# Lecturer Note On
# MINERAL PROCESSING
# [MTPC203(TH2)]

ORISSA SCHOOL OF MINING ENGINEERING, KEONJHAR

ଓଡିଶା ଖଣି ଯାନ୍ତ୍ରୀକ ବିଦ୍ୟାଳୟ, କେଉଁଝର

GOVERNMENT OF ODISHA | ଓଡିଶା ସରକାର


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**Metallurgical Engineering Department**

**Orissa school Of Mining Engineering ,Keonjhar**


**Subject code: TH-2(MTPC203)**

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## Vision and Mission of the Department

**VISION:** To offer quality technical education In the field of Metallurgical Engineering with orientation towards industry, entrepreneurship, higher education and to strive for developing professionally competent technicians meeting the needs of the global economy.

**MISSION:**

**M1 :**To develop students in the field of Metallurgical Engineering as highly motivated, skillful and qualified manpower for employment and higher learning

**M2 :**To promote a conducive environment for all round development of students.

**M3 :**To promote linkages with external agencies to meet changing needs of industry and society. **M4 :** To Improve Laboratories

## Program Education Objectives (PEOs)

**PEO 1:**Diploma professionals will be able to make a successful career in metallurgical industries or higher studies to meet the needs of future requirements.

**PEO 2**:Diploma metallurgists will have technical and behavioral competencies through adequate exposure to industry.

**PEO 3:**To impart technological knowledge and skills for solving real-time engineering problems.

**PEO 4:**To develop human resources with capabilities of effective communication, moral values and socialresponsible .

## Syllabus

| UNIT | CONTENT | HOUR |
|---|---|---|
| UNIT-1 | **Definition and importance**<br>Role in the metallurgy industry ,Various mineral resources of India , Mineral and Ore , Types of Ores Metallic ores (e.g., iron, copper, gold), Non-metallic ores (e.g., limestone, phosphate), scope and objective of Ore dressing ,Different physical and chemical property of ore with their application to mineral dressing | 5 |
| UNIT-1I | **Size Reduction**<br>Importance of Comminution in mineral processing, Mechanisms of size reduction, Blake jaw Crusher, Dodge jaw Crusher, Roll crusher & angle of Nip, capacity and reduction ratio of crusher, Laws of Crushing, Ball mill operation, open circuit grinding and close circuit grinding | 15 |
| UNIT-1II | **Sizing & Concentration Methods**<br>Ro-tap Sieve Shaker Particle size analysis, Basic fundamentals & principle of jigging, operations and application of wilfley table, principle of heavy media separation, industrial process using heavy liquid and heavy suspensions (Du - Pont process & Chance process), Principle of froth flotation, practical utility of frother, collector, modifier, activators, depressant (without physic – chemical Principle), Magnetic and Electrostatic separator with their application to mineral dressing (Two Drum Ball-Norton Wet magnetic separator, High Tension or Huff's Electrostatic separation) | 20 |
| UNIT-IV | **Advanced Topics in Mineral Dressing**<br>Advanced Comminution Techniques: High-Pressure Grinding Rolls (HPGR), Ultra-Fine Grinding (UFG), Microwave-Assisted Comminution, Advanced Gravity Separation Techniques: Multi-Gravity Separator (MGS), Advanced Flotation Techniques: Microbubble & Nanobubble Flotation, Magnetic & Electrostatic Separation: High- Intensity Magnetic Separation (HIMS), Sustainable & Eco-Friendly Mineral Processing: Dry Beneficiation Technique, Zero-Waste Processing | 5 |

## UNIT:1

**Mineral Resources and Ore Dressing**

1. Definition and Importance of Mineral Resources

A mineral resource is a naturally occurring substance found in the Earth's crust that has economic value and can be extracted and processed for useful purposes.

Mineral resources are important because they:

Provide raw materials for industries.

Supply metals required for engineering and manufacturing.

Support construction and infrastructure development.

Provide fuels and energy resources.

Generate employment and contribute to economic development.

Support industries such as iron and steel, cement, fertilizer, electronics and automobiles.

**2. Role of Minerals in the Metallurgy Industry**

Minerals are the basic raw materials of the metallurgical industry. Ores obtained from mines are processed to concentrate the valuable mineral before extraction of the metal.

The general sequence is:

Mining → Ore dressing → Extraction of metal → Refining → Metal/Alloy production

Importance in metallurgy

Source of metals: Iron ore provides iron, bauxite provides aluminium, copper ores provide copper, etc.

Concentration: Ore dressing increases the percentage of valuable minerals before metallurgical extraction.

Reduction of impurities: Gangue materials such as sand, clay and unwanted minerals are removed.

Lower processing cost: Concentrating the ore reduces the quantity of material that must be treated in subsequent operations.

Improved recovery: Proper mineral processing increases recovery of valuable minerals.

Production of suitable feed: Concentrates can be prepared with appropriate size and composition for smelting or other extraction processes.

**3. Various Mineral Resources of India**

| **MINERALS** | **DEPOSITS** | |
|---|---|---|
| Chromite | Orissa,Karnataka,Maharashtra,Jharkhand,MadhyaPradesh,Chhattisgarh, Tamil Nadu and Manipur. | |
| Bauxite | Orissa,AndhraPradesh,Chhattisgarh,Gujarat,MaharashtraandJharkhand. | |

| | | |
|---|---|---|
| Copper | Singhbhum (Jharkhand), Balaghat (MadhyaPradesh) and Jhunjhunu and Alwar (Rajasthan). | |
| IronOre | 1. Haematite resources are located in Orissa, Jharkhand, Chhattisgarh, Karnataka, Goa, Maharashtra, Andhra Pradesh and Rajasthan.<br><br>2. MagnetiteresourcesarelocatedinKarnataka,AndhraPradesh,Goa, Kerala, Jharkhand, Rajasthan and Tamil Nadu. | |
| LeadZinc | Rajasthan,WestBengal,AndhraPradesh,Gujarat,MadhyaPradesh,Uttar Pradesh, Orissa, Maharashtra, Meghalaya, Tamil Nadu and Sikkim. | |
| Manganese | MainreservesfallinKarnataka,followedbyOrissa,MadhyaPradesh, Maharashtra and Goa.<br>MinoroccurrencesofmanganeseareinAndhraPradesh,Jharkhand, Gujarat, Rajasthan and West Bengal. | |
| Tungsten | ThemainreservesareatDegana,Rajasthan.ItalsooccursinMaharashtra, Haryana, West Bengal and Andhra Pradesh. | |
| Dolomite | MadhyaPradesh,Chhattisgarh,Orissa,Gujarat,Karnataka,WestBengal, Uttar Pradesh and Maharashtra. | |
| Gypsum | Production of gypsum is confined to Rajasthan, Tamil Nadu, Jammu and Kashmir,andGujarat.Rajasthanisthemainproducerofgypsumfollowed by Jammu and Kashmir. | |
| Graphite | AndhraPradesh"Jharkhand,Gujarat,Karnataka,Kerala,MadhyaPradesh, Maharashtra, Orissa, Rajasthan and Tamil Nadu. | |
| Limestone | MadhyaPradesh,Chhattisgarh,AndhraPradesh,andGujarat:Rajasthan, Karnataka, Tamil Nadu, Maharashtra, Himachal Pradesh, Orissa, Bihar, Uttaranchal and Uttar Pradesh. | |
| Magnesite | Uttaranchal,TamilNaduandRajasthanwhileminordepositsareinJammu andKashmir,Karnataka,HimachalPradeshandKerala. | |

4. Mineral and Ore

Mineral

A mineral is a naturally occurring inorganic substance having a definite chemical composition and characteristic physical properties.

Examples: Quartz, calcite, hematite, magnetite.

**Ore**

An ore is a naturally occurring mineral or aggregate of minerals from which a valuable metal can be extracted economically and profitably using available technology.

Examples:

Hematite → iron ore

Chalcopyrite → copper ore

Bauxite → aluminium ore

Difference between Mineral and Ore

**Mineral**

Naturally occurring inorganic substance. Mineral deposit from which a metal can be economically extracted.

May or may not have economic value. Has sufficient economic value for extraction.

Can contain valuable or non-valuable minerals. Contains valuable mineral along with gangue.

**5. Types of Ores**

Ores can broadly be classified into:

Metallic ores

Non-metallic ores

**5.1 Metallic Ores**

Metallic ores contain minerals from which metals can be extracted.

Iron ores

Hematite ($Fe_2O_3$)

Magnetite ($Fe_3O_4$)

Limonite

Siderite
Copper ores
Chalcopyrite ($CuFeS_2$)
Chalcocite ($Cu_2S$)
Cuprite ($Cu_2O$)
Malachite
Gold ores

Gold commonly occurs as native gold, often associated with quartz and sulphide minerals.

Other metallic ores
Bauxite → Aluminium
Galena ($PbS$) → Lead
Sphalerite ($ZnS$) → Zinc
Chromite ($FeCr_2O_4$) → Chromium
Pyrolusite ($MnO_2$) → Manganese

**5.2 Non-Metallic Ores/Mineral Resources**

Non-metallic minerals do not serve primarily as sources of metals.

Limestone

Mainly composed of calcium carbonate ($CaCO_3$).

Uses:

Cement manufacture
Lime production
Construction
Flux in metallurgy
Phosphate minerals

Mainly contain phosphate minerals such as apatite.

Uses:

Fertilizer production
Phosphoric acid production
Chemical industries

Other non-metallic minerals
Mica – electrical and insulation applications
Gypsum – cement and plaster
Dolomite – refractory and flux applications
Graphite – electrodes and refractories
Silica – glass and foundry industries
6. Scope and Objectives of Ore Dressing
Definition of Ore Dressing

Ore dressing, also called mineral processing, is the process of separating the valuable mineral from the unwanted gangue materials by using mainly physical and sometimes physicochemical methods.

**Main objectives**
To increase the concentration of valuable minerals.
To remove unwanted gangue materials.
To obtain a concentrate suitable for extraction.
To improve the recovery of valuable minerals.
To reduce the quantity of material sent to metallurgical processes.
To reduce transportation, fuel and processing costs.
To improve the efficiency of subsequent extraction processes.
To recover useful minerals from low-grade ores.
**Scope of Ore Dressing**

The major operations include:

Crushing → Grinding → Screening → Classification → Concentration → Dewatering

Common concentration methods include:

Gravity separation
Magnetic separation
Electrostatic separation
Froth flotation
Dense-medium separation
**7. Physical and Chemical Properties of Ores and Their Application in Mineral Dressing**

Different minerals have different physical and chemical properties. These differences are used to separate valuable minerals from gangue.

A. Physical Properties

1. Specific Gravity / Density

Different minerals have different densities.

Application:
Used in gravity separation.

Example: Heavy minerals can be separated from lighter gangue using shaking tables, jigs and spiral concentrators.

2. Magnetic Properties

Some minerals are strongly attracted to a magnetic field, while others are weakly magnetic or non-magnetic.

Application:
Used in magnetic separation.

