is to be supported , a hydraulic water chamber , a reciprocationg system for pulsion and suction of water through screen

- Uses of jigs :

1. Used for cleaning coal
2. Heavy media separation including alluvial gold

- While treating coal and mineral the lighter particle is concentrate for coal and heavy fraction  is concentrate for mineral
- For this very reason gravity separation is product is called light or heavy rather than concentrate or tailings.

Differential motion table separator:

- Here an ore of bed experience a horizontal shaking motion which lead to the segregation of particles according to either size of density.
- If the particles are of same density then the particle's will segregates according to size with the fine particles sinking and the coarse particles rising to the top. And if the particles with different density exist then particles with higher density will sink to a lower level then lighter.
- Shaking tables:
- Here a differential motion(shaking where forward and backward moment accours) and a riffled deck with cross flowing water is used to create a particle separation.
- The shaking motion is asymmetrical, being slow in forward direction and being rapid in backward direction. Due to differential motion a conveying motion is imparted on the particle which are in contact with the table deck in the direction of motion due to friction.

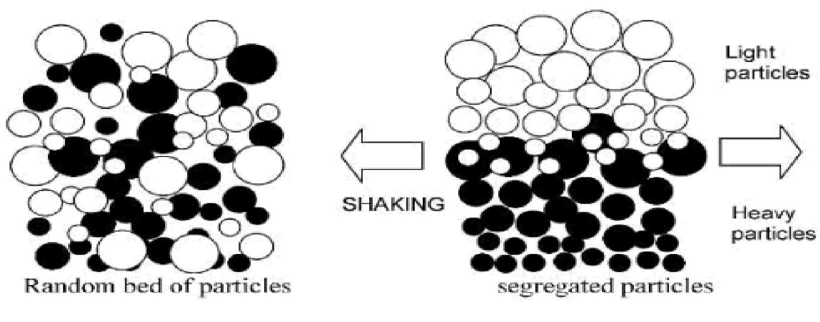


Fig. 15.8. Segregation of particles due to horizontal shaking motion.

- Wilfley table :

1. It consist of slightly inclined flat surface or deck with a series of parallel ridges and riffles along the direction of motion .

2. The riffles are tapered towards the opposite end of the reciprocating drive.
3. Feed is introduced at the corner of the table at about 25 per cent solid (by mass)and with the shaking motion , the particles spread out over the table
4. 4- Water is introduced along the top edge of the deck to assist segregating and transport of particles on the table.
5. Due to this the particles moves diagonally across the deck from the feed end.
6. As the feed material spreads out over the table the particles stratified in layers behinds the riffle.
7. The riffles help to transmit the shaking motion to the particle and prevent the particle washing directly off the table.
8. Here if the table operates in a correct manner then the middling's fraction discharge at the diagonally opposite corner of the table to the feed.
9. Size separation will be very difficult it there is range of size increases

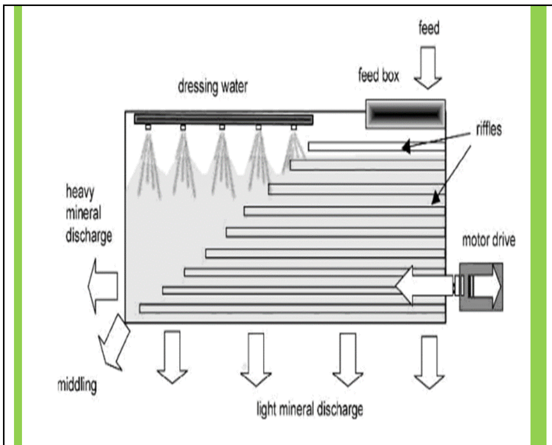
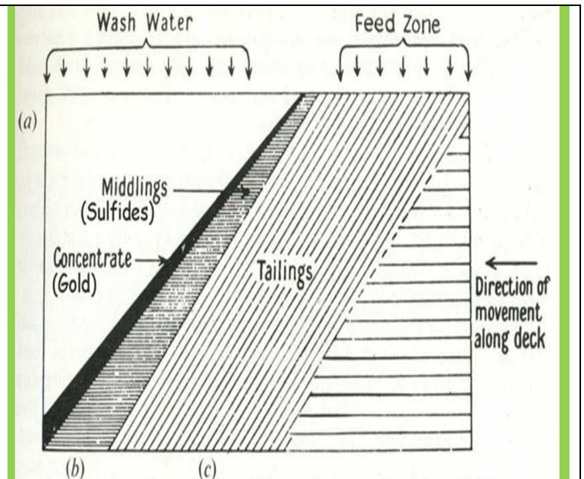


Fig. 15.9. Shaking table arrangement.



Separation of Ore Minerals on a Shaking Table

## Operating parameters

1. Particles size , shape
2. particles density
3. deck shape
4. riffle design
5. water and feed flow
6. stroke and speed of the table and deck slope

The lower size limit for an effective separation on a table is about 50 micro meter even if the density difference is high

- For optimum table operation the feed flow of solids and water onto the table must be uniform and constant

## Flowing film concentrator:

- Fluid flow can be classified into three categories:

1. laminar or stream line flow [ Re <= 2100 ]
2. turbulent or eddy flow[ Re >= 4000 ]
3. mixed flow –combination of laminar and turbulent flow [ 2100 <= Re <= 4000

- Re= average velocity x diameter x kinematic viscosity

- Kinematics viscosity = viscosity of the fluid / specific gravity of the fluid

- 1-liquid films under laminar flow have specific mechanical properties that can be easily adopted to separate the mineral according to their specific gravity.
- 2-Specific mechanical property is that , the velocity of the fluid is not the same at all depth of the film .
- 3- suppose we consider a fluid flowing in a rectangular open channels then the fluid velocity at the bottom of the depth at A is nil and is maximum at the top B . similarly in case of a pipe the flow is maximum along the central axis and nil at the inner periphery of the pipe .
- 4- This property in turn depends upon the viscosity of the fluid .
- Experimental facts of flowing film concentrate can be summarized as follows:
- 1-fine- heavy particles
- 2-coarser- heavy and fine light particles
- 3-coarser – light particles
- It is interesting to note that flowing film concentrate places the coarser heavy particle with the fine light particle . this is reverse of stratification that takes place during jigging .

Heavy media separation or dense media separation : ( HMS)or (DMS)

1-Also called sink float separation .

2- Here a fluid (medium) is used whose density lies between the density of two mineral

3- Here the lighter mineral will float in the fluid medium and the heavy mineral will sink

It is a special concentration process which mainly depend upon specific gravity. Here particle size do not come into account.

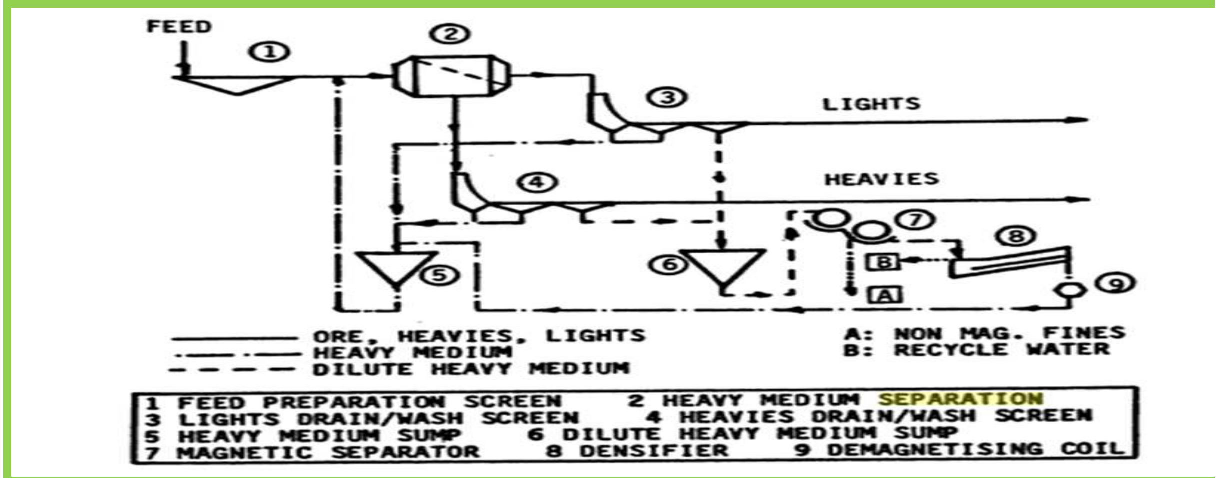
In this process the mineral is put into a fluid whose specific gravity lies in between the specific gravities of the two minerals that are to be separated from each other.

If there are more than two mineral in an ore then the heavy mineral is generally recovered as sink and the waste as float.

For example the most metallic oxide lies in the range – 3.5 to 4.5 gm/cc, silica the main component of gangue having a density of 2.65 gm/cc. we use a heavy media whose density is 3.gm/cc , here the metallic oxdie sink but silica flot.

Generally heavy minerals or alloys grounded up to -100 mesh size are normaly used . examples are galena , and ferro silicon.

Heavy media separation circuit



## Froth flotation:

Principle of concentration in this process depend on  surface characteristic of minerals(hydrophobicity /hyrophillicity), some minerals adhere to water and some air.

Or we can say difference in wettability of different minerals

So due to adhesion of some mineral to the air bubbles it rise in the pulp and get separated from the from the mineral with are completely wetted .

In maximum case mineral are not having this properties to adhere to air bubbles or foam (hydrophobicity0  . that means natural hydrophobicity is not there so by using chemicals, mineral surface are selectively alter so that they have the necessary properties for separation.

Example of some minerals showing hydrophobicity

1- Hydrocarbons (coal)

2- Elemental sulphur

Mainly used for sulphide mineral concentration to separate usefull minerals and silica

And generally used for fine grained ore that are not amenable to conventionally gravity concentration

So function of chemicals is selective coating a particle surface with a mono layer of non polar oil .

1- selective attachment of valuable minerals to air bubble this is due to fact that on adding chemical reagent (collector)to the pulp or slurry this reagent will adsorbed on the surface of the mineral forming a continuous heteropolar film in the range of molecular level .

The heteropolarity of the film is such that , the non polar part of the film is oriented away from the mineral body . So the mineral particle as a whole behaves lkike a non polar particle , becomes non wettable and attached itself preferentially with a air bubble.

In froth flotation the mineral is usually transferred to the froth or float fraction leaving the gangue in the pulp.

Direct flotation and indirect flotation is there it is just vies versa of previous.

Reagents

1- collectors

2- frothers

3- modifiers

Collectors : main function of collector is it makes the selected minerals hydrophobic by forming a continuous film of heteropolar at molecular level.

Due to this these minerals get adhere to air preferentially and start floating .

Collectors classification :

1- cationic- if the part which impart water repellancy to the mineral surface carries a negative charge

2- anionic - if the part which impart water repellancy to the mineral surface carries a positive charge

Collectors are heteropolar that means one portion is polar and other is non polar.

Examples of collectors :

Anionic collectors : potassium or sodium ethyl xanthate, dithio phosphate, fatty acids

Cationic collectors: fatty amines aceates

Frother :

main function is to form a stable and particular size of froth on which collector coated mineral get attached and floated up.

These are heteropolar in nature having one of more water repellent and water loving polar group.

The froth must be stable and strong enough to support the weight of the desired mineral attached to it and permits it separation from the pulp.

Most important point is these froth must breakdown when they are removed from the flotation cell.

Examples : pine oil, aliphatic alcohol, cresylic acids

Modifiers or regulator :

They modifies the action of collector either by enhancing or by reducing its water repellent effect on the mineral surface .

They make collector action more selective towards certain mineral

1- activator – it help in reactivate or increase the susceptibility to flotation of some mineral that has been depressed ex- cuso4 is a standard activator for sphalerite

2- ph regulator: optimum result only in a particular range of ph value of the pulp .for this reason proper ph control of the pulp is of greater importance.