Example: Magnetite can be separated from non-magnetic gangue using magnetic separators.

3. Electrical Conductivity

Minerals differ in their ability to conduct electricity.

Application:
Used in electrostatic separation.

Conducting and non-conducting particles can be separated using an appropriate electric field.

4. Size and Shape

Mineral particles can differ in size and shape after crushing and grinding.

Application:
Used in screening and classification.

Screening separates particles according to size.
Classification separates particles according to settling behaviour, which depends on size, density and

shape.

5. Hardness

Different minerals have different resistance to scratching and abrasion.

Application:
Useful during crushing and grinding because softer and harder minerals behave differently during size reduction.

It also influences the degree of liberation obtained during grinding.

6. Colour and Lustre

Minerals may have different colours and surface appearances.

Application:
Can assist in hand sorting and optical/automated sorting.

7. Cleavage and Fracture

Minerals break along particular planes or irregularly depending on their cleavage and fracture characteristics.

Application:
Influences crushing and grinding behaviour and can help achieve selective liberation of valuable minerals.

**B. Chemical / Physicochemical Properties**

1. Surface Wettability

Some mineral surfaces are naturally water-loving (hydrophilic), while others can be made water-repellent (hydrophobic).

Application:
This property is the basis of froth flotation.

2. Surface Chemical Properties

Different minerals react differently with collectors, activators, depressants and other flotation reagents.

Application:
Used for selective flotation of valuable minerals.

3. Solubility

Minerals differ in their solubility in water or particular chemical solutions.

Application:
Useful in chemical or hydrometallurgical separation processes and in some mineral-processing operations.

4. Chemical Reactivity

Different minerals react differently with acids, alkalis and other chemicals.

Application:
Used for selective dissolution or chemical treatment of minerals.

5. Oxidation-Reduction Behaviour

Minerals can differ in their tendency to oxidize or reduce.

Application:
Important in flotation and in the treatment of sulphide and oxide ores.

**UNITOPERATIONS(OREDRESSING)**

**DistinctionbetweenMineralandOre**

| MINERAL | ORE |
|---|---|
| • Mineralsarenaturallyoccurringinorganicsolid compoundwithcrystallinestructureandadefinite range of chemical. | • Ore is the rock form which the metal is extractedinaconvenientandeconomicallyway. |
| • AllMineralsarenotore. | • Alloresare mineral. |
| • Clayis a mineral ofaluminum. | • Bauxiteisthemainoreof aluminum. |

## UNIT:02 SIZE REDUCTION

**Importance of Comminution in Mineral Processing**

Comminution is the process of reducing the size of mineral particles by crushing and grinding. It is one of the most important operations in mineral processing because valuable minerals are usually locked within a matrix of unwanted gangue minerals.

**Importance**
1.Liberation of valuable minerals
2.Comminution breaks the ore into smaller particles so that valuable minerals become physically separated, or liberated, from gangue.
3.Improves concentration efficiency
4.Properly sized and liberated particles can be efficiently separated by methods such as gravity separation,
5.magnetic separation, flotation, and electrostatic separation.
Increases surface area
6.Grinding produces finer particles and greatly increases their surface area, which is particularly important for flotation and leaching.
7.Prepares ore for further processing
8.Ore must generally be reduced to a suitable size before beneficiation, extraction, or chemical treatment.
9.Improves recovery of valuable minerals
10.Adequate size reduction increases the probability of separating valuable minerals from gangue, thereby
Size reduction occurs when an applied force produces stress within a particle that exceeds the particle's strength, causing it to fracture. The main mechanisms are:

**1. Compression**

The particle is subjected to compressive forces between two surfaces.

Causes the particle to fracture mainly by crushing.
Produces relatively coarse products.
Common in jaw crushers, gyratory crushers, and cone crushers.

Example: A piece of ore squeezed between the jaws of a jaw crusher.

**2. Impact**

A sudden force is applied to the particle, producing a high rate of loading and causing fracture.

Effective for brittle materials.
Produces relatively fine particles.
Common in impact crushers and hammer mills.

Example: Ore particles struck by rapidly rotating hammers.

**3. Attrition**

Size reduction occurs because of rubbing or friction between particles or between particles and the grinding surface.

Produces fine particles.

Important in grinding operations.
Common in ball mills and stirred mills.

Example: Particles rubbing against each other as they move inside a grinding mill.

**4. Shear**

The particle is subjected to forces acting in opposite directions, causing it to break by shearing.

Particularly useful for materials that are weak along certain planes.
Can produce fine particles.
5. Cleavage

A particle breaks along a preferred crystallographic or structural plane where the material is relatively weak.

Depends strongly on the mineral's crystal structure.
Can produce relatively clean fractures.

## CRUSHING

**Gangue:-**Unwanted particles or worthless portion of ore is known as gangue.

Comminution of anyore is carried out in several stages using different crushing equipments. So the objective crushing is to reduce the large lumps into smaller sizes. Depending upon the feed and product particle size, the crushing operation can be classified as follows:

1. **Primary crushing:** The feed material is usually the run of mine.

2. **Intermediate crushing or secondary crushing:** The feed material is usually product of a jaw crusher.

3. **Fine crushing or coarse grinding:** The feed material is usually comes from the secondary crushers.

4. **Fine Grinding:** The objective of fine grinding is to produce ultra fine material less than one micron.

■ **Mechanism of Size Reduction:** Crushing is a mechanical operation in which has forceof large magnitude is applied to a relatively brittle solid material in such a direction that its failure takes place. The theory of size reduction for solids is quite complex, but can be attributed to the action of following forces acting on the particle:

1. A huge compressive force exceeding the ultimate strength of the material may be responsible for size reduction as actually happens in case of jaw, gyratory and roll crushers.

2. A sufficiently high impact force may be responsible for size reduction. Impact force is largely utilized in hammer & ball mills.

3. Attrition,rubbingactionorfrictionalforcesmaybeutilizedforsizereduction.Suchaction is largely responsible for crushing in attrition mill, tube and pebble mills.

4. Cuttingforceisutilizedinknifeedgemillstoreducethesizeoffibrousmaterialslike mica, asbestos.

**BasicRequirementsofCrushingEquipment's:**

Anidealcrusherorgrindershouldhavethefollowingcharacteristics:

**a.** Itshouldhavealarge capacity.

**b.** Itshouldrequireasmall(energy) inputperunitweightof production.

**c.** Itshouldyield aproductofuniformsizeorintherequiredsizerange.

**<u>ClassificationoftheSizeReductionEquipment's:</u>**

(InTheOrderOfFinerSizeProduct)

**<u>A. PrimaryCrushers</u>**:

1. Jaw crusher.

2. Gyratorycrusher.

**<u>B. Intermediatecrushers:</u>**

1. Crushingrolls.

2. Conecrusher.

3. Disccrusher.

**<u>C. FinecrushersorCoarseGrinders:</u>**

1. BallMill.

**<u>D. FineGrinders:</u>**

1. Rod mill.

2. Pebblemill.

3. Tube mill.

4. Hammermillwithinternal classifier.

● **<u>Primarycrushersareoftwotypes:</u>**

1. Jaw crusher.

2. Gyratorycrusher.

**<u>ClassificationofJawCrushers:</u>**

Fromcapacityandworkingmechanismpointofviewjawcrushersare three types such as:

**1. Blakecrusher.**

**2. Dodgecrusher.**

**3. Universalcrusher.**

Thefunctionalfigureofdifferentjawcrushersareasshown schematically in

the figure.

**BLAKEJAWCRUSHER**

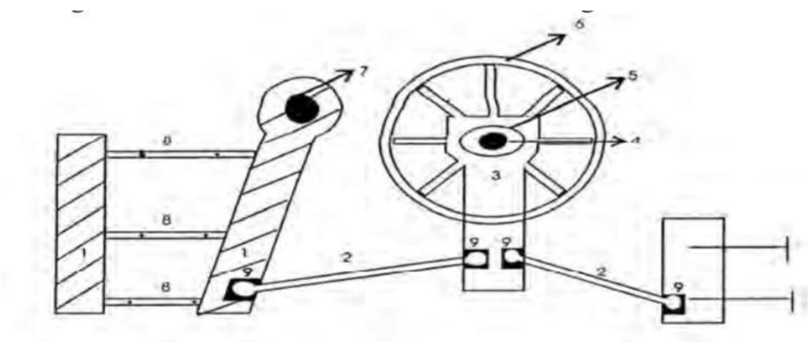
Itisaprimarycrusherusedmostwidely.Ithasitsmovingjawpivoted(hinged).Thoughthe working principles of Blake andDodgecrushers maybedifferentfrom constructionalpoint of view theyarealmostidenticalexceptingtwonotabledifferenceswhich will be discussed afterward. The Blake crusher may be classified as single toggle or double toggle type.

**ApplicationofBlakeJawCrusher**

Itisusedforreducingrun-of-mineoreorcoaltoasizesmallenoughtobetakenbythenext crusher in the series during the first stage of crushing.

**TechnicalSpecifications**

1. ToggleType:Singleordoubletoggle




1. Jaw Plates 2. Toggles 3. Pitman 4.Main Shaft
5. Eccentric 6. Flywheel 7. Top hinge 8. Check P
9. Bearings
[ Blake Jaw Crusher ]

2. Feedsize:100mm

3. ProductSize:(5-15)mm

4. Capacity:20-30kg/hr.

5. JawType:OnefixedjawandonemovablejawwithMnsteelLiner.Provisionsforoutput gap adjustment is available.

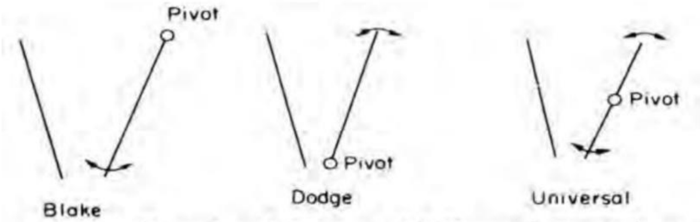


Fig-- Functional figures of different jaw crushers.

6. Feedmaterials:Coal,ironore,Mnore,Chromiteore,Rock,Mgore,Aluminiumoreetc.

7. Motorcapacity:Preferablywith(415-440)V/3Ph/50Hzelectricsupply, andonsiteisolator switch

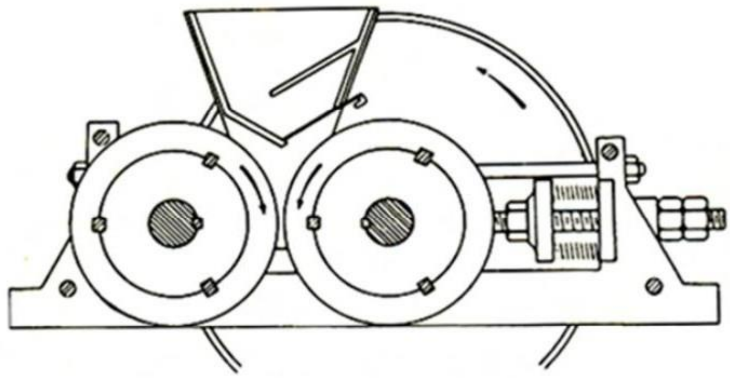
**ComparisonbetweenBlake&DodgeCrusher:**

| **BLAKEJAWCRUSHER** | **DODGEJAWCRUSHER** |
|---|---|
| 1.Ithasgottwotoggles. | 1. Ithasonetoggleinthe formofalever |
| 2.Ithasonepitman | 2.Ithasnopitman |
| 3.Themovablejawispivotedatthetop, sohas a variable product discharge opening while feed receiving opening is fixed. | 3.Themovablejawispivotedatthebottomso the discharge opening is fixed. The set isfixed, while the feed receiving opening varies. This results in almost uniform sized product. |
| 4.No choking takes place here as it has variabledischarge.Itoperatesonprincipleof forced feed. | 4.Chokingisaverycommonproblemasthe set is quite small compared to receiving opening. |
| 5.Thiscrusherismechanicallymorebalanced and has fewer breakdowns. Further it is built for much larger capacity. | 5.Mechanicallythedesignofthiscrusheris inferior.Soitisbuiltonlytolowercapacity. This machine has more breakdowns as compared to the other. |
| 6.Productsizedistributionislarge& produces more fines. | 6.Productsizedistributionismoreuniform. |
| 7.Blakeispreferred atlargeindustrialsetups whereelaboratescreeningfacilityisavailable along with other comminution machines. | 7.Adodgeispreferredwherejawcrusheristo be used as the only comminution equipment. |
| 8.Thismachineisofhighercostforsame output. | 8.Thismachineischeaperforsameoutput. |
| 9.Becauseofforcedfeedlubricationityields a coarser product. | 9.Aschokefeedingispossible,itcanyielda much finer product. |

**CrushingRolls:**

- Consistattwoheavycylindricalrollrevolving/rotatingtowards each other
- RollsaremadeofwearresistingcastHadfieldmanganesesteel
- Rollcentersareatthesameheightseparatedbyadistance.
- Crushingoccurbycompressiveforce.
- Rollsturntowardseachotheratsamespeedtoavoid slip.
- Rollsare300mmdiameterand600mm long.
- Rollspeedis50-300rpm
- Feedsize12-75mm
- Productsize12-20mm.

# CRUSHINGROLL



## ANGLENIPOFA CRUSHER

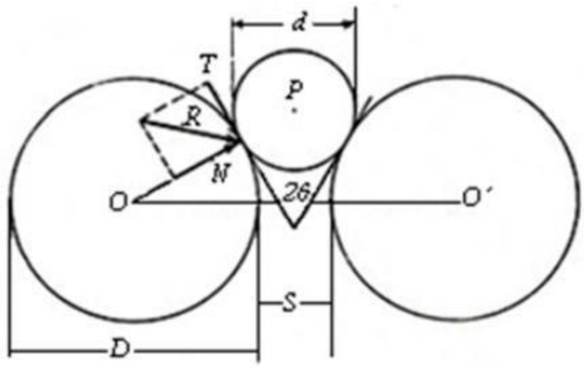
Itisdefinedastheanglesubtendedbetweenthetwotangentsdrawnatthepointsofcontact of the rolls and the particle to be crushed.

1. Rolldiameter(D).

2. Particlediameter(d).

3. Interrolldistance(S).Assumingtheparticletobespherical.

4. Frictionfactorbetweentheroll&themineral (μ).




## CharacteristicsoftheCrushingRolls:

1. Ithasareductionratio (r.r)isaround3 -4onlywhichisverylowcomparedtoothersize reduction equipment.

2. Ityieldsauniformsized product.

3. Theproductofthecrushingrollscontainsfewerfinesasthemassificationtimeislimited and no repeated crushing takes place.

4. Capacity:

Capacityoftherollcrusher dependsonthefollowingfactors:

i. Speedofrevolution(N).

ii. Widthofthefaces(W).

iii. Diameteroftherolls (D).

iv. Set(S),theinterrolldistance

v. Specific gravityofrock (ρ)lb/in3

6.Rollscanbeoperatedeitherwetordry.Drycrushinghasaloweroutputbutcauseslesser wear of the rolls.

5.Itisbestoperatedonchokefeedingformaximumoutput.Inopenfeedingtheoutputis less.

**<u>Uses</u>:**

The rolls are most suitable in effecting only a smaller size reduction in a single operation. Therefore, it is common to employ a number of pair of rolls in series to achieve higher reduction ration. Crushing rolls are extensively used in crushing oil seeds, gun powder and coalbecauseoflowerresidencetimeofthefeedaslowerresidencetimereducestheeffectof heat on the feed material.

❖

## Laws of Crushing

The laws of crushing describe the relationship between the energy required for size reduction and the size of the particles. The three important laws are:

### 1. Rittinger's Law

Rittinger's law states that the energy required for size reduction is proportional to the new surface area produced.

$$E \propto \left(\frac{1}{D_2} - \frac{1}{D_1}\right)$$

or

$$E = K_R \left(\frac{1}{D_2} - \frac{1}{D_1}\right)$$

Where:

- $E$ = energy required
- $D_1$ = initial particle size
- $D_2$ = final particle size
- $K_R$ = Rittinger's constant

Application: Mainly applicable to fine grinding, where a large amount of new surface area is created.

### 2. Kick's Law

Kick's law states that the energy required for size reduction is proportional to the logarithm of the size reduction ratio.

$$E = K_K \ln\left(\frac{D_1}{D_2}\right)$$

Where:

- $K_K$ = Kick's constant
- $D_1/D_2$ = size reduction ratio

Application: Mainly applicable to coarse crushing, where relatively little new surface area is produced.

### 3. Bond's Law

Bond proposed that the energy required for size reduction is proportional to the new crack length produced, and lies between the concepts of Kick and Rittinger.

The commonly used Bond equation is:

$$E = 10W_i \left(\frac{1}{\sqrt{P}} - \frac{1}{\sqrt{F}}\right)$$

Where:

- $E$ = energy required, usually in kWh/tonne
- $W_i$ = Bond's work index
- $P$ = 80% passing size of product
- $F$ = 80% passing size of feed

Application: Widely used for crushing and grinding equipment design and power calculations.

**BALL MILL**

**<u>ClassificationofBallMills:</u>**

Ballmillscanbeclassifiedaccordingtothe

a. Shapeofthemill.

b. Methodsofdischargeofthegroundore.

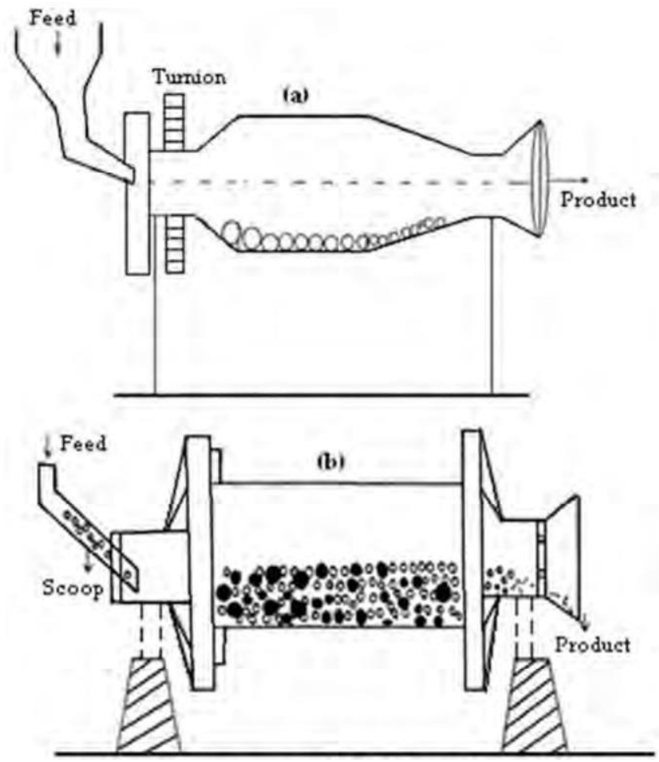
c. Weatherthegrindingisconducted dryorwet.

**<u>ShapeoftheMills:</u>**

Accordingtotheshapethemillsareclassified as:

1. Cylindro-conicalmills:Hardingmill(wherefeed&dischargeendsarefixed).

2. Cylindricalmills.Thisrepresentstheusualball mills.




**2.MethodofDischarge:**

Cylindricalmillsarealsoclassifiedaccordingtothemodeofproductdischargetakingplace from the mill. According to the discharge method mills are classified as:

a. Peripheraldischargemill:Dischargeofthegroundproducttakesplacethroughmeshed cylindrical shell.

b. Gratemill:Dischargeofthegroundproducttakesplacethroughascreenextendingasa diaphragm across the full section of the mill at the discharge end.

c. Overflowmill:Dischargeofthegroundproducttakesplacebyfreeoverflowfromtheaxis of the mill.

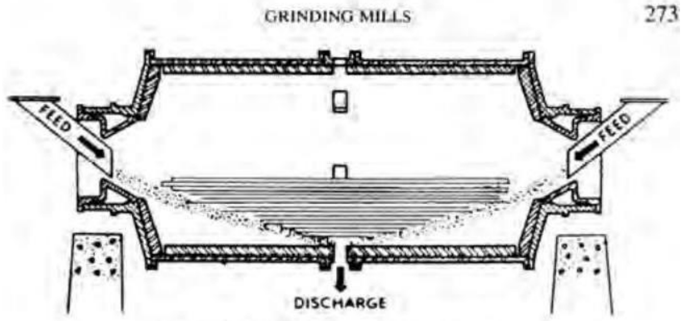



FIG. 7.16. Central peripheral discharge mill.

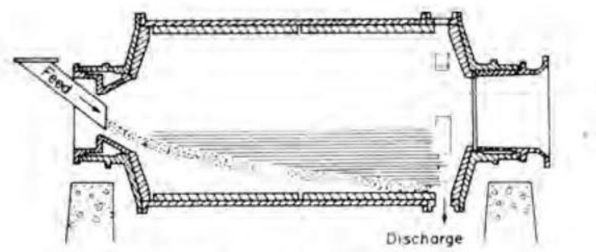



FIG. 7.17. End peripheral discharge mill.

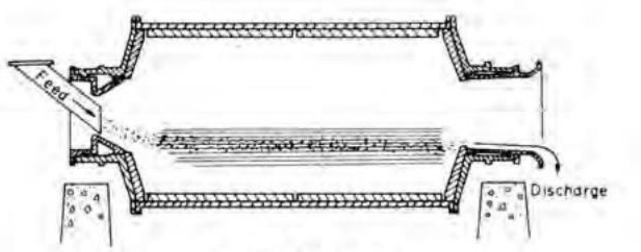



FIG. 7.18. Overflow mill.