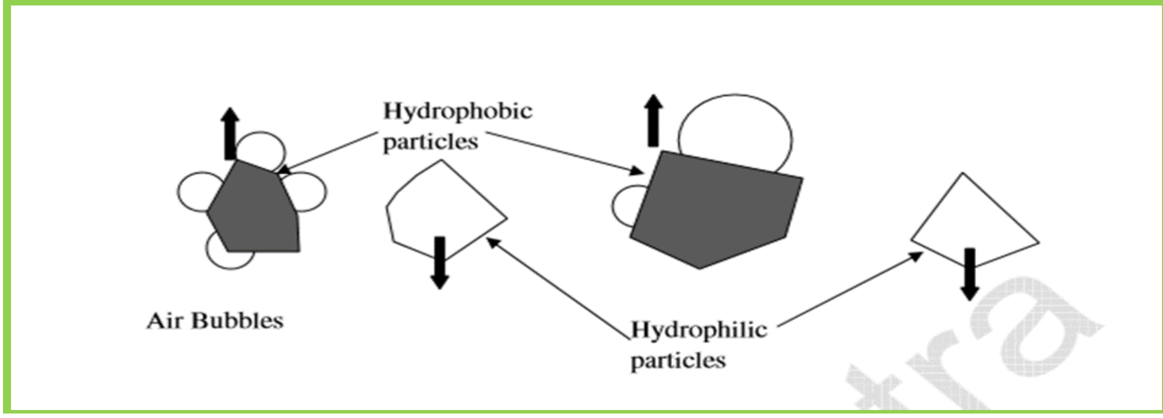
ex- ,soda ash, and h2so4

3- depressant : some times we want differential flotability for which it is desirable to prevent or supress the flotation of one mineral over another . Ex= cyanide,lime acts both as ph regulator and depressant

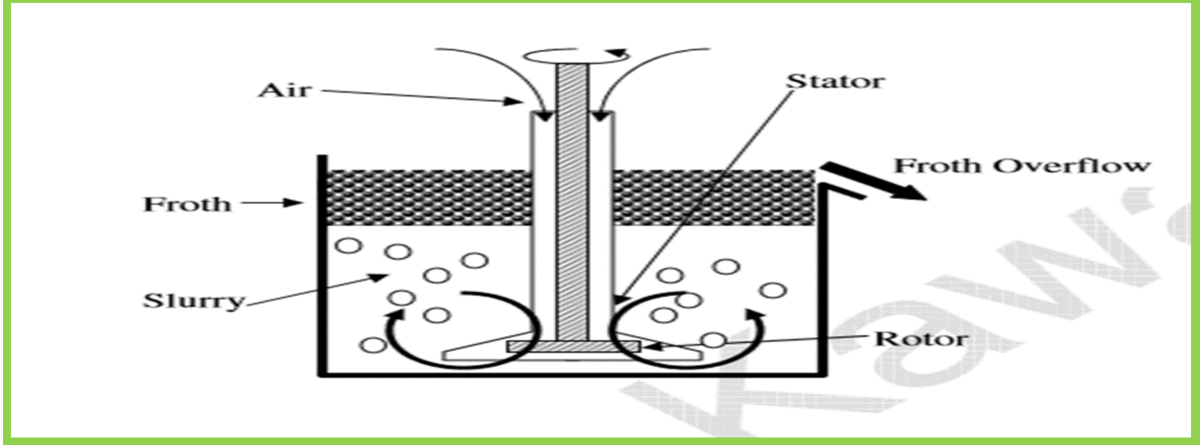
4- dispersant :sometimes the gangue may be of such nature that it flocculates to such an extent which may interfere with effieient flotation of the desired mineral . It is essential to use a dispersant .

A **dispersant** or a dispersing agent or a plasticizer or a superplasticizer is either a non-surface active polymer or a surface-active substance added to a suspension, usually a colloid, to improve the separation of particles and to prevent settling or clumping.

Ex- starch and glue



Selective attachment of the air bubbles to hydrophobic particle .the buoyancy of the bubble then carries these particles to the surface , leaving the hydrophilic particles behind




Magnetic separation

Magnetic separation :

Principle : difference in the magnetic properties between different minerals or between minerals and gangue

Used to separate : valuable minerals from non magnetic gangue

Eg- magnetite(magnetic) from quartz (non magnetic )

Magnetic gangue or contaminants from non magnetic values

Eg- tin ore that is cassiterite (non magnetic ) is separated from traces of magnetite ,wolframite (gangue)

classification of material on basis of whether thy are attracted or repelled by the magnet :

diamagnetic: these material get repelled in the magnetic lines of force where the field intensity is smaller .

ex- quartz

Diamagnetic material cannot be separated by magnetic concentration process because force involved are very small.

Paramagnetic: these material get attracted along the line of magnetic force to a point of greater field intensity .

Paramagnetic materials can be concentrated in high intensity magnetic separator

Examples of paramagnetic minerals : ilmenite ($FeTiO_3$) , rutile ($TiO_2$),

wolframite ($(Fe\ Mn)WO_4$), monazite

$(Ce,La,Nd,Th)PO_4$

, siderite (Feco3), Pyrrohotite ($FeS$), Chromite ($FeCr_2O_4$), hematite ($Fe_2O_3$) and manganese material.

If we see elements such as Ni co, Mn Cr , Ce, Ti , O and Pt are paramagnetic in nature but in most cases the paramagnetic properties of mineral is are due to presence of iron in some ferro magnetic form .

Ferromagnetism is a special case of paramagnetism where very high force is involved .

If we see ferromagnetic materials they retain magnetism even after removal from the field called remanence. They can be concentrated using low intensity magnetic separator.

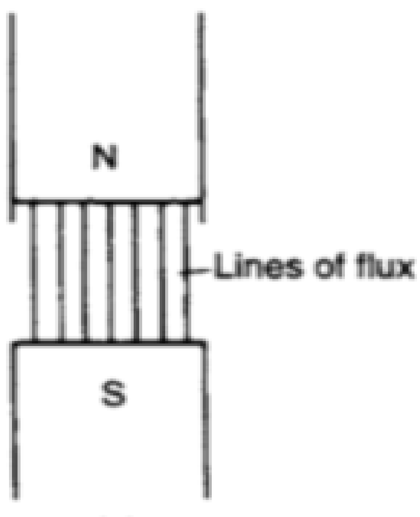
Ex- magnetite ,

Magnetic separator design :

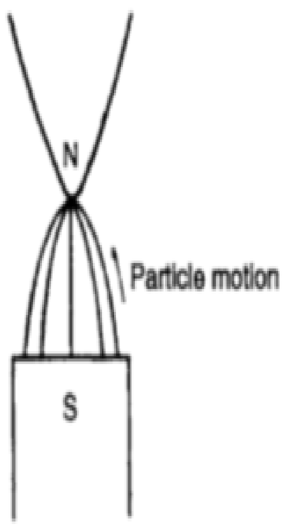
Prime requirement of magnetic separator is a provision of a high intensity field in which there is a steep field strength gradient

From this figure (a)we can see there is field of uniform flux (lines are straight ), magnetic particle will orient themselves but not move along the lines of force since there is not field gradient here.

But to produce a non uniform flux(conversing flux)(we have to change the shape of the pole by making one pole tapered which concentrate the magnetic flux into a very small area giving high intensity and other pole is flat due to which the same total magnetic flux distributed over a large area. Due which a steep field gradient across the gap by virtue of different intensity field. Can seen from fig (b)

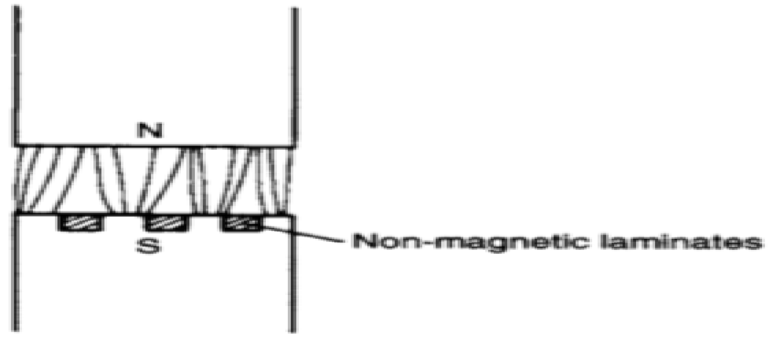



(a)




(b)

- Other method of producing a field gradient is : shown in the fig c Using a poles with is constructed of alternate magnetic and non magnetic laminations.




2nd important point about the separator is provision for regulating the magnetic field so as to deal with various kind of material. This can be achieved by using electromagnetic separator by varying the current; if permanent magnetic is there we can vary the interpole distance

Industrial magnetic separator:

It a continuous processing machine and separation is carried out on moving steam of particles passing into and through the magnetic field.

It is essential that speed of particles must be closely controlled while passing through the magnetic field which rules out free fall as a mean of feeding.

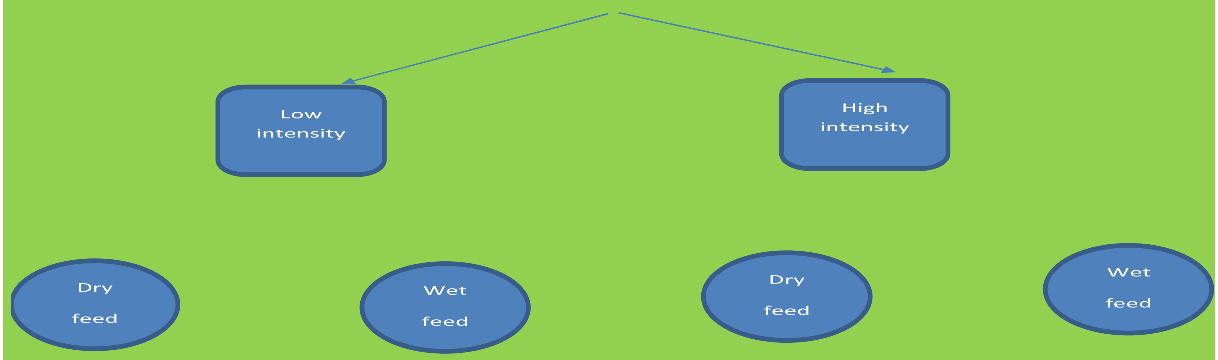
Industrial magnetic separator:

- It a continuous processing machine and separation is carried out on moving steam of particles passing into and through the magnetic field .
- It is essential that speed of partciles must be closely controlled while passing through the magnetic field which rules out free fall as a mean of feeding .
- To transport the feed through the field we can use either drum of belt

- Some times flocculation or agglomeration of the particles take place during M.S called (magnetic flocs) if the
- 1- Particles are very fine and highly susceptible
- 2- Field is intense
- Due to formation of these magnetic flocs they entrain gangue and can bridge the gaps between magnetic poles. Reducing the efficiency of separation.
- Flocculation is especially serious with dry separation machine operating on fine materials. This can be minimised if the ore is feedthrough the field in a monolayer , this effect is much less serious , but off course , the capacity of the machine is drastically reduced .
- 2nd method to reduce is by passing the material through the consecutive magnetic field, which are usually arranged with successive reversal of the polarity. This cause the particles to turn through 180 degree , each reversal tending to free the entrained gangue particle .
- This process has a great disadvantage that is flux leakage occurs from pole to pole reducing the effective field intensity.

Provision for Collection of magnetic and non magnetic fraction must be incorporated into the design For better working the magnetic are allowed to come in contact with a conveying device rather that the pole of the magnet, which carry them out of the magnetic field

Type of magnetic separator



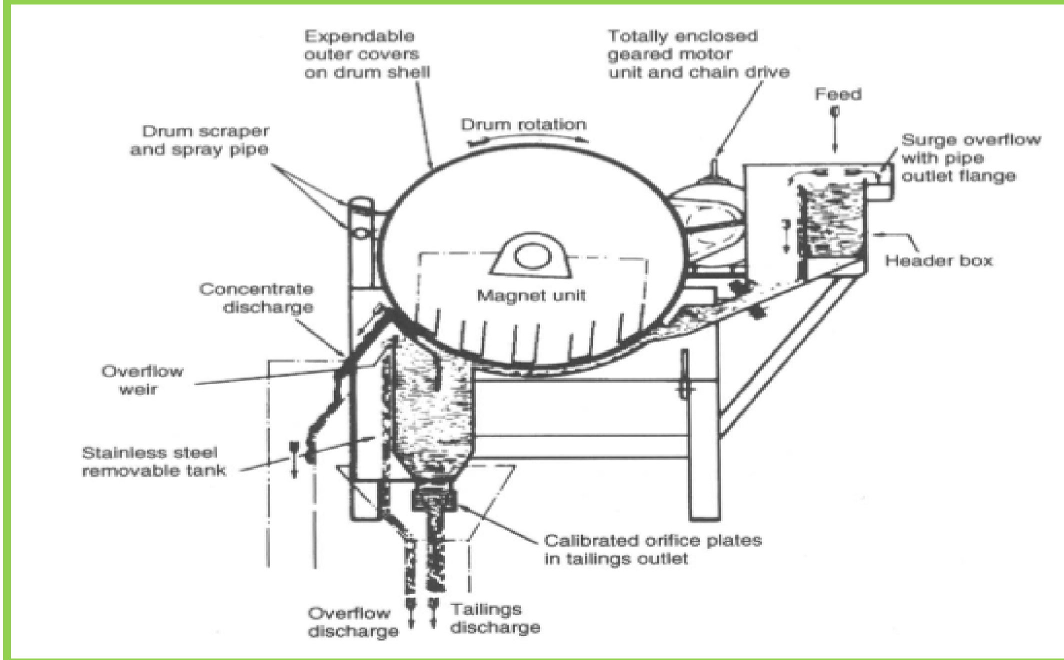

## Dry Low intensity magnetic separator

- Used for concentration of coarser sand which are strongly magnetic in nature
- Concentration is carried out using drum type separator
- Process is called is cobbing

## Wet low intensity magnetic separation

- When the size of feed is less than 0.5 cm
- This produce clean product and prevent dust loss
- Widely used for purifying the magnetic medium in the dense medium separation process as well as concentration of ferro magnetic sand

## Drum separator:




Commonly used for cleaning the medium in DMS circuits and widely used for concentration of finely ground ore.