**<u>TheoryofBallMill Operation:</u>**

Ballmillsmaybecontinuousorbatchtypeinwhichgrindingmediaandtheoretobeground are rotated around the axis of the mill. Due to the friction between the liners–balls & liners– ore lumps, both the ore and balls are carried up alongthe inner wall of the shell nearlyto the top from where the grinding media fall down on the ore particles below creating a heavy impact on them. This usually happens at the toe of the ball mill.

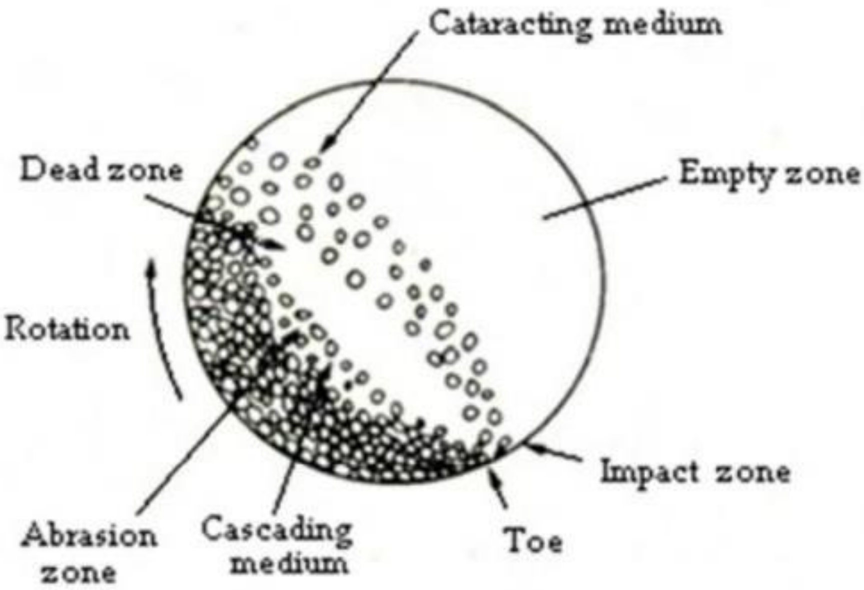
Theenergyexpandedintheliftingupthegrindingmediaisthusutilizedinreducingthesize of the particles as the rotation of the mill is continued. In fact the grinding process is attributed to three different stages of ball mill working. They are:

a. Cascading(attritionbetweentheballsandparticles).

b. Cataracting(impactof the ballonthe particles).

c. Centrifuging.

Allthesestagesofworkingareshownschematicallyinbelow




CASCADING:-Grindingoccursdueto attrition,andballswillnotbecarriedupalongthe inner wall to a greater height,they roll over each other or slip.

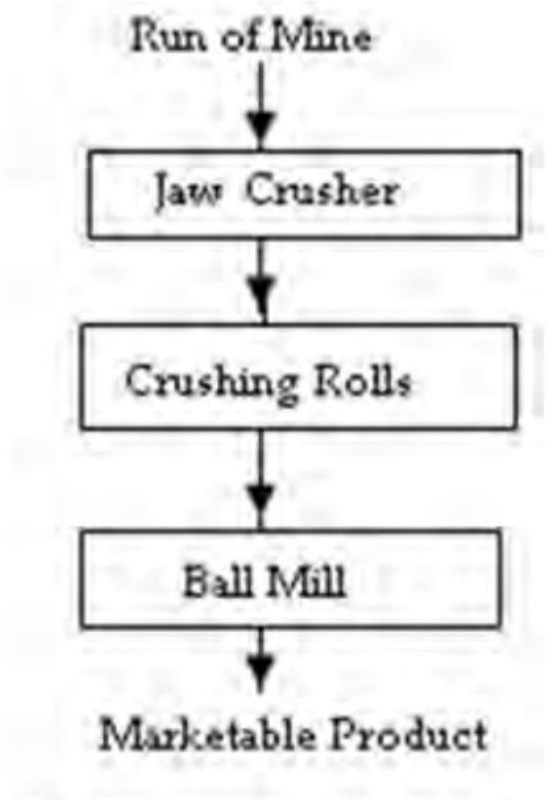
CATARACTING:-If speed increases then balls will be raised to a greater height and fall downandcreate alargeimpact,Thisimpactis largelyresponsibleformostofthegrinding.

CENTRIFUGING:-If the speed of rotation becomes too high, the balls are carried over and overagain allalongtheinnerliningasiftheyarestickingtotheinnerwallandthereishardly any grinding. This condition is known as centrifuging of the mill.

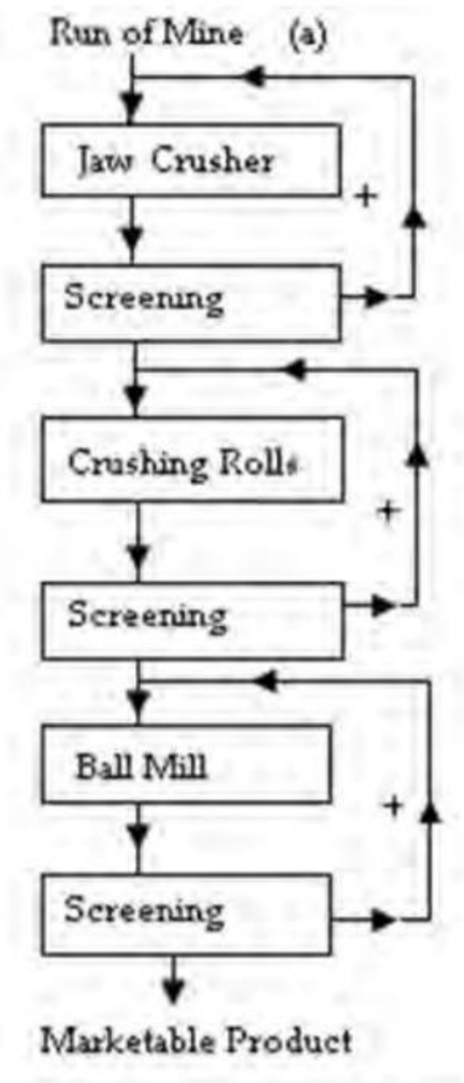
## GRINDING

**Open Circuit Grinding Operations:** The usual meaning of grinding here is comminution and has nothingto do the product particle size. In manymills the feed is broken into particles ofsatisfactorysizebypassingitoncethroughthemill.Whennoattemptismadetoreturnthe over sized particles in the product once again to the crusher for further size reduction the product simply passes-off to the next stage of size reduction.

Suchamethodofsizereductionatvariousstagestillthedesiredproductisobtainedistermed as open circuit grinding. A bright example is dodge crusher operatingon choke feeding. This grinding may require excessive amount of power and much of the energy is wasted in regrinding the particles that are already fine enough.




**Close Circuit Grinding Operation:**In another method the partially crushed material is screened and the oversized material is returned back to the crusher for further crushing and the undersized product is given as the feed to the next machine for further size reduction. If such a method is followed in all successive crushers till the desired product is obtained it is termedasclosedcircuitgrinding.Thismethodofgrindingoperationisgenerallyadoptedas such a process has been found to be economical making full capacity utilization of all equipments efficiently. This process avoids unnecessaryregrinding.


Run of Mine
(a)
Jaw Crusher
+
Screening
Crushing Rolls
+
Screening
Ball Mill
+
Screening
Marketable Product

UNIT:02 SIZING AND CONCENTRATION METHODS

LABORATORYSIZINGTECHNIQUE

## Introduction

Size analysis of various products of a crushing mill constitutes a fundamental part of the laboratory testing procedure.particle size has a great role to playduring reactions between solid-liquidorsolid-gas.Sotheproductfromthecrushingequipmentistobeanalysedforits size for all practical purposes. Further the size analysis of the product is required to evaluate the energy consumption and the size reduction process it may require for further size reduction.

## Particlesizeandshape

The size of a spherical particle can be defined uniquely by its diameter. However, there is no unique dimension by which the size of an irregular particle can be described. The term most oftenusedtodescribean irregularparticleistheequivalentdiameter ($\overline{)}$). Therecanbevarious shapes to describe a particle as discussed below:

1. Accicular:Needlelikeparticles.
2. Angular:Sharpedgedpolyhedrons.
3. Crystalline:Particlesofregulargeometricshapes.
4. Fibrous:Regularorirregularthreadlikeparticles.
5. Dendritic:Particleshavingbranchedcrystallinestructure.
6. Flaky:Platelike particles.
7. Granular:Equidimensionalirregularshapedparticles.
8. Irregular: Lackofanysymmetryintheparticles.
9. Nodular:Particleshavingroundedirregularshape.

## ParticleSize:

Thecrushedoreparticles aregenerallyirregularin shapeanditis quitedifficulttodefinethe sizeoftheparticleuniquely. In caseofspherical particles,thediameteristhesize.Forcubes the edges, the long diameter or diameter of a sphere of equal volume may be considered as the size. But for totally irregular particles there is no such standard method. So it is impossible to define what is meant by size of the particle.

### CommonMethodsofSizeAnalysis:

Particle size is usually defined as the narrowest regular aperture through which mineral particlepassesthrough.Throughthisdefinitionisapplicabletopolyhedronsitisnotvalidfor rodshapednarrowparticles.Particlesizecanbedeterminedbyvariousmethodsasdescribed below table;

| Methods | Approximate size range (microns) ($1\ \mu m = 10^{-6}\ m$) |
|---|---|
| Sieve analysis | 100000 -10 |
| Elutriation | 40 – 5.0 |
| Optical microscopy | 50 – 0.25 |
| Sedimentation(gravity) | 40 – 1.0 |
| Sedimentation(centrifugal) | 5 – 0.05 |
| Electron microscopy | 1 – 0.005 |

**Microscopic Measurement:** For measuring the particle size under microscope, it is customary to sprinkle them on a slide and to measure their diameter in random directions or in any two perpendicular axes within the plane of vision. In both the cases the smallest dimensionisneglected.Fornumberofparticlesthedimension+ismeasuredandtabulatedas follows:

| Number of observations | $x_i$ |
|---|---|
| 1 | $x_1$ |
| 2 | $x_2$ |
| $n$-1 | $x_{n-1}$ |
| $N$ | $x_n$ |

**Now average size,** $\bar{x} = \frac{x_1+x_2+x_3+x_{n-1}+x_n}{n}$

**2. Elutriation:** Elutriation is based on the fact that a particle will just be sustained in an upward rising current of water or any other fluid if the velocity of the water current is equal tothatwhichtheparticlewouldattainwhenfallinginstillwater.Thisworkson theprinciple of Stoke’s law of settling.

**3. SieveAnalysis:** Thisisthemostimportantmethodofsizingthemineralparticles.This is widely used to determine the efficiency of size reduction operations and also used as a yardstickforassessingthefinenessofagroundproduct.Assieveanalysis hasbeenthemost important method of size analysis it has become pertinent to discuss about the standard screens British Standard Sieves:

## Britishstandardsieves:-

In the British system a screen is designated with a number called mesh number and the apertureofscreenopeningistermedasmeshsize.Meshnumberisdefinedasthenumberof square openings available per linear inch length on the screen surface. If the screen has 4 openingsperlinearinchlengthofthescreensurfacethenthemeshnumberofthescreenis4. Likewise we have screens of 20, 40 … 200, 270and 400 mesh number. When mesh number increases aperture of the screen opening decreases and vice versa. or sieves used worldwide for the purpose.

**ASTM Standard Sieve Series:**

| Mesh Number | Aperture (in mm) | Mesh Number | Aperture (in mm) |
|---|---|---|---|
| 3 | 6.680 | 35 | 0.417 |
| 4 | 4.699 | 48 | 0.295 |
| 6 | 3.362 | 65 | 0.208 |
| 8 | 2.362 | 100 | 0.147 |
| 10 | 1.651 | 150 | 0.104 |
| 14 | 1.168 | 200 | 0.074 |
| 20 | 0.833 | 270 | 0.052 |
| 28 | 0.589 | 400 | 0.037 |

**<u>Screen Analysis Equipment:</u>**For sieve analysis, screening is usually carried out in a mechanised sieve shaker called Ro-tap sieve shaker. Ro-Tap Sieve Shaker: Figure3.2.shows the Ro-tap machine schematically. It consists of a movable cage with a base a and a top plate bbetweenwhich13halfheightor7fullheightsieveswithpanandcoverlidcanbemounted. 55 The mounted sieves are subjected to rotary shifting motion while at the same time the lever c strikes the top plate once per revolution. This striking vibrates the screen cloth for better screening. A timer switch with the motor is used to control the time duration of screening. The machine is so designed that it performs the most ideal screening operation within the specified time period.

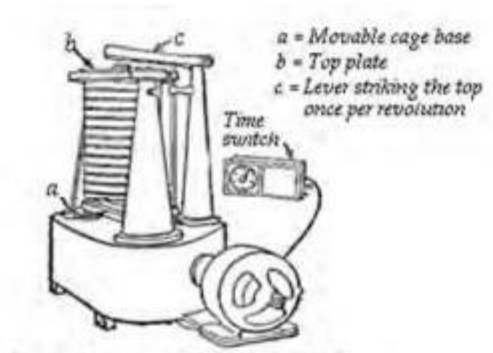
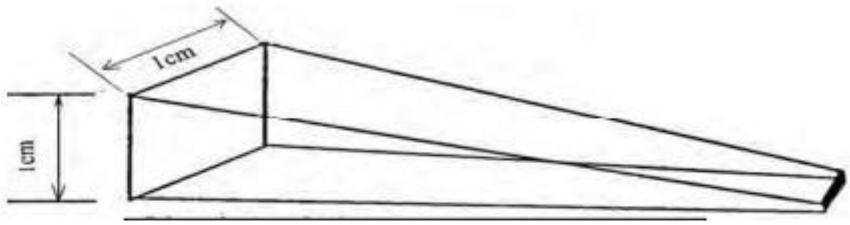



Fig 3.2. Rotap Sieve Shaker

## WILFLEY TABLE

### PrincipleofWilfley Table

- Thevelocityofthefluidisnot the sameat alldepths of thefluid film.
- Thevariationin fluidvelocityhappensduetotheviscosityo thefluids.
- Flowingfluidfilmcaneffectivelyseparatecoarselightparticlesfromtheheavysmall particles.
- Duringtablinglargersphericalparticlesmovefasterthanthefixeirregularparticles down the strem during tabling.
- Tablingtakesplaceonaninclinedshakingtablewhichisknownaswilfleytable.
- FlatplanesurfaceiscalledDECK.
- Tableisshakenasymmetrically.
- Thelighterganguematerialsarethrownintothesuspensionandaredischargedout over the edge of the tableopposite to the feed box by the wash water.
- Speedof thetable( 200– 300 ) strokes\min.
- StrokeLength(12 –15)mm
- Finerfeedmaterial➔Higherspeed➔Smallerstroke length.




- $2/3^{rd}$oftotalsurface areaoftableiscleated/riffledandrest$1/3^{rd}$portionisunriffled.
-

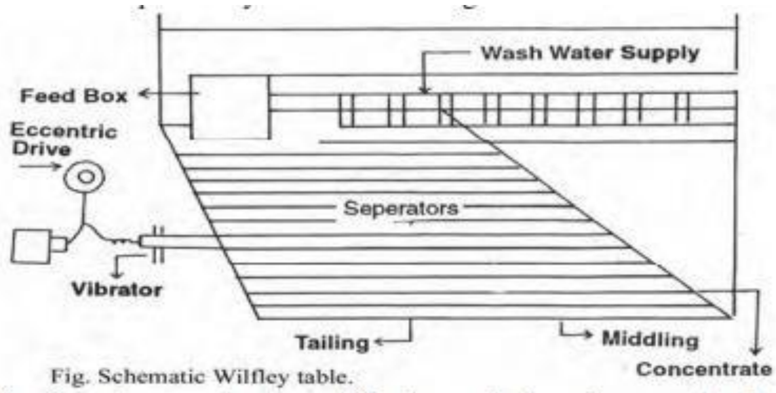


Fig. Schematic Wilfley table.

- Thenormalinclinationinboththedirectionsislimitedto0-3degrees.Formajorityof ores a slope of 0.75-1.25 degrees is used.

## Costof Operation.

- Power0.5 -------- -- 0.8Kw/hr
- Repairing,costofcleats&deckasandwhen required.

## ImportantUseofWilfleyTable:

- Itiswidelyusedtoconcentrate cassiteriteortinore.
- Itiswidelyusedtoconcentratefreemilledgold ores.
- Itiswidelyused forbeneficiationofnonmetallicslikeglassandsand.
- Itiswidelyused forbeneficiation chromiteandtungsten ores.
- Itiswidelyusedtorecoverthepartofgalenaandsphaleriteincoarseaggregateof lead-zinc ores. 5. It is widely used for cleaning fine coal.
- Itis widelyusedforbeneficiation of some iron ores.
- Itisadopted asapilotandguidetoflotationplants.

## JIGGING:-

Jigging is one of the most ancient methods of ore concentration. It is a special form of hindered settling resulting in stratification of particles into layers of different specific gravities followed by removal of the stratified layers. The stratification is achieved by repeatedlyaffordinganopportunitytoaverythick suspensionofmixedparticlestosettlefor a short time.

**PrinciplesofJigging:**Thethreephysicalfactorsresponsibleforstratificationsof particles during jigging are:

a. Hinderedsettlingclassification.
b. Differentialaccelerationatthebeginningofthefall.
c. Consolidationtricklingatthe endofthe fall.

## Hinderedsettlingclassification:

Theessentialdifferenceinhinderedsettlinginjigsandclassifiersisthatinjiggingthesolid - fluid mixture is very thick and it approximates to a loosely packed bed of solids with interstitial fluid flowing through the particles rather than fluid carrying the solid particles with it happens in the case of classifiers. The thick solid-fluid suspension used in jigs cannot be maintained for a long length of time and also doesn't allow sufficient play between the particles for their complete rearrangement. As the jigs produce a fluidized bed for few seconds,itoffersanopen bedalternativelyandparticlerearrangementtakes placeduringthat time period only. Other parameters remaining same higher settling ratios are obtainable in jigs compared to classifiers.

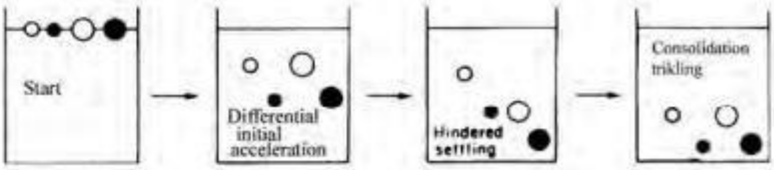
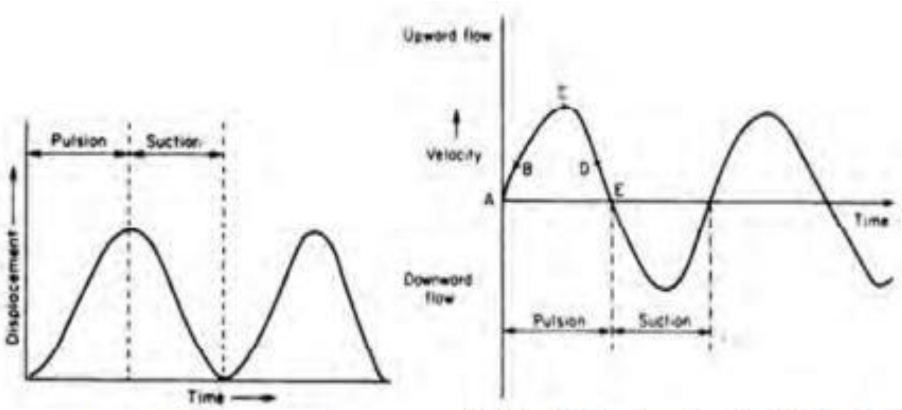



Fig.7.1. Effect of Hindered Settling During Jigging.

**Jigging Cycles:** Short falls are to be realized in jigs for stratification to occur. This is obtained by pulsation and suction of water or any other fluid through a bed of ground ore held on a perforated grate or sieve. During pulsation & suction the fluid moves up and downwardrespectivelywithreferencetoastationarypoint.Fig.7.3.ConsolidationTrickling. 99 During pulsation the ore bed expands while during suction the bed gets compacted. Most jigs use bath pulsation & suction, but in same jigs the suction is avoided. The plot of fluid velocity with respect to time describing a full cycle of pulsation and suction is termed as jigging cycle.




(a) Movement of the piston in a jig.

(b) Speed of flow through ore bed during the jigging.

Fig.7.4. A Schematic Jigging Cycle.

## Differentjiggingcycles:

Jiggingcycleissaidtoconsistofpulsationandsuction.Belowfigureshowsseveraljigging cycles schematically.

- Type A &Busepulsationonly.
- TypeC&Dusepulsationandsuctionbothbeingsymmetrical.
- TypeEasymmetricalpulsationand suction.
- TypeFsymmetricbutunequalsuctionand pulsation.

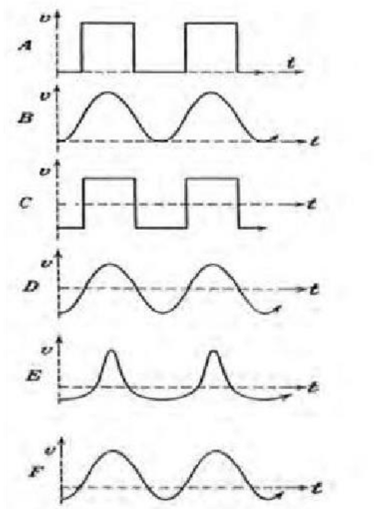



Fig.7.5. Several Idealized Jigging Cycles.