1- Consist of rotating non magnetic drum

2- 3-6 stationary magnets of alternating polarity

3- Initially drum separators used electromagnetics

4- Modern devices used permanet magnets made up of rare earth or ceramics magnetic alloys , which retain there intensity for indefinite period of time .

5- Separation is by pick up principle where magnetic partilces are lifted by the magnets and pinned to the drum and are conveyed out of the field , leaving the gangue in the tailing compartment.

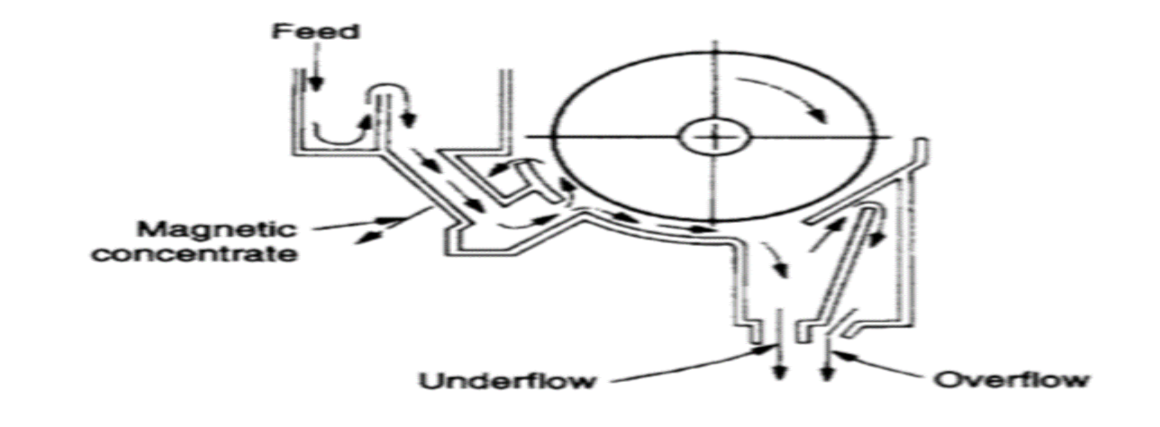
6- Water is introduced into the machine to provide a current which keep the pulp in suspension

7- 8- filed intensity upto 0.7 tesla at the pole surface can be obtained in this type of separator.

8- Above drun separator is a concurrent type where by the concentrate is carried forward by the drum and passes through the gap where it is compressed and dewatered before leaving the separator

9- Above design produce clean products from relatively coarser material

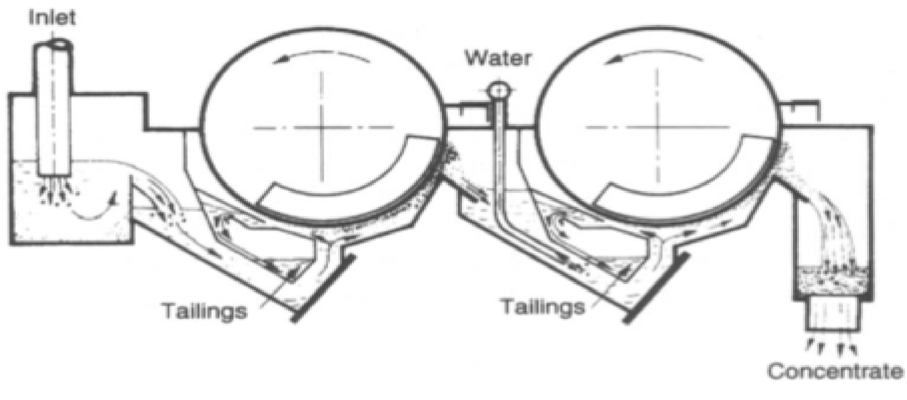
Counter rotating drum separator




- Above fig shown a counter rotation drum separator where the fed flow directis just opposite to that of drum rotation.
- Used in roughing operation , where occasional surges in the feed must be handled
- 2- where magnetic material losses are kept minimum , while extreme clean concentrate is not required
- When high sold load is encountered

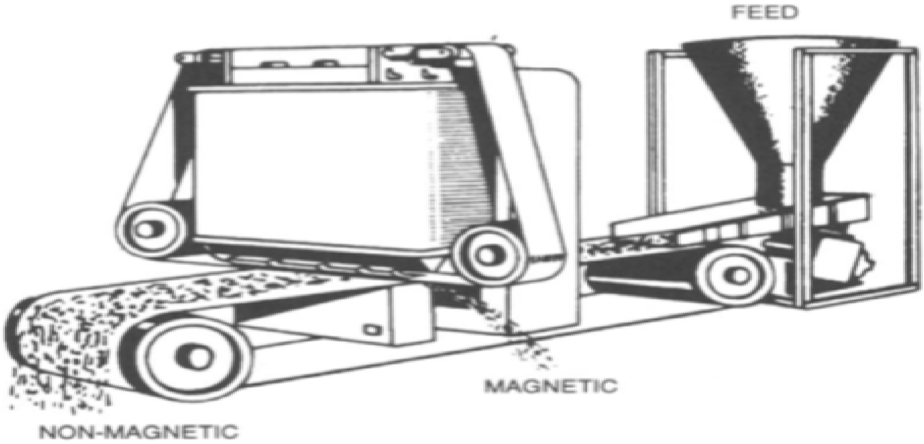
Counter current separator

- 1-Here tailings are forces to travel in the opposite direction to the drum rotation and are discharged to the tailings chute
- Used for finishing operation on relatively fine material of particle size less then about less than 250 micrometer



Counter-current separator

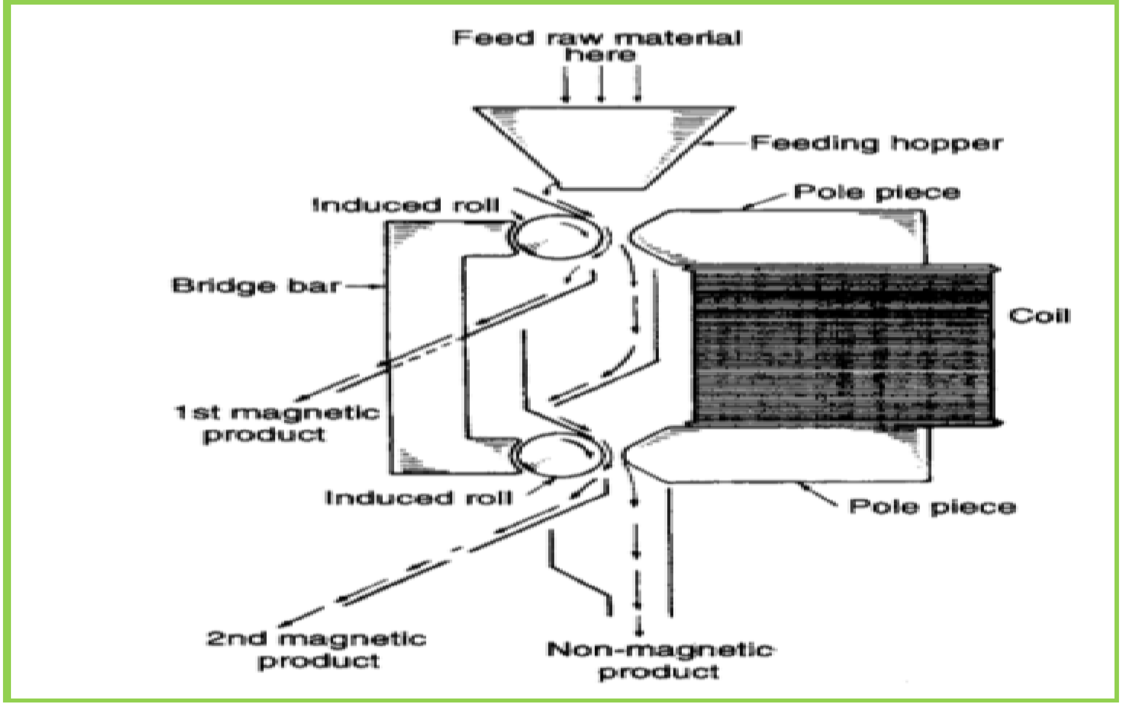
Cross belt separator: initially are used for recovering ilmenite from heavy mineral concentrate ,




- This system is obsolete

- There are replaced by rare earth roll magnetic separator and rare earth drum magnetic separator
- Rare earth magnetic separator uses magnetic and non magnetic lamination
- Feed is carried to the magnetic roll by thin belt so there is no bouncing and scattering .they enters the magnetic zone with same horizontal velocity This leads to a better separation,

High intensity separator:




Used for separation for of paramagnetic materials . here generally high intensity magnetic field of greater then 2 T is used

Induced roll separator(IRMs)

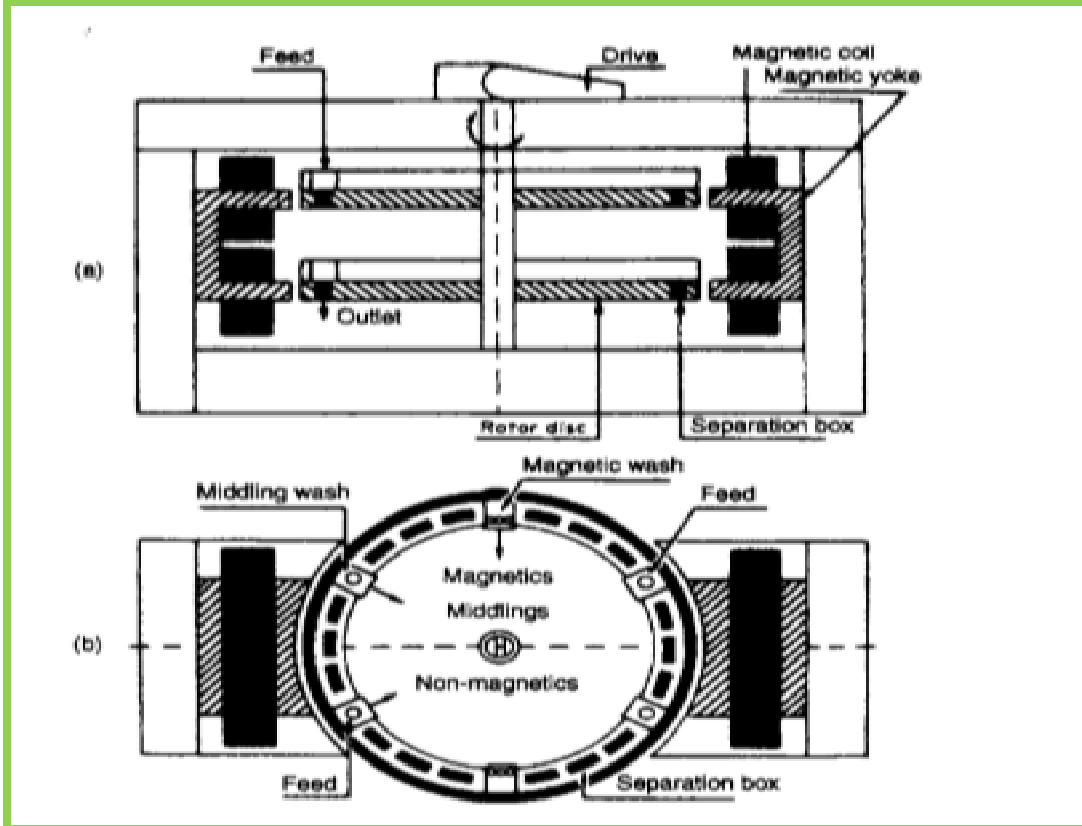
- Widely used  treat beach sand , wolframite, tin ore glass sand , tin ore, glass sand, and phosphate rock,

- The roll on which the ore is fed, is composed of phospated steel
- Laminates compressed together on a non magnetic stainless steel shaft, by using tow types of lamination slightly differing in outer dia , the roll is given a serrated profile which promotes the high field intensity and gradient required.
- Here strength of the field is nearly 2.2 T in between the feed pole and roll .
- Here non magnetic particles are thrown off the roll into the tailing compartment
- Magnetic particles are gripped , carried out the influence of the field deposited in magnetic compartment . where as non magnetic particles are thrown off the roll into the tailing compartment .
- The gap between the feed pole and the rotor is adjustable and usually decreased from pole to pole to take off successively more weekly magnetic products .
- This system is replaced by new rare earth roll and drum separator .

Draw back of  dry high intensity separation :

- Dry high intensity separation is largely limited to ore containing little , if any material finer than about 75 micrometer .
- The effectiveness of the separation on such fine material is severely reduced by the effect of air current , particle-particle adhesion and particle –rotor adhesion

Jones separator (Wet high intensity magnetic separator ) whims




- It consist of high strength structural frame
- The magnetic yokes are welded to this frame with the electromagnetic coils enclosed in air cooled case .
- Actual separation takes place in the plate boxes which are on the periphery of the one or two rotors attached to the central roller shaft.

The feed which is thoroughly mixed slurry , flows through the separation via fitted pipes and launder into the plate box which are grooveed to concentrate the magnetic filed at the tip of the ridges

Feeding is continuous due to rotation of the plate boxes on the rotors and the feed point are at the leading edge of the magnetic field

Each rotor has two symmetrical disposed fid point

The magnetic particles are held by the plate , where as the remaining non magnetic slurry passes straight through the plate box and is collected in a launder .

Before leaving the field any entrains non magnetic are washed out by low pressure water and are collected as middling’s .

When the plate box reaches a point where that is midway between the two magnetic poles where the magnetic field is essentially zero , the magnetic particles are washed out with high pressure water spray operating at 5 bar pressure

Here field intensity over 2 T can be produced in these machines the production of 1.5 T filed requires an electric power consumption in the coils of 16 kw per pole

Electrical Principle : difference in the electrical conductivity of different minerals in a feed helps in separation .

Some minerals are good conductors some are bad conductors .

E.S is an universal concentration methods because every minerals shows difference in electrical conductivity.

Main application area: separation of minerals from heavy sand found in beach.

separation

Limitation of this process

1- feed must be completely dry

2- capacity is very small for finely divided material

3-very fine particles must be required which increases the comminution cost

electrical separation classification

A- electrostatic separation – employ charge field with little or no current flow

B- high tension separation – high rate of electrical discharge , with electron flow and gaseous ionisation

Electrostatic separation vs high tension separation

| **Electrostatic separation** | **High tension separation** |
|---|---|

| | |
|---|---|
| 1-utilise high voltage where virtually true electrostatic process employing charge field wit<br><br>h little or no current flow . | 1-use of high rate of electrical discharge, with electron flow and gaseous ionization having major importance. |
| 2- utilise lifting effect | 2-utilise pinning effect |
| 3- magnitude of force involved is very low | 3- magnetite of force involved is high |

E.S.S and Concept of lifting effect in electrostatic separation

Electrostatic separation :in case of electrostatic separation materials having a tendency to become charged with a definite polarity are separated from each other by use of lifting effect even though there conductivity may be similar .

What is lifting effect ?

Attraction of particles carrying one kind of charge towards an electrode of the opposite charge is know as lifting effect , such particles are lifted from the separation surface towards the electrode.

Examples : if quartz is present with other minerals (poor conductors) then quart will gain a negative charge very readily and may be separated from the other minerals by an electrode which carrying a positive charge.

pure electrostatic separation is inefficient even if we have clean minerals

E.S.S is very sensitive to humid and temperature.

## High tension separation and concept of pinning effect

In pinning effect non conducting minerals particles having received a surface charge from the electrode , retained this charge and are pinned to the opposite charged separator by positive –negative attraction.

## Operation of H.T.S

1- mixture of ore minerals of varying susceptibility to surface charge is fed on a rotating conducting drum (mild steel, other conducting materials)

2-this rotating drum is earthed through support bearings .

3-electrodes assembly consists of (brass tube having a fine wire at the front, span the complete length of the roll and is supplied with fully rectified Dc supply up to 50 K.v usually of negative polarity.

4- the voltage supplied should be so high that it should ionise the air . (cab seen as corona discharge) arching between the electrode and the roll must be avoided as this destroyed the ionisation.

5-when ionisation occurs the mineral received 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.

6- where as the particles with relatively higher conductivity do not become charged as rapidly , as the charge rapidly dissipated through the particles to the earth 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 effect at all.

**Table 13.1** Typical behaviour of minerals in high-tension separators

| *Minerals pinned to rotor* | *Minerals thrown from rotor* |
|---|---|
| Apatite | Cassiterite |
| Barite | Chromite |
| Calcite | Diamond |
| Corundum | Fluorspar |
| Garnet | Galena |
| Gypsum | Gold |
| Kyanite | Hematite |
| Monazite | Ilmenite |
| Quartz | Limonite |
| Scheelite | Magnetite |
| Sillimonite | Pyrite |
| Spinel | Rutile |
| Tourmaline | Sphalerite |
| Zircon | Stibnite |
| | Tantalite |
| | Wolframite |

**Table 13.2** Typical beach sand minerals

| *Magnetics* | *Non-magnetics* |
|---|---|
| Magnetite – T | Rutile – T |
| Ilmenite – T | Zircon – P |
| Garnet – P | Quartz – P |
| Monazite – P | |

T = thrown from high-tension separator surface.
P = pinned to high-tension separator surface.

Design of the electrode assembly is such that they create a very dense high voltage discharge

Variables affecting the h.t.s performance :

1-roll speed

2-position of the electrode wire with respect to the electrode tube.

3-position of the electrode wire with respect to the roll.

4-variation of dc voltage and polarity

5-the splitter plate position

6-the feed rate

7- heating of the feed

Heating is essential because best result obtained with dry material. Process become difficult in high humid condition

Single pass of the feed through the roller will not enrich the ore we have to go for multiple pass.

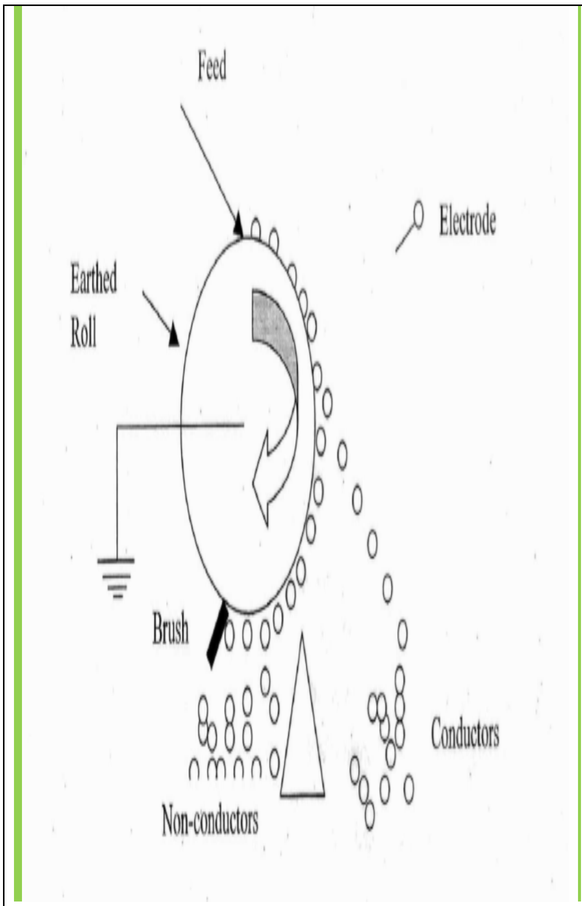
This is carried out by deflecting the falling particles to lower sets of roller and electrode until required enrichment is obtained.

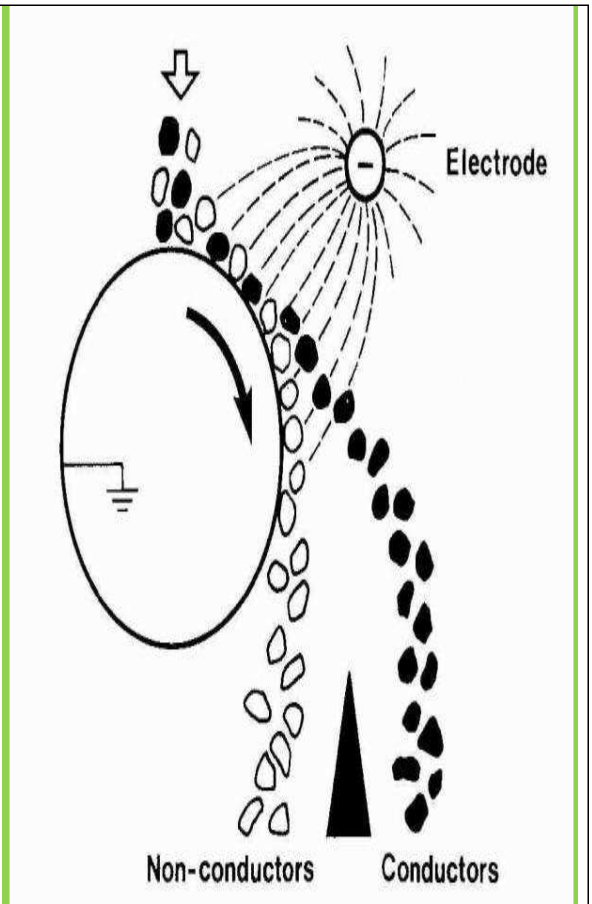
Feed size in hts is 60-500 micrometer in dia

Influence of particles size: surface charge on a coarse grain are lower in relation to its mass than on a finer grain . Thus a coarser grain is more readily thrown from the roll surface and the conducting fraction often contains a small proportion of coarser non conducting and similarly the finer particles are most influenced by the surface charge and the non conducting fraction often contains some fines conducting particles.

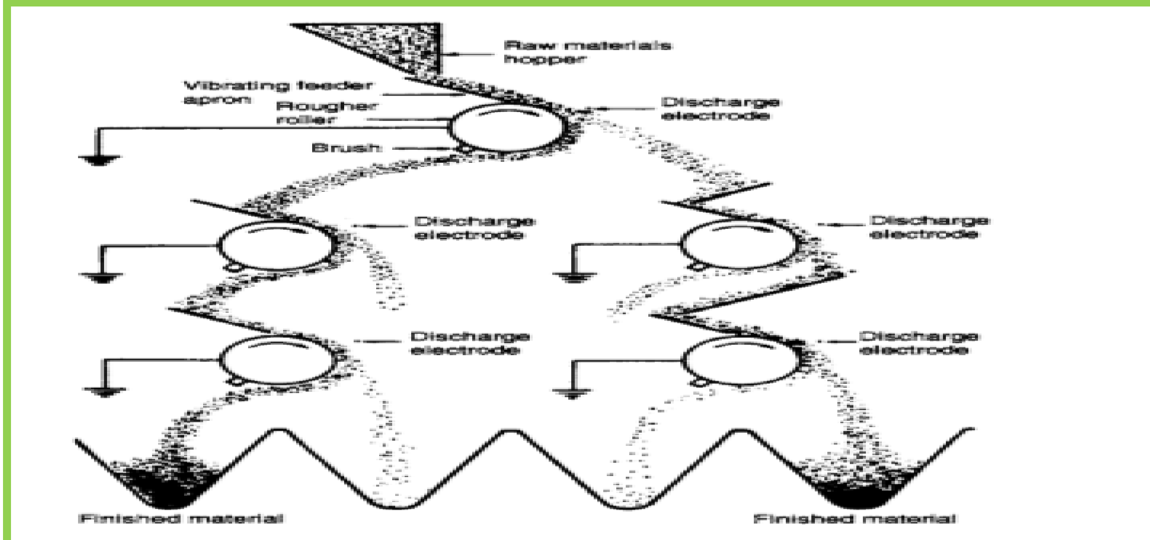
Final separation of the product is carried out by purely electrostatic separation which employs the lifting effect.