## ClassificationofJigs

Jigsareclassifiedtotwo types:

a. Handjig.
b. Mechanicaljig.

## Handjig:

This is the simplest of alljigs which consists of a framed sieveheld byhands and is actuated bytheoperatorwithareciprocatingverticalmotion.Ingeneralaperforatedcylindricalshape container is used. After filling up the vessel with minerals up to the desired level it is closed tightly. With a rope and pulleyarrangement it is made to move up and down in a water tank to attain the condition of pulsation and suction of water in the mineral bed. As the process is continued or repeated for several times complete stratification takes place. This jig is mainly used in the laboratory to demonstrate the effect of jigging operation.

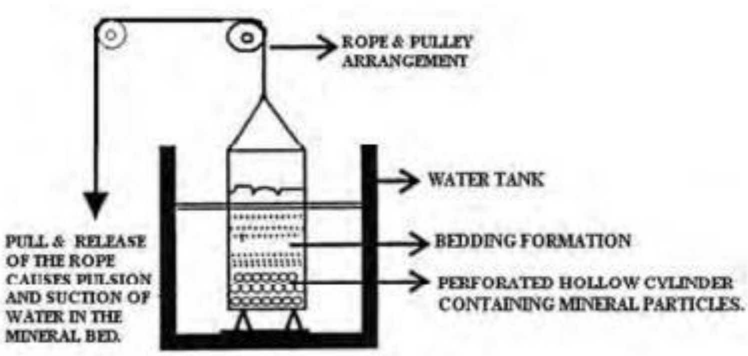



Fig. Laboratory Hand Jig.

## Mechanicaljigs:

MechanicalJigsareofvarioustypes. Butregardlessoftypetheyareessentiallycomposedof:

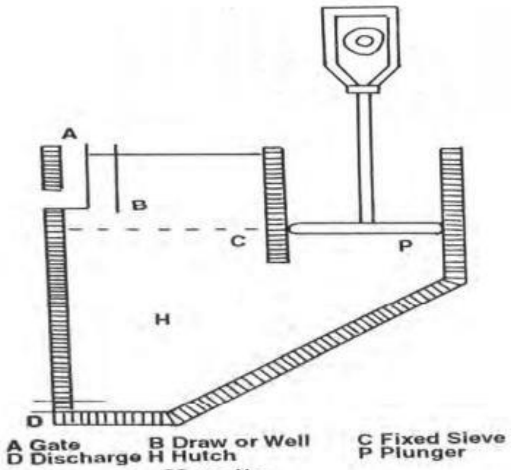
i. shallowopentankcontainingascreen-bottomonwhichoreissupported.
ii. AAhydraulicwaterchamberor hutch.
iii. Areciprocatingsystemforpulsationandsuctionofwaterthroughthescreen.

**TypicalMechanicalJig:**

Therearedifferentmechanicaljigssuchas:

1. Fixedsieveplungerjig.
2. FixedsievePulsatorjig.
3. PneumaticorBaumjig.

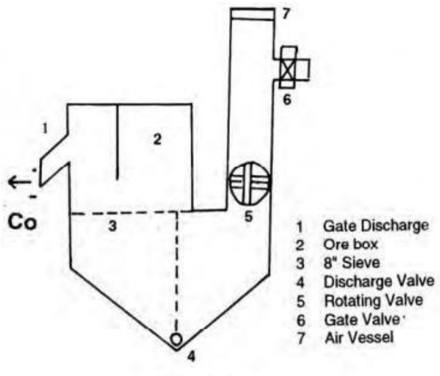
**Fixed Sieve Plunger Jig (Harz Jig):**The harz jig has a fixed sieve. The jigging motion is obtained by plunger, P reciprocating in a compartment adjoining the sieve compartment, C. The bottom layer (usually the concentrate) is removed through the gate, A. The upper layer (usually tailings) is discharged at the end away from the feed. Working: The crushed & graded ore is held on the sieve, C. Water is held in the hutch, when the plunger is pushed down water rushes up and when the plunger is moved up, water rushes down through the mineral bed held on the screen. 104 When water moves up it imparts a pulsation andwhen water moves down it imparts suction to the mineral bed. So both pulsation and suction takesplacealternativelyresultinginjigging.Jiggingdurationrangesfrom0.2to 0.6sec(100- 300 cycles per minute).



Harz jig

**2. PlungerJig:**Theplungerjigconsistsoforeboxofsize:24’’x8’’x6’’fittedtoonehalf of the tank and then plunger is fixed in the other half. The plunger is made to move up and down by mechanical arrangement. The bifurcation board between the jigging and plunger section at the centre extend sufficiently below the jigging sieve to ensure even arrival of water impulses at the sieve. Sieve plays an important role in jigging. Different types of jigs are used for different materials. Smaller materials use woven wire sieves, average sized material use punch plates while larger sized materials need barred grates.

**3. Pulsatorjigs:**Inthisclassofjigstherenosuctionstroke.Thejiggingisduetoimpulses ofwaterflowingunderpressurefromthewaterservicepoint.Theseimpulsesareobtainedby placingarotatingdeviceinthewaterserviceline.Thenumberofimpulsesisaround 200/minute. This type of jig can handle around 100tons/sq.foot/day.




Pulsator Jig

**4. Diaphragm Jigs:**Bendelari diaphragm jig is the most popular diaphragm jig used worldwide.ThisjigisanimprovedversionofHarztypejig.Inthiscaseadiaphragmisused in place of plunger to produce pulsion and suction of water in the ore bed held on the sieve. The mineral separation is rapid compared to Harz jig. Constructional features of this jig are shown schematically in the figure.

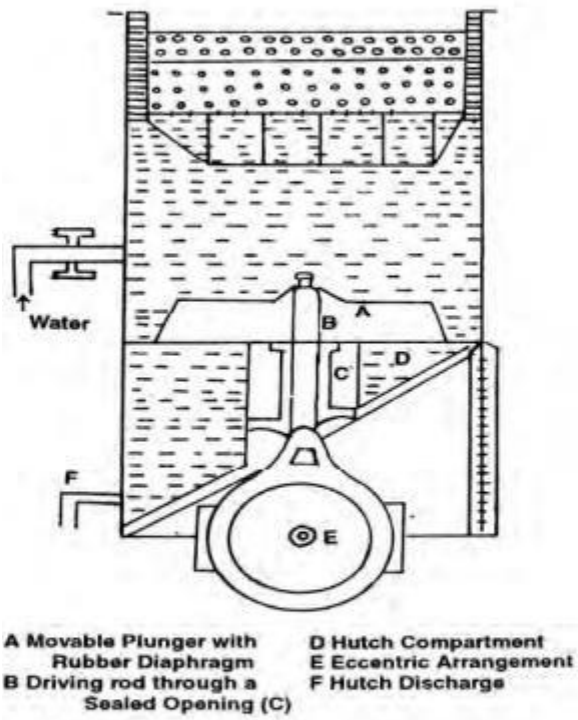



Fig. Bendelari Jig

Inthiscasetheplungerissealedtotheframebyarubberdiaphragm;hencethereisnowater leakage around the plunger which is a frequent problem in harz jig. Further the jigging surface is more accessible in this case as the actuating mechanism is placed at the bottom.

Thisresultsinanappreciablesavinginfloorspaceandweight.107ComparedtotheHarzjig, the Bendelari jig has a more open bed, larger capacity consumes less water and requires less maintenance. The jigging cycles range from 0.2-0.8 seconds, i.e.100-160 strokes per minute.

**5. Pneumatic or Baum Jigs:**Baum jig resembles the plunger jig in construction but differs in the working principle. With little modification it has been in use for the last 150 years. Presently it is extremely popular in coal washing. In this case air under pressure is forcedin&outofalargeairchamberononesideofthejigvesselcausingpulsionandsuction to the jig water. This in turn causes pulsion and suction through the crushed coal bed held on the screen. Thus stratification is caused finally. Baum jig has the advantage of handling wide range of sizes with high capacity.

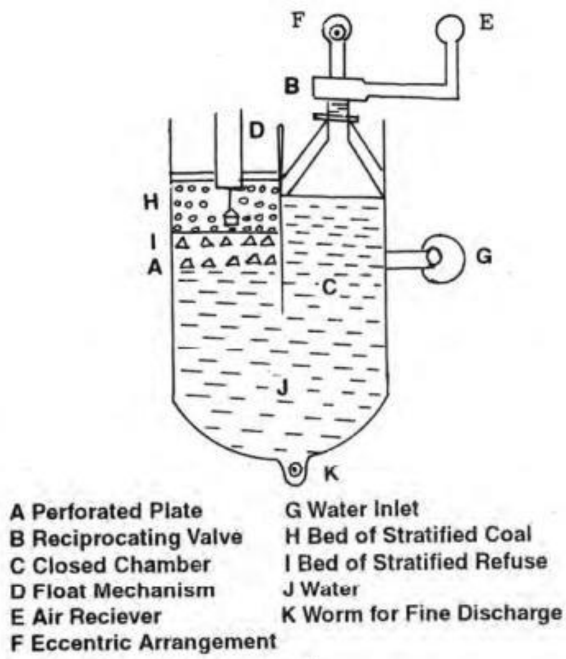


Fig. Baum Jig

**Advantagesof Jigs:**

1. Jigs are primarily used to concentrate coarse-minerals. In coal washing, up to 4 - 5inchescoalpiecescanbewashedinJigs. Incaseofores,piecesupto Iinchsizecan be treated. Hydraulic jigs can wash coal up to 1/8 inch & minerals as fine as 20#. Pneumatic jigs can treat minerals as fine 65# mesh and as coarse as 1-1.5 inches but not in a wider size range.
2. Excludingwashingofcoalitisusedwidelytobeneficiatenonmagneticironores.
3. Jigsarecheaptooperateandsubstantiallyfoolproofandoffersaneasyaccessfor inspection.

## Limitationsof Jigs:

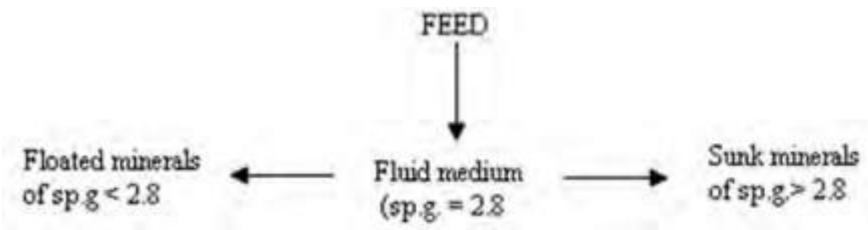
- Jigsareobsoleteforsulphideores.
- Itrequireslargeamountofwaterduringorebeneficiation.
- Finescannotbetreatedinjigs.Jiggingisapplicabletotheorethatistoocoarsefor complete liberation.
- Jigsdonot provideacomplete solutiontoanymineralbeneficiation problem.