High tension separator principle




Arrangement of H.T.S for effective separation




Modern electrostatic separators are two types

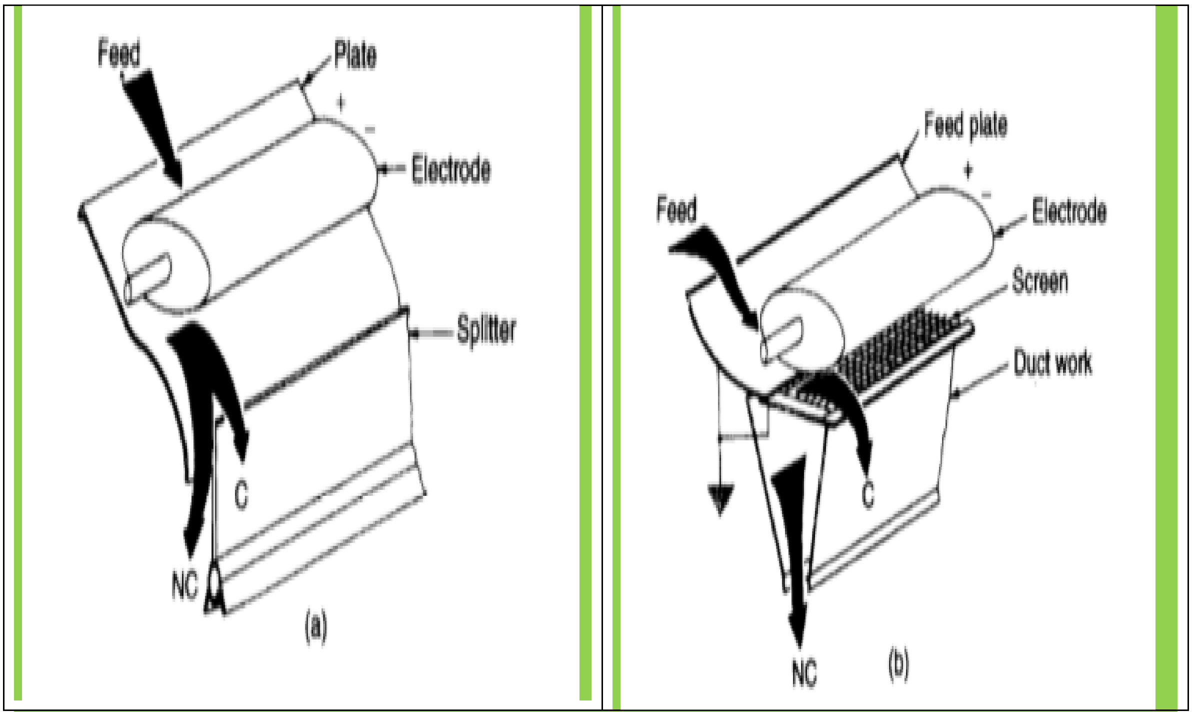
1- plate type- used for separation of small amount of non conducting from a predominantly conducting feed

2- screen type used for separation of small amount of conducting from a mainly non conducting feed .

But in both case principle of operation is same.

In both case electrostatic field is introduced by large oval high- voltage electrode and feed are moved on either plate of screen which are grounded .

Principle operation of E.S.S (a)plate and (B)screen separator




Operation of modern (E.S.S )plate and screen type

Here the feed particles moved down through a screen or plate which is grounded one ,and over the plate a large oval electrode is there which induces an electrostatic filed on the plate and screen , due which the conducting particles are lifted toward the charged electrode so as to decrease the energy of the system, here the non conductor grains are poorly affected by the field

And due to difference in size of the feed material the fine grains are most affected by the lifting force due which fine conductors preferentially lifted to the electrode where as coarse non conductors are most effetely rejected .

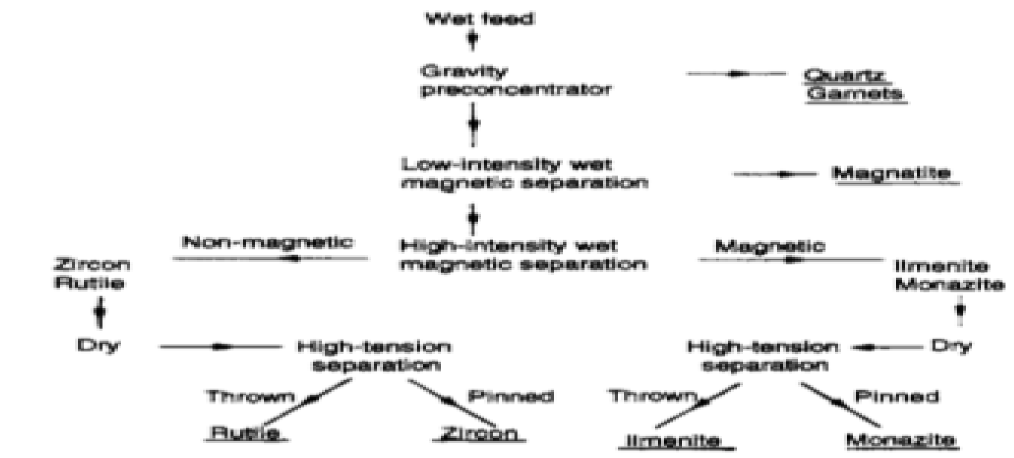



**Figure 13.26** Typical beach sand treatment flowsheet

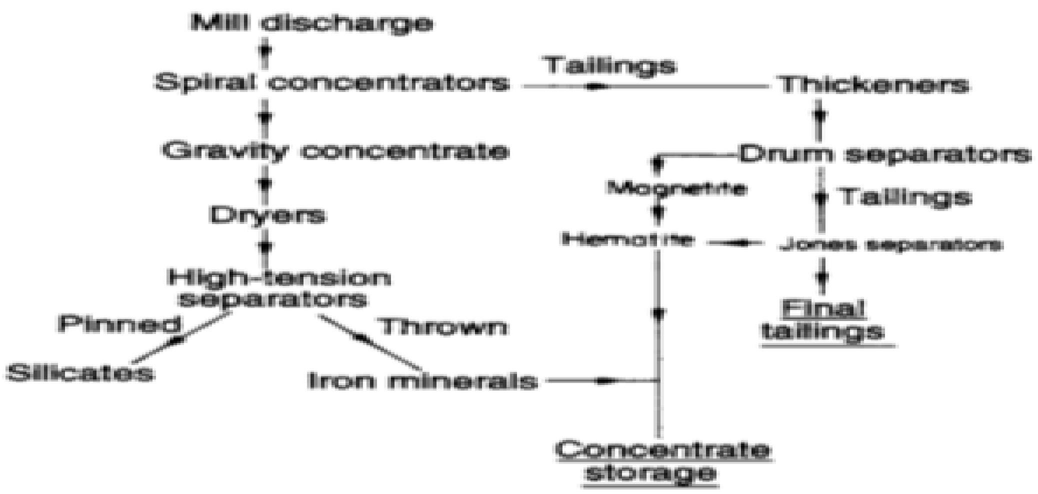



**Figure 13.28** Flowsheet of Scully concentrator

## Advancement of electrostatic separator

Mineral sand industries mainly use

1-HTR separator

2-ESP separator

for better separation use of :

1-using multiple M/C

2-multiple recycle structure

Ore kinetics has introduces some advanced machines which are developed version of HTR, ESP

1-new corona stat

2-ultra start M/C

Advanced m/c employed additional static electrode which improves efficiency of separation.

Unlike existing m/c the static electrode are not exposed , making the m/c much safe to operates.

New m/c are introduced by many manufacture

Roche mining :-carara HTR  separator which incorporate an additional insulated plate static electrode .

Outokumpu technology : eforce HTR separator which incorporate additional static electrode as well as electrostatic feed classifier

# MODULE-III

Agglomeration

What is agglomeration: agglomeration is a technique by which the fine iron ores are converted into lumps.

Why agglomeration is required :

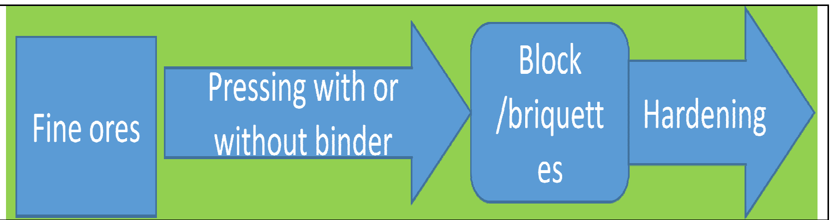
1- use of fine iron ore in iron making , since during communiation of iron ore some of the ores are converted into fines. So these fines cannot be feed into furnace directly so it is first converted into lumps .

Why we cannot charge fines into blast furnace :

1- if we charge fines into furnace it get converted into lumps inside the blast furnace and it will reduces permenabilty for gases and slag and metals .

2- heavy dust loss occurs from the top in the b/f gas.

## Agglomeration techniques

<table>
<tr><td>1-briquetting</td><td>
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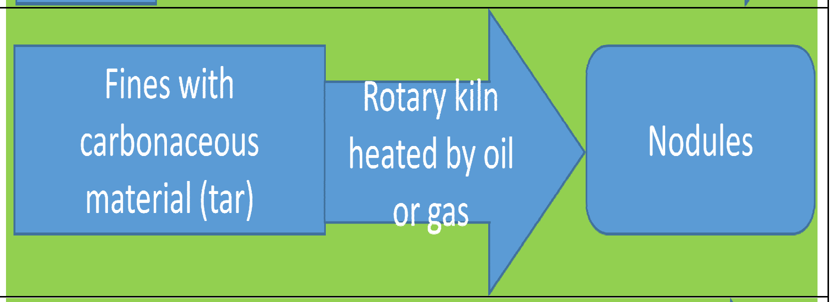
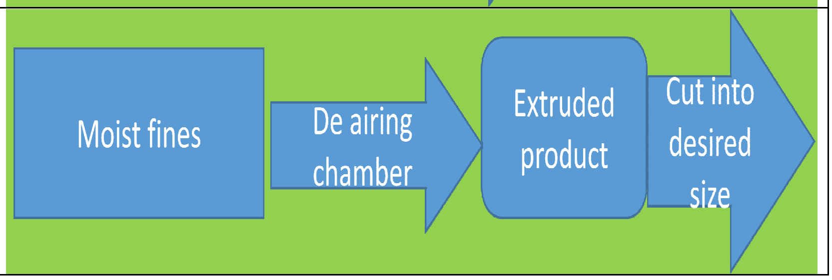
<tr><td>2-nodulising[rotary kiln sintering</td><td>
</td></tr>
<tr><td>3-vacuum extrusion</td><td>
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</table>

| | |
|---|---|
| 4-sintering | Mass of ore fines → Incipient fusion temperature → Lump |
| 5-pelletising. | Ore fines → Balling → Green ball → Firing → Hard ball |

Sintering technique

- Sintering principle
- Process variable
- Equipment for sintering
- Mechanism of sintering
- Raw materials requirement’
- Sinter types

## SINTERING PRINCIPLE:

here the iron ore fines or iron bearing fines are mixed with solid fuel(coke ) and put on a permeable grate.

Top layer of this sinter bed is heated to the sintering temperature (12-1300 ) by a gas or oil burner and air is drawn downwards, through the grate , with the help of exhaust blower connected. From underneath to the grate. A narrow combustion zone is formed on the top and this combustion travels downwards layer by layer upto sintering level

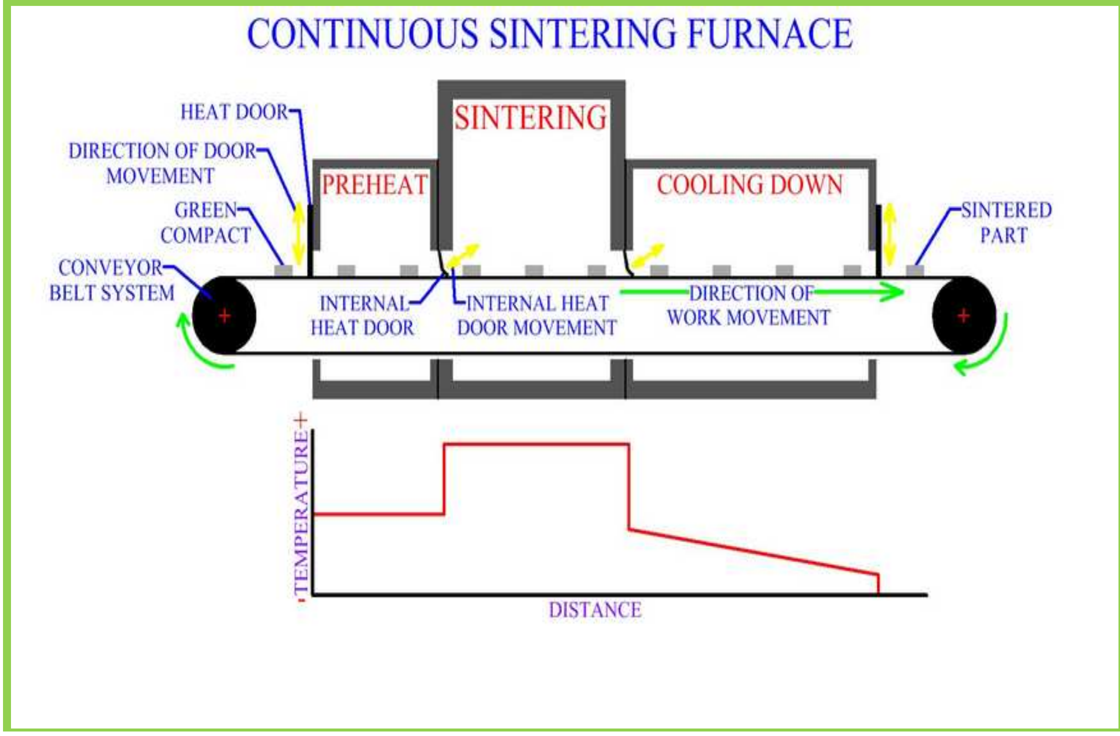
The cold blast drawn through the bed cools the already sintered layer and thereby gets itself heated. The heat contained in the blast is utilized in the drying and preheating the lower layers in the bed that is in advance of combustion of each layer.

In the combustion zone bonding of grains takes place and a strong and porous aggregate is formed.  The process is over when the combustion zone has reached the lowest layer of the bed.

The sinter formed is droped after partial cooling it is then broken , screened , and cooled to produce desired fraction. The undersized is recycled and over is send to b/f .

Up draught sintering{for ferrous ore) here the air is suck downards through the ore bed , or grate

Down draught sintering[for non ferrous ore] here the air is suck upward through the ore bed, grate.



## Process variables in sintering

During sintering time and temperatures plays a important role in deciding the nature and strength of bond develop during sintering of a given mix. And area under the curve above 1000 degree centigrade for iron ore is the effective factor in deciding the extent of sintering , rather than The whole area under the curve from room temperature toi the combustion temperature (1300).

And the nature of the time-temp graph will depend upon the rate of heating and cooling of a give mix.

Sintering is a heat exchange process where there is a exchange of heat between solid and gas,

So obtain faster rate of heat exchange , the heat capacity should be maximum , the rate of air drawn should be maximum for that the permeability of the bed should maximum .

1- bed permeability as decided by the particle size and shapes of the mix.

2- thickness of the bed

3- total volume of air blast drawn through the bed for its sintering.

4-rate of blast drawn through the bed during sintering.

5-amount and quality of solid fuel used.

6-amount and type of carbonate

7-amount of moisture in the charge .

8-chemical composition of ore fines

9-any non uniformity in the bed composition.

1-the fine concentrate is charged as a layer 15-50 cm thick on to the endless revoilving belt or grate or pallets which moves over wind boxes at regular speed .

2- burners under the ignition hood is used to start the combustion of the bed surface . This combustion is propagated through the mass or charge by a current of air drawn through the charge into the wind box below which is connected a suction fan sufficient high temperature are develop in the material to cause partial or incipient fusion which produces a porus cinder like material called sinter.

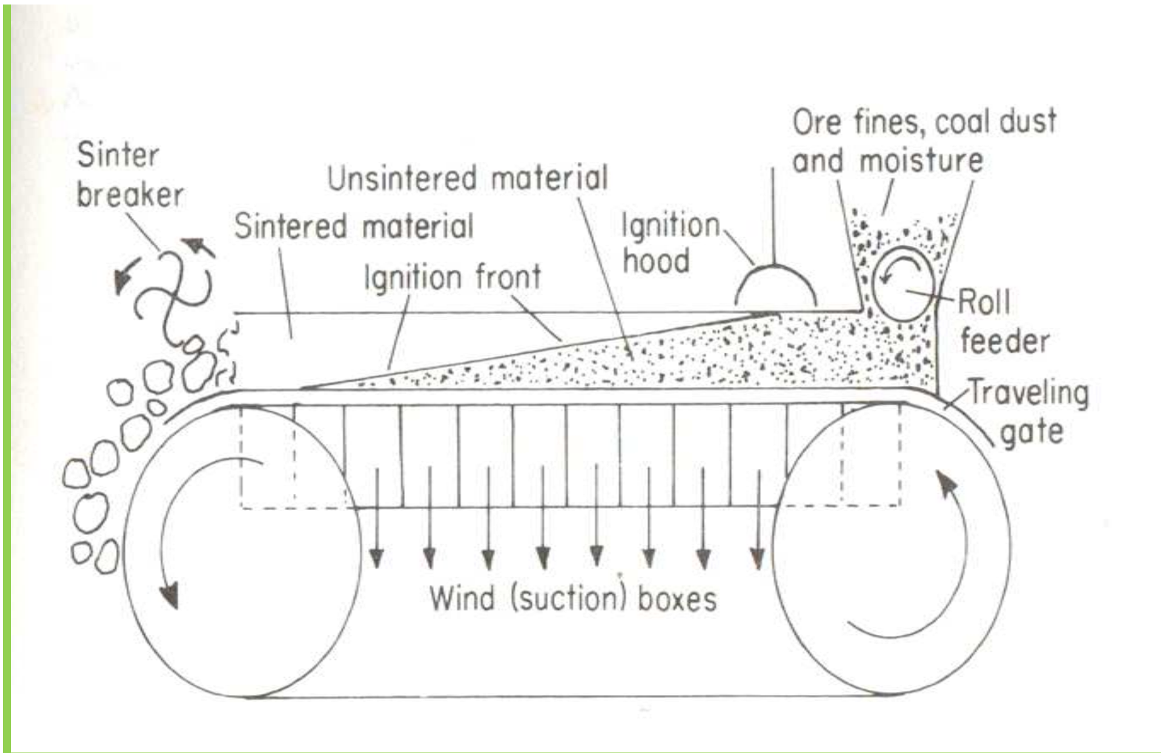
3- when the sinter reaches the end of the machine it is discharged and cooled .

4-The cooled sinter is sized to give a uniform product .

The sinter roasting of sulphide ore does not require

addition of any fuel to the charge because the sulphur in the charge itself act as a fuel .But for an oxide or fuel is required ex- iron ore

Equipment for sintering [DWILIGHT LLYOED SINTERING MACHINE ]




Mechanism of sintering

layer below the ignited top layer undergoes changes in the order.

Wet ore- drying-calcination-preheat

Two types of bond formed during sintering:

1-solid state bond or recrystallisation bond or diffusion bond :Here a bond is formed due to recrystallization of parent particles at the point of contact in solid state.

2-slag bond or glass bond:bond is formed due to formation of slag or glass at the point of contact of two particle , which depend upon the mineral and flux.

More is the slag bond stronger is the sinter but with less reducibility and more is the diffusion bond more is the reducibility but less is the strength.

## Sinter types

Acid sinter : the sinter mix does not contains flux at all

Flux is added in the furnace separately.

Now a days it is eliminated

Fluxed sinter :the amount of flux added in the mix in such that the basicity of the mix is equal to that of slag to be produced

Super flux : the amount of flux added in the mix is such that the basicity of the mix is greater than that of slag to be produced.

## Pelletisation technique

Here the very fine iron ore or iron bearing materials(100 mess size) are rolled into balls with addition of binders and additives .

Raw materials may be flue dust collectd from b/g steel making shop, fines produced during upgradation of lean ores. Pyrite reside.

- Process of pelletisation
- How bonding occurs in pelletisation
- Mechanism of ball formation
- Commercial production and equipment used

## Process of pelletisation

In this process the fine iron ores are rolled in the presence of additives and binders into green ball and to get the desired strength these green balls are dried preheated and fired at a high temperature of( 1250-1350 )degree centigrade. So on heating this at high temperature sufficient strength is produced between the particles. And here the sensible heat of out going gas is recovered which is feed back in the induration period. This process is carried out in oxidizing atmosphere

| |
|---|
| 1-prepration of feed |
| 2-production of balls and sizing |
| 3-green ball indurations which consists of [a-preheating – firing-cooling of hardened pellets.]also called hardening |
| 4-cooling of hardened pellets |

bonding theory

Moisture is very much essential for pelletisation process and it must be in less quantity.

Excess moisture is also determintal .

How this moisture helps in binding the particles ?

Surface tension of the moisture present in between the particles help in binding.

Rolling of moist particles  lead to formation of high density balls .

Easy with which the particles are rolled into balls depend upon the grain finess that is surface area. More surface more will be tendency of balling.

Three water particle system

1-pendular state:[ in this type of water particle system water is present at the point of conatct between the particles and the surface tension hold the particles.

2-funnicular state:[ in this type of system all the pores are fully occupied by water in an aggregate system.

3-capillary state:[in this system akl the pores are fully occupied by water but there in no coherent film of water covering the entire surface of particle.

So strength of the ball depends upon the surface tension and mechanical interlocking.

Diagram of water particle system

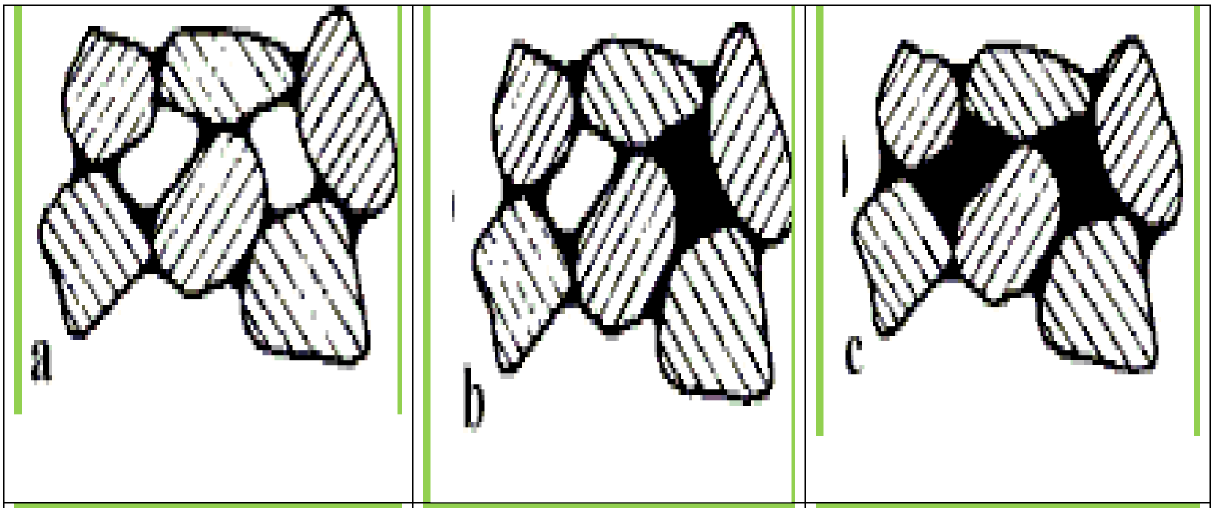



**Figure 1:** Distribution of liquid in the agglomerates; a-pendular state; b-funicular state; c-capillary state (Schubert, 1977).

Example showing the strength of green ball with critical amount of water:

When we go to sea beach for dry sand to wet sand which is just attached with the sea . We find a region in between these two which contains less water . So if we determine the strength the strength is maxium for the sand from middle region.

## Mechanism of ball formation

Mechanism behind this ball formation is the nucleation and growth mechanism .

1-So first stage is nucleation of ball

2-Then growth of this ball

But the entire process depend upon the critical amount of moisture (water) present in the feed.