## HEAVYMEDIASEPARATION

### Introduction:

Ifafluidisavailablewhosespecificgravityisintermediatebetweentwosolidswhichareto be to separated, then one of the simplest process will be to suspend the mixed mass in that fluid. As per law of buoyancy, one of the solids will float at the top of fluid level while the other one will sink to the bottom of the vessel. Then a mechanical arrangement will be required to draw 85 out different products from the top and bottom of the vessel. A typical example can be the separation of wood chips from gravel or sand using water medium.

**Principle of Heavy Media Separation:**The basic principle involved in the gravity concentration process is the ‘Float and Sink’. This is carried out by using a fluid whose specific gravityis in between the specific gravities of the two mixed up minerals particles in the crushed ore. Since most of the minerals are heavier than water, water is not a suitable fluid medium for practicing ‘float and sink’ method of separation. For this process to be effectivefluidsheavierthanwaterarerequired.Thebelowfigureexplainsthebasicprinciple involved in HMS.




**Laboratory GradeHeavy Fluids:**Mostoftheheavyorganicliquidsareused asheavy fluids and can be used onlyon a laboratoryscale to assess the optimum separation obtainable by gravity concentration. One of the most useful heavy fluids is acetylene tetra bromide whose specific gravity is 2.96. This fluid can be diluted with carbon tetra chloride with sp.8of 1.59 to yield a series of fluids with a sp.g varying from 2.96 to 1.59. Another group of useful fluids of low specific gravity is the aqueous solution of zinc chloride ($ZnCl2$) and calciumchloride($CaCl2$).Highcostoflaboratoryheavyfluidsprecludestheiremploymentin industrial applications.

**Industrial Grade Heavy Fluids:**For industrial application pseudo liquids can be prepared by suspending solids in water. These fluids can be used almost like true liquids provided the particles to be separated are coarser compared to the size of particles used to prepare the medium. This medium is continuously agitated to prevent settling of particles used to form the pseudo fluid but the agitation allows the settling of heavy particles in the crushed ore to be separated. Finely divided quartz, magnetite, galena or ferrosilicon is used formakingupthesuspension.TheabovefigureSchemeofheavyMediaSeparation.86range of specific gravity for fluids of commercial interest is 1.3-2. Such fluids are mainly used to separate coal from clay. Pseudo fluids are much cheaper than organic liquids of high specific gravity,sothecostoffluidlossisnotsignificant.Butontheotherhand,theuseofpseudo fluids is not as simple as that of true fluids.

**HeavyMediaSeparationCircuit:** Asimpleheavymediaseparationcircuitwould essentially consist of the followings:

i. Aseparatingvesselinwhichheavysuspensioniskeptwithaprovisionforintroducingthe feed and withdrawing the product continuously.

ii. Meanstocleantheproductseparated,recoverthemediaandrecirculateittothevesselfor further utilization.

## SpecificIndustrialProcessesUsingHeavyLiquids:

Threedifferentprocesseshavebeendevelopeduntilnowusingtrueheavyliquids.The processes are:

1. LessingProcess.
2. BertrandProcess.
3. DuPontProcess.

## LessingProcess:

Lessing process is used to clean coal in a solution of calcium chloride having an approximatespecificgravityof1.4. Itismostusefulinseparatingcoalfromclay&slate.

**Lessing'sSettlingTank:** Settlingtakesplaceinacylindricaltankof30ftheight&6- 10 ft. diameter with a conical bottom as shown schematicallyin the figure6.2. Graded raw coal freed from dust and fines is introduced into the tank through a central pipe to mix up with theseparatingsolution thoroughly. As per "float &sink"principlecleaned coal floats up and is removed from the tank bya chain scrapper oranysuch mechanical arrangement. The slate, shale and sand drop to the 'conical bottom and are removed by the help of a bucket conveyor. Both cleaned coal and slate are delivered to the draining towers.

Afterdraining,theyarewashedcleanoftheCaCl2solution.Thewashliquorisreturnedto the concentration tank for recalculation CaCl2 solution to the settling tank.

320litersofCaCI21iquoriswithdrawnfromtheseparatingtankaftereachtonofrawcoal cleaned. During cleaning of coal the specific gravity of the parting solution drops to 1.2 from 1.4 due to addition of wash water and inherent moisture in the coal. 320 liters of parting liquid withdrawn from the tank is made-up to 640 titers and concentrated to a volume to yield CaCl2 87 solution of specific gravity 1.4. Subsequently the solution is recirculated to the separating tank for further cleaning of coal.

# FLOTATION

## Introduction:

Flotation is the most widely used method of wet concentration of ores for separating the valuableconstituentoftheorefromtheworthlessgangue.Theprocessisprimarilyasurface phenomena based on the adhesion of some mineral particles to air and simultaneous adhesion of other particles to water in the pulp. It is the most efficient but is the most complex of all ore beneficiation processes. A In this process adhesion is made between air bubbles and small mineral particles in such a way that they rise in that pulp. The floating mineralized froth is then skimmed off while the other minerals are retained in the pulp. The above fact is known as flotation proper. There is another term called skin flotation.

In general flotation depends on a number of interrelated physico-chemical factors. After treatment with reagents, the air bubbles attach it to the mineral particles and lift them up to the surface of water. The mineral is usually transferred to the froth leaving behind the gangue in the pulp. This is termed as direct flotation. However, duringreverse flotation the gangueisseparatedintothefloatfractionwhilethevaluablemineralisretainedinthepulp.

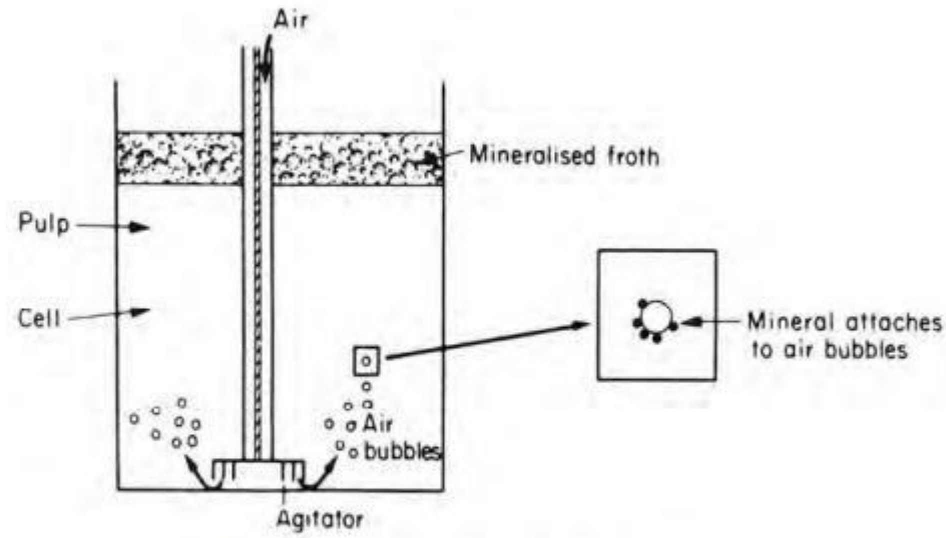



Fig.9.1. Basic Principles of Flotation.

**Physico-ChemicalPrinciplesofFlotation:**Physico-chemicalprinciplesofflotation can be explained in terms of surface energy & surface tension, contact angle, polarity and adsorption.

**FlotationReagents**:

Frothflotationbeingaphysico-chemicalprocessrequiresanumberofchemicalreagentsfor its successful operation. Broadly the flotation reagents can be classified under following categories:

1. Frothers
2. Collectors
3. Modifiers.

**Frothers:** Frothers are heteropolar surface active organic reagents, capable of being adsorbedontheair-waterinterface.Theadsorptionoffrothersatthebubble-waterinterface reduces the surface tension and stabilizes the air bubble. In the froth bubble, the non-polar group is oriented towards the water phase providing the necessary water repellency to the froth as required. A typical froth bubble is shown schematically in the below figure .

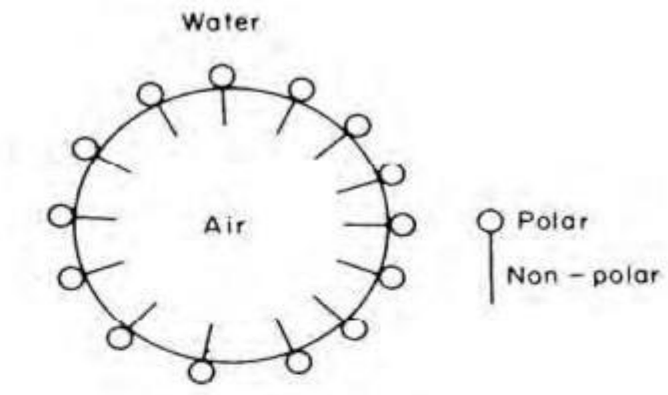



Fig.9.4. Schematic Froth Bubble.

The frothers practically have no effect on the floatability of the mineral particle in the pulp. Production of persistent froth of desired selectivity and durability is of prime importance in successfulflotation.Thefrothshouldbestrongandstableenoughtosupporttheweightofthe desired mineral attached to it and permits it's separation from pulp. On the other hand, the froth should break down readily after its removal from the flotation cell. Most widely used frothersarepineoil,isobutylcarbinol(MIBC),turpineol,aliphaticalcohols&cresol(cresylic acid).

## Collectors:

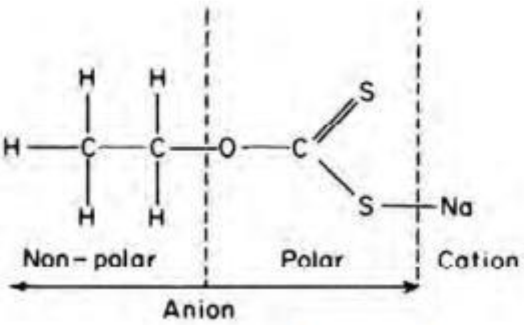
The collector is said to be the most important reagent in flotation. Each collector molecule containsapolarandanon-polargroup.Itgetsadsorbedonthemineralsurfaceandformsa continuous heteropolar film all around the particle.

The heteropolar film is so formed that the polar part is attached to the mineral surface and thenon-polargroupisprojectedoutwardlyprovidinghydrophobicitytothemineralsurface. This results in attachment of mineral particles to the air bubbles available in the pulp and ultimately results in flotation. Collectors are broadly classified according to the chemical nature of the nonpolar part available in them as follows:

1. Anionic collectors

2. Cationic collectors.

**Anionic Collectors:** These are the most widely used collectors in froth flotation. If the nonpolarpartofthecollector,whichimpartswaterrepellencytothemineralsurface,carries a negative charge on it, it is termed as an anionic collector. The structure of an anionic collector is shown schematically in the below figure.




9.5. Structure of an Anionic Collector: Sodium Ethyl Xanthate.

Sometypicalanioniccollectorsare:

1. Potassiumorsodiumethylxanthate(Xanthogenates),
2. Dithiophosphates(Aerofloats),
3. Thiocarbamates,
4. Fattyacids
5. Sulphonates.