Suppose the amount of water is les then critical amount then there is non unifom water distribution in the system , the major amount or water will be present in granulate material leaving non granulated material dry. And if the amount is more then critical amount then growth will be more where as strength will be reduced due to increase in plastic behavior.

- Nucleation formation region:-
- A bond is formed immediately  between particles when one wet  particle comes in contact with another dry or wet particle .in this way other particles are also attached with it and a highly porous loosely held aggregate is formed. And due to rearrangement and partial packing in short duration to from a small spherical stable nuclei.
- Transition period : after nuclei are formed they pass through a transition period . In this period rearrangement of particles occurs which lead to removal of pores and voids. System goes from pendular –funnicular- to capillary.
- this wet granulates grows if they are favorable oriented. In this process some granules may even break because of impacts, abrasion etc. growth occurs by two alternative methods.

A- growth by assimilation: is possible when balling proceeds with out the addition of fresh feed material.[during rolling some small particles breaks due to rolling action and these particles attached with bigger one and bigger will grow more big. Here thee is no addition of fresh materials.

B- growth by layering : growth occurs by addition of fresh materials. [here the ball pick up new materials while rolling the amount of materials picked up by the balls is directly proportional to its exposed surface.

Equipment or industrial practice

- Two type of pelletiser are there :
- 1- disc
- 2-drum

Disc pelletiser: it consist of a disc with outward sloping perpheral wall .resemble like flying saucers. Which rotates around its own center , in an inclined position to horizontal .

Dia of disc -3.6-5.6 m .

Inclination is 45 degree to the horizontal.

The material to be pelletized is generally fed directly onto the disc and moisture level is made up with the help of moist material on the disc. It can also control the material flow pattern on the disc. In the reason where water is added seeds are easily formed . With the growth of these seeds their fractional drag against the disc decreases and the centerifugal force acquired by them increases and consequently they move out of nucleation zone. They also tends to rise on the inclined surface of the pelletiser in the direction of rotation and fall down against the toe section of the disc. The height and the width of trajectory of the ball movement increases with the size of the ball until eventually the balls are deflector downwards by the scraper. During this movements the ball encounter fresh feed and growth takes place more by layering while compaction assimilation plays a relatively minor role.

The rate of production of balls on a disc is a function of the following variables

1- diameter of the disc

2-height of the peripheral wall

3- angle of inclination of disc

4-place on the disc where mix is fed

5-speeed of rotation

6-place where water is sprayed

7-rate of feed

8-rate of moisture addition

9-rate of withdrawl of the product

10-nature of size of feed.

11-desired size range of pellets and percentage recycled

12- binders and flux.

Drum pelletiser

This type of pelletiser is a steel drum which is having both end open with a length to diameter ratio of 2.5-3.5 rotating around its own axis in a slightly inclined position to the horizontal .

Length-6-9 m

Dia-2-3m

Angle of inclination-2-10 degree

Rotate at (Rpm)-10-15 rpm

Here the charge is fed from that side of the drum which is at higher level.water is also sprayed there the material rolls over the surface of the rotating drum and slides downward due to inclination of the drum in a cascading motion. And finally it comes out at other end.

## Disc vs drum

| Disc pelletiser | Drum pelletiser |
|---|---|
| 1-acts as classifer | 1-Not acts as classifer |
| 2-Growth accous mainly by layering | 2-Growth occurs mainly by assimilation |
| 3-more flexible to operate | 3- less flexible |
| 4- close sized products | 4- wide range of products side |
| 5-screening is rarely adopted and hwen if very narrow size range products is required | 5-screening is required must |
| 6-specific production rate is more here | 6- specific production rate is less |
| | |

## Testing of agglomerate

Determine the Room temperature physical properties: such as resistance to abrasion and impact during handling and charging are :

A-Shatter test,(impact test)

b- tumbling test (abrasion test)

C-Porosity test

D-Compression test

## Shatter test:

It is done to determine the impact strength of the raw materials as raw materials are charge from a big height into the blast furnace and during handling also its suffers .

In this test a standard amount of material is taken and it is dropped for a certain no of drops from a standard height on a standard floor. And then the amount of material retained on or passed through the certain sieve expressed as percentage of the original weight is indicated as the shatter index.

Shatter test in u.k:

Developed in U.K and test in U.k : 20 kg sample is taken with size +10mm dropped 4 times from height of 2 m. the material is then screened and shatter index is expressed as the percentage materials greater than 10mm surviving.

Tumbling test and abrasion test

This test is used to determine the strength and abrasion resistance of sample.

Also called micum test .

Here a standard weight of material is tumbled in a standar size drum for fixed number of revolution which is carried out at a standard speed . The percentage material passing through or retained on a certain seive is the index.

According to these test pellets are high quality products then sinter and natural ore.

In case of micum test :sample weight : 50kg

Drum dia  x length 1x1 m

Speed(rpm)=25

No of revolution = 100

Compression test

- Compression test: we cannot measure the compression strength of the raw material as there are not in regular size. But pallets we can measure as it is regular in size.
- Standard weight of material is taken (2kg) with standard size 10-15 mm size is dried and placed in a cylinder of 200mm dia and a load of 100 t is applied on it via piston . the + 5mm materials surviving the test is the compression strength index.

Porosity:

Porosity : expressed as the volume of pores as a percentage of total volume of the material tested. Two types of porosity are there open and closed . open pores are those pore which is accessible to fluids.

Reducibility test:

This test determines the rate of reduction of raw materials under blast furnace condition.  Since condition inside the b.f is different in different region from top to bottom. So a special apparatus is designed to carry out this test. Here we use a special apparatus with tempeartur of 900- 1000 degree centigrade and reducing gas of co2 or co+N2 of constant  composition for study. Here the sample of know weight of certain fixed size and is placed in the furnace in the form of static bed of fixed dimension .

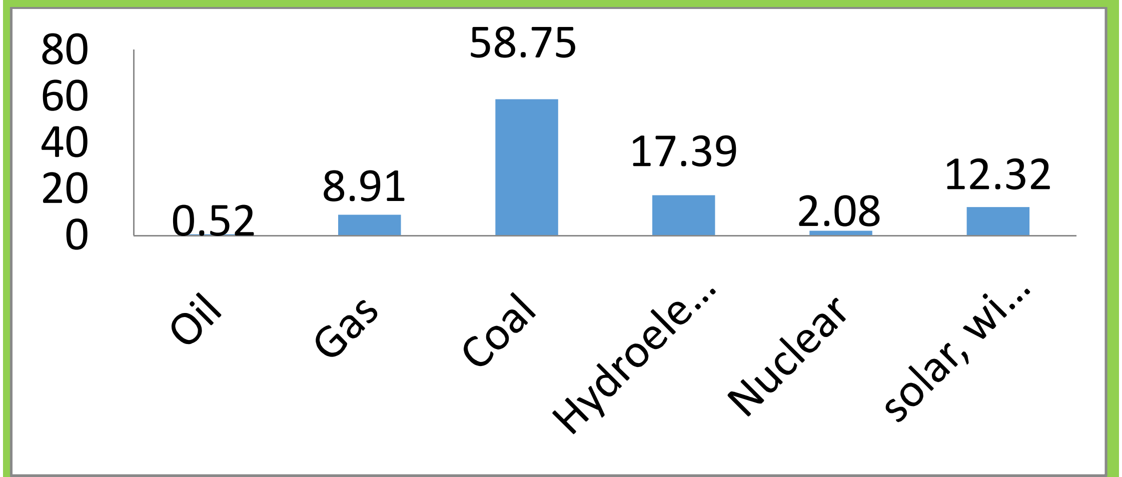
# MODULE-1V

Primary energy resources of the World

- Three major categories of the energy resources around the world:

1. Fossil fuel
2. Nuclear fuel
3. Renewable resources

Energy resources distribution in India




Fuels and their general classification

- Fuels are the materials that store potential energy in forms that can be practicably released and used as heat energy.

Thus explosives are not fuels ( as the rate of energy release is very high and cant be practicably used as heat energy)

Fuels which release energy by the process of combustion are simply termed as fuels whereas those which produce energy by the process of nuclear fusion or fission are called as Nuclear fuels.

Four major categories of a fuel:

1. Fossil fuels are those which have been derived from the fossil remains of plants and animals and are found in the crust of earth. E.g. coal, petroleum, natural gas etc
2. By product fuels are the by product of some regular manufacturing process and are of a secondary nature. Ex coke oven and blast furnace gas in the process of coke and iron making.
3. Chemical fuels are of an exotic nature and normally not used in conventional processes. Ex are Hydrazine( rocket fuel) , ammonium nitrate, etc.
4. Nuclear fuels release heat by fission or fission wherein the mass is converted into energy.

Classification…

- Depending on the states of the fuel occurrence they are :

1. Solid fuels
2. Liquid fuels
3. Gaseous fuels

Further fuels under any general classification can be classified as Primary and Secondary fuels.

Primary fuels are those which occur in nature such as coal, wood , petroleum, natural gas etc.

Secondary fuels are those which are derived from primary fuel such as fuel oil and kerosene oil derived from petroleum.

## Coal

- A combustible black/brownish-black sedimentary or metamorphic rock primarily composed of carbon along with other elements such as hydrogen, sulfur, oxygen and nitrogen.
- Rank of a coal is the maturity of the coal.
- Peat lignite bituminous anthracite
- Peat has lowest rank as it is most immature where as anthracite has highest rank

## Some important terms

- Coalification or metamorphism is the process of conversion of lignite to anthracite.
- Carbonization of coal is the heating of coal in absence of air at high temperature to produce a residue coke, tar and gas.
- Gasification of coal is the heating of coal with insufficiently less quantity of air in addition to steam to produce a gas rich in CO and H2.

- Caking and coking coal: when powdered coal is carbonized, it forms an expanded lumpy mass. Such coals are called caking coal and the phenomena called caking of coal.
- However in cases where the residue is very hard and strong it is called coke and the process called coking of coal.
- **All coking coal are caking in nature but not all caking coals are coking in nature.**
- Caking corresponds to a slower heating rate and coking to a faster rate of heating.
- Bituminous coal is used essentially as coking coals.

Non caking/coking are those bituminous coals which have high percentage of moisture and oxygen and do not form gel on heating

Basis for reporting the analysis of coal

- Run of mine coal: The crude coal as obtained from the mine is called as run of mine coal. There is no treatment of coal like size reduction, moisture elimination etc.
- As received coal: from mines to costumer end transportation involves size reduction, washing, weathering etc. thus coal received at the customer end is reported as received coal for the analysis.
- Air dried: during transportation and storage there may be change in the moisture content depending upon the atmospheric temperature and humidity.

- Dry coal: when study has to be done without the effect of moisture, then coal analysis is reported as DRY basis.
- Dry-ash free(d.a.f.) : By eliminating both ash and moisture content , data reported is Dry-ash free. This is suitable for coal with low ash content (<10%)
- Dry-mineral matter free( d.m.m.f.) analysis is suited for high ash content (>10%)
- Proximate analysis: finding out the weight percentages of moisture, volatile matter, fixed carbon and ash in coal. It gives an approximate composition of the coal to decide its utility for a purpose.
- Ultimate analysis: finding out the percentage of carbon, hydrogen, oxygen, nitrogen and sulfur of the pure coal free from moisture and inorganic constituents. Used by the designer of coal burning equipments.
- Combustion is an exothermic chemical reaction of a fuel with oxygen or air at high temperature to liberate heat.
- Calorific value is the quantity of heat in kcal liberated by the combustion of unit quantity of fuel.
- For solid and liquid fuel it is expressed in kcal/kg and for gas it is kcal/$Nm^3$ N means normal temperature and pressure (0°C and 760 mmHg)
- Gross and net calorific value: gross calorific value includes the latent heat during condensation of water vapor formed during combustion and thus is higher than net calorific value.

- Peat: It is the first stage product in the formation of coal from wood under the action of temperature, pressure and bacteria.
- Calorific value is around 4500kcal/kg.
- Light brown in color lots of fibers are present with around 90% moisture.
- Mainly used as a domestic fuel after sun drying for 40-50 days.

## Classification of coal

- Lignite: It is the second stage in the formation of coal. It occurs in thick seam up to 30 meters of thickness.
- Having moisture content about 60% calorific value reaches around 5000kcal/kg(on 10% moisture basis)
- On exposure to atmosphere, the brown color of lignite darkens and the moisture content reduces to equilibrium value of 10 to 20%.
- Major deposits are found close to the earth surface.
- Bituminous coal: It is the most common variety of coal. Moisture content is less than 10% and carbon content varies 75-90%.
- Calorific value on mineral matter free basis goes up to 9000 kcal/kg.
- Most of the coking coals are bituminous coal.

- Anthracite is the most matured coal thus high carbon content (85-95%) and low volatile matter (<10%).

- This coal is hard, non coking and burns without smoke to give intense localized heat.
- Calorific value ranges between 8000-8500kcal/kg, slightly lower than bituminous pertaining to low hydrogen content.
- True anthracites do not occur in India and are found mainly in U.K and U.S.A
- Used in boilers, domestic ovens and metallurgical furnaces.

## Coal washing

Impurities present in coal must be removed before it is used.

1. Fixed and inherent impurities are those which are present in the coal forming plant. These cant be separated by washing. Inherent impurity is less than 3%.
2. Free impurities are those adhering to the surface of the coal and comprising mainly of dirt and rock particles which can be removed by washing.

Objectives of coal washing:

1. Reduces its ash content
2. Reduces its sulfur and phosphorous contents which are detrimental particularly to metallurgical coals.
3. Increases its heating value
4. Improves its coking properties
5. Reduces the clinkering tendency

6. Increases the fusion point of the ash by removing alkali chlorides

Principle of coal washing

Based on the difference between specific gravity of pure coal (1.3) and free impurities (>1.7), a washing medium with specific gravity 1.5 is selected.

Heavier dirt will settle down while the lighter pure coal will float.

Washability of coal is defined as the extent of removal of free dirt is commonly known as washability of a coal.

- Proximate analysis:

1. Determination of moisture content: loss in weight of coal sample caused by heating for one hour at 105C is the moisture content.

% Moisture= (loss in weight/weight of initial coal)x100

2. Determination of volatile matter in coal: it is the loss in weight of moisture free powdered coal when heated in a crucible fitted with cover in a muffle furnace at 950C for 7 minutes.

% volatile matter= (loss in weight of moisture free coal/weight of moisture free coal)X100

- Determination of Ash in coal: it is the weight of residue obtained after burning a weighed quantity of coal in an open crucible at 750C in a muffle furnace till constant weight is achieved.

% Ash in coal=(weight of residue ash formed/weight of coal initially taken)X100

Determination of fixed carbon: it is determined indirectly by deducting the sum total of moisture, volatile matter and ash percentage from 100.

% fixed carbon in coal=100-(%moisture+%volatile matter+%ash)

Ultimate analysis of coal

- Determination of total, carbon, hydrogen, nitrogen, oxygen and sulfur percentages in coal comprises of ultimate analysis.

Determination of carbon and hydrogen in coal:

Step 1: known amount of coal sample is burnt in a current of dry oxygen thereby converting C and H of coal into $CO_2$ and $H_2O$.

Step 2: $CO_2$ and $H_2O$ are passed over tubes containing anhydrous calcium chloride and potassium hydroxide which absorb $H_2O$ and $CO_2$ respectively.

Step 3: increase in the weight of $CaCl_2$ tube represents the amount of water formed, while the increase in the weight of KOH tube represents the amount of $CO_2$ formed.

- %of H and C in coal can be calculated as below :

Let x= weight of coal sample taken, y=increase in the weight of $CaCl_2$ tube

Z= increase in the weight of KOH tube.

% carbon in the coal sample= (12z/44x)X100

% hydrogen in coal = (2y/18x)X100

Determination of nitrogen in coal:

Kjeldahal's method is used to find out the % nitrogen in coal and is given by

% Nitrogen in coal= (Volume of acid usedXNormality)/(weight of coal)X1.4

- Determination of sulfur in coal is done by burning completely a known amount of coal in a bomb calorimeter in a current of oxygen.
- Sulfate formed in the ash is extracted using dilute hydrochloric acid and then treated with barium chloride solution to precipitate sulfate as barium sulfate.

S $SO_4$ $BaSO_4$

32 gms sulfur in coal will give 233 gms $BaSO_4$

If x= weight of coal taken and y= weight of $BaSO_4$ obtained as precipitate, the % sulfur = (32y/233x )X100

Determination of Oxygen in coal is done indirectly by the formula % oxygen in coal= 100-(% of C + H +N +S + ash)

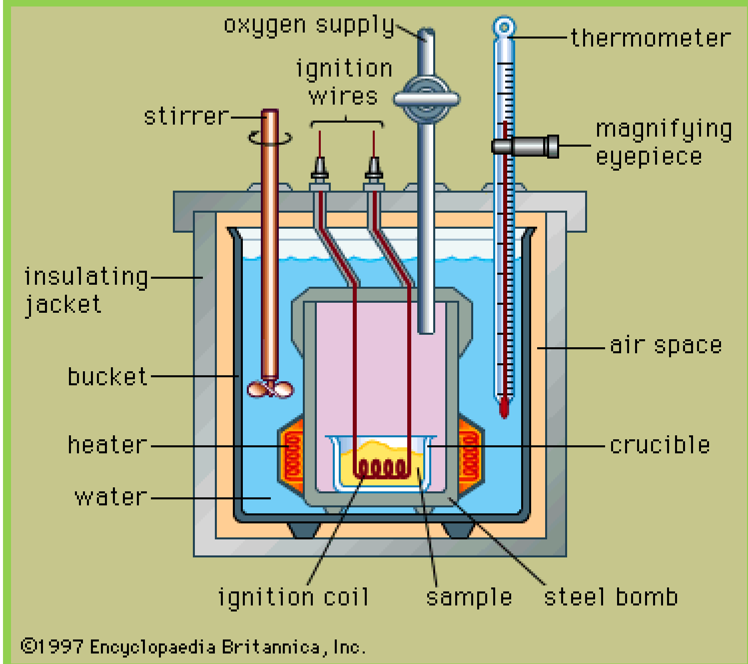
Calorific value and its determination

- It is defined as the quantity of heat liberated by the combustion of unit quantity of fuel.
- Principle of C.V determination. When a weighed amount of fuel is burnt in calorimeter, the heat liberated is used up in heating the calorimeter and the water in the calorimeter.

- **Higher calorific value or gross calorific value**: total amount of heat liberated when one unit of the fuel is burnt completely and the combustion products are cooled down to room temperature.
- **Lower or net calorific value**: the amount of heat liberated when one unit of the fuel is burnt completely and the combustion products are allowed to escape.

Net C.V= Gross C.V-Latent heat of water vapors formed

Determination of calorific value by bomb calorimeter.




Observation and calculations

- Weight of the fuel taken in the crucible=x kg
- Weight of water in the calorimeter=y kg
- Water equivalent of the weight of the calorimeter, stirrer, thermometer and bomb= z kg
- Initial temperature of water in calorimeter=$t_1$°c
- Final temperature of water in calorimeter=$t_2$°c

- Let the gross calorific value of the fuel = C kcal/kg
- Heat gained by water= $y(t_2 – t_1)$kcal
- Heat gained by the calorimeter= $z(t_2 – t_1)$kcal
- Heat liberated by the fuel = xC kcal
- Heat liberated by the fuel = heat gained by the water and calorimeter.
- $xC = (y + z)(t_2 – t_1)$
- $C = (y + z)(t_2 – t_1) /x$ kcal/kg
- Net calorific value or lower value is found by subtracting the latent heat of vapor formation
- Net calorific value = Gross C.V – latent heat of water vapor
- = (C – 0.09HX587 ) kcal/kg

Where H is the percentage of hydrogen in the fuel.

Carbonization of coal-coke making

- Carbonization or destructive distillation is the heating of coal in the absence of air to produce coke and the co-product as coke oven gas which on cooling gives products like tar, benzol, naphthalene, phenol etc.
- Depending on the temperature up to which the coal is heated there are two kinds of carbonization, low temperature carbonization (LTC)and high temperature carbonization (HTC).

Carbonization type

| Low temperature carbonization | High temperature carbonization |
|---|---|
| ➢It is carried out at 700C | ➢It is carried out at 1100C |
| ➢It produces semi coke used as smokeless domestic fuel | ➢It produces metallurgical coke for use in blast furnace and cupola furnace in foundry |
| ➢Yield of coke oven gas is low in LTC about 150-160Nm$^3$ gas / ton dry coal | ➢Yield of coke oven gas is high in HTC about 290-300Nm$^3$ gas / ton dry coal |
| ➢Yield of tar is high | ➢Yield of tar is low |
| ➢Ammonia yield is low | ➢Ammonia yield is high |
| ➢Calorific value of the coke oven gas obtained is more 6000-6500kcal/Nm$^3$ | ➢Calorific value of the coke oven gas obtained is less 4200-4400kcal/Nm$^3$ |
| ➢Soft coke is produced having high porosity | ➢Hard and less porous coke is produced |
| ➢Volatile matter is more (5-7%) in LTC coke. Hence lower ignition temperature | ➢Volatile matter is less (1-2%). Hence ignition temperature is more |
| ➢Coke yield is more (about 80% of dry coal) | ➢Coke yield is less (about 75% of dry coal) |

## Coke vs coal for metallurgical purpose

- Coal : too dense and fragile so neither blast will penetrate it quickly for burning nor it is strong enough to stand nearly 25 m burden. And other properties are
- High volatile matter,
- High ash content ,(
  large volume of slag will produce )
- less fixed c, (low calorific value )
- High in moisture content

For iron making we need metallurgical coal also called coking coal which can be converted into coke .

Criteria of coke for iron making in b/f-

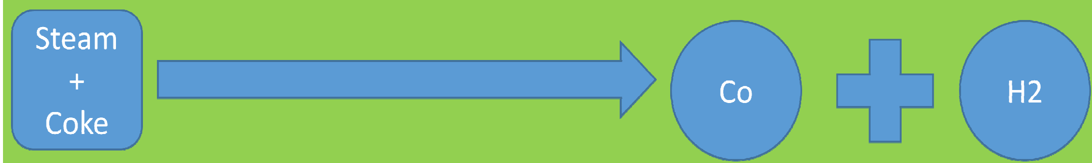
- v.m < 2 %,
- ash content < 10 %
- fixed c =85 %
- Coal is used in Dri(sponge iron making
- ) and smelting reduction process

Gaseous fuel

1- water gas –

- synthesis gas
- Composition – Co + H2
- Flammability
- Carbon monoxide poisoning

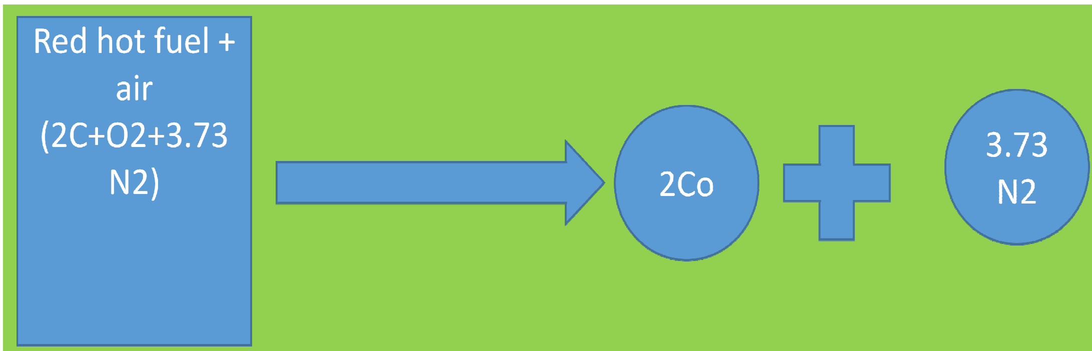
Production : this reaction is endothermic so the fuel must be continuously heated to keep the reaction




2-producer gas-

- Different meaning in uk and usa
- Usa: it is a generic name refers to wood gas , syngas , town gas
- This gas is very poisonous because it contain large amount of carbon monoxide in it.
- In uk it is also called suction gas

- Here air is passed over red hot carbon (coal) which produce co . The nitrogen in air remains unchanged and dilute the gas , s it has a low calorific value .




3-blast furnace gas- also called top gas

The gas is produced as a by product from the blast furnace due to reduction of ore

Composition : Co, 18-20%$CO_2$, 60%$N_2$, moisture,

It has moderate calorific value due to presence of Co in it .

Its is used to drive turbines and for reheating purpose .

Gas is poisonous due to presence of Co

Reference books

1- Mineral processing technology by Berry A Willis

2-principle of mineral dressing by A.MA .GAUDIN

Note pictures and diagram are taken from Mineral processing technology by Berry A Willis books and from internet .