Xanthates,thiocarbamates&dithiophosphatesareprimarilyusedtofloatsulphideminerals while fatty acids and sulphonates are used for nonsulphide minerals.

**Cationic Collectors:** The characteristic property of this group of collectors is that the nonpolarwaterrepellantgrouphasapositivechargeinplaceofanegativechargeasinthe case of anionic collectors. The schematic molecular structure of the cationic collector is shown in the
figure,

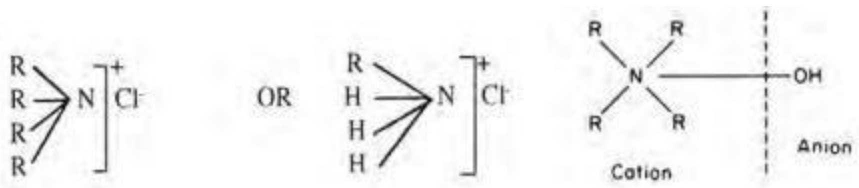



Fig.9.6. Structure of Cationic Collector.

The most general cationic collector is the fatty amine acetate. Cationic collectors are very sensitivetothepHofthepulp.Theyaremostefficientinslightlyacidicsolutionsbutinactive instronglyalkalineoracidicmedia.Theyarespecificallyusedtofloatoxides,carbonatesand silicate minerals.

4. **ModifiersorRegulators:**

Sometimes it may be necessary to use a modifier before any collector can be made to functioneffectively.Bymeansofamodifier,itispossibletoaccomplishthefollowings:

a. Utilizecollectorsunderoptimumconditions
b. Preventorcontrolmutualmineralinteraction.
c. Preventorcontrolactionofatmosphericairoraquaticingredientsatthemineral surfaces.
d. Modifyfavourablyoradverselytheabilityof some minerals toacquirefloatability.

Duetotheactionsofthediversechemicalreagentstremendousflexibilityisachievedwith regards to the floatability of the minerals. This is one of the two major reasons behind the success of froth flotation and the other being the applicability of flotation to particles of much finer size on which no other processes can be applied so successfully. Fig.9.6. StructureofCationic Collector.

Accordingtotheirfunctionthemodifyingagentsmaybeclassedintooneofthefollowing categories:

i. pHregulator.
ii. ii. Activator.
iii. DepressantorDepressor.
iv. iv. Dispersant.

## i. pH Regulator:

Inthemodernfrothflotation,alkalinecircuitsareusedalmostexclusivelyforsulphideores. For anyparticular ore there is a definite range of pH (7 to 13) at which optimum results are obtained. Forthis reason proper pH control of the pulp is of great importance: The reagents commonlyusedtocontrolpH&obtainthedesired alkalinityarelime,sodaashandsulfuric acid. But use of sulphuric acid has been highly restricted in the present days.

## ii. Activator:

It is not only difficult but also impossible to float certain minerals with collectors and frothers alone. Some times xanthates are found ineffective in floating sphalerite and under such condition an activator is used to obtain the desired floatability of sphalerite. The activator ions are adsorbed at the mineral surfaces and enhance adsorption of collectors at the same surface thereafter. The outstanding example of this type of reagent is copper sulphate($CuSO_4$)whichisusedtoactivatesphalerite.Hydrogensulphide($H_2S$)orsodium sulphide may be used for galena. Copper carbonate or lead nitrate is used to improve the floatability of various non-metallic minerals with fatty acid type collectors.

## iii. DepressantorDepressor:

Insomecasestoinduceselectiveflotation,itisrequiredtopreventorsuppresstheflotation ofamineraloveranother.Toachievesuchaselectiveflotation,aclassofreagentsisadded to the pulp called depressant or depressor. Depressing agents are used only to assist separation of a mineral from another. The basic mechanism of this activity is that the depressant gets adsorbed at the mineral surfaces and subsequentlyinhibit the adsorption of collectors. Beside lime, which works both as a pH controller & depressant the other widely useddepressantissodiumcyanide.Sodiumcyanidealongwithzincsulphateisadepressant for sphalerite. Dichromate salts are used to depress the flotation of galena.

### iv. **Dispersant:**

Sometimes the gangue may have the nature of flocculating along with the minerals. The extentofflocculationmaybesuchthatitinterfereswiththeefficientflotationofthedesired minerals.Thenitbecomesimperativetouseadispersantordeflocculator.Sodiumsilicateis used as a dispersant. Starch, casein and glue are used to disperse both gangue and carbonaceous materials associated with metallic minerals.

# MAGNETIC ANDELECTROSTATICSEPARATOR

## MagneticSeparation:-

1. Itistheseparationofvaluablemineralfromofthe gangue.

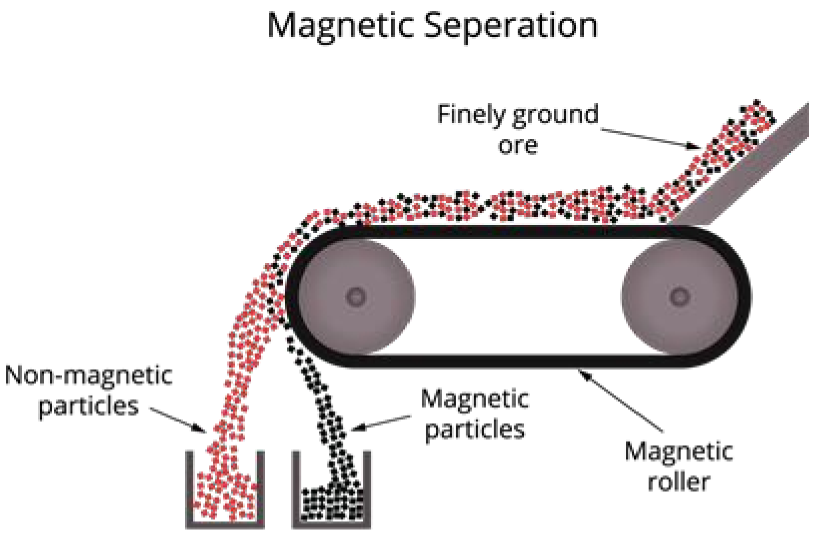
2. Itistheseparationofonemineralfromanotheressentiallybasedonthedifferenceinthe value of magnetic attractability of the minerals.

3. Theoreismagneticbutthegangueisnonmagnetic.

4. Theoreispassed overtheconveyorbeltthatruns over2roller,oneofwhichis magnetic.

5. Thenonmagneticparticlesdropdown firstdueto the gravity.

6. Themagneticparticles willstayonthebeltfora littlelongertimeanddropdownlittle later.




Magneticseparationistheprocessofseparatingcomponents ofmixturesbyusingamagnet to attract magnetic substances. The process that is used for magnetic separation separates non-magnetic substances from those which are magnetic. This technique is useful for the selectfewmineralswhichareferromagnetic(iron-,nickel-,andcobalt-containingminerals) and paramagnetic. Most metals, including gold, silver and aluminum, are nonmagnetic.

A large diversity of mechanical means are used to separate magnetic materials. During magneticseparation,magnetsaresituatedinsidetwoseparatordrumswhichbearliquids.Due to the magnets, magnetic particles are being drifted by the movement of the drums. This can create a magnetic concentrate (e.g. an ore concentrate).

## ElementsinDesigningMagneticSeparators:

Thefollowingfactsareessentialandtobeconsideredduringthedesigningofamagnetic separator:

1. Productionofasuitablyconvergingmagneticfield.

2. Easyregulationofmagneticfieldintensity.
3. Evenfeedingoforeparticleas astreamorribbon.
4. Controllingthepassagespeedoforeparticlesthroughthemagnetic feed.
5. Avoidanceofnonmagneticmaterialswithinmagneticfieldas occlusion.
6. Suitablemeanstodisposetheproducts.
7. Provisionforproductionofamiddlings.
8. Eliminationorreduction ofmovingpartsto aminimum.

## ApplicationsofMagneticSeparation:

1. Forremovaloftrampironincoarseandintermediatecrushingcircuitsasaprotection to the crushing machineries.
2. Toconcentratemagnetiteore.
3. Toconcentrateoresotherthanmagnetiteafterconvertingironorestomagnetiteby magnetic roasting.
4. Toremovesmallquantitiesofironorironmineralsfromtheceramicraw materials

## ELECTROSTATICSEPARATOR

Anelectrostaticseparatorisadeviceforseparatingparticlesbymassinalowenergycharged beam. An example is the electrostatic precipitator used in coal-fired power plants to treat exhaust gas, removing small particles that cause air pollution.

Electrostaticseparationisamethodofconcentratingorseparatingmineralsfromeachother on the basis of their differences in electrical conductivities. The basic principle of electrostatic separation is the coulomb's law which implies like charges repel and unlike chargesattract. Itwasfirstusedtoseparatezincorefromleadsulphideore.However,itwas abandoned after introduction of froth flotation. But recentlyit has got a new lease of life for separating nonmetallics. Electrical concentration can be broadly classified into:

- Electrostatic separation.
- 2.Hightensionseparation.

## Theory:

It works on the principle of mutual attraction of unlike charges and mutual repulsion of like charges (Coulomb'slaw).Onthebasisofelectrostaticcharge,abodyissaidtobepositively charged if it is deficient in electrons and is said to be negatively charged if it has excess of electrons. From the electrostatic point, materials can be classified as:

**a. Conductor:**Whenelectronsarehighlymobile inthem(Metals).

**b. Insulators:**Nomobilityofelectronsinthem(plastics, rubber).

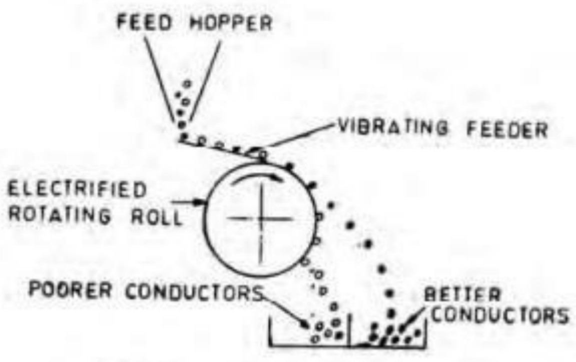
**c. Semi-conductor:** Highermobilityofelectronsinthemascomparedtoinsulatorsbutmuch less conductivity compared to conductors.

Electron mobility increases in all materials when they are placed inside an electrical field. Almostallthemetallicoresandmineralsgainelectronmobilityanddevelopexcesselectrical charges when they are placed or brought near a strong electrical field. This is due to electrostatic induction. However, the extent of induction will vary over a large range depending on the material. Depending on the extent of induction ore particles can be classified as:

a. Better conductors.

b. Poorconductors.

**ElectrostaticSeparatorSetup:**Inelectrostaticseparationthefeedmaterialisbrought near a revolving roll which is either permanently electrified or electrified by means of induction. When the feed material touches the roll or comes near the electrified roll it develops an electrostatic charge on its surface by induction, conduction or by friction from charged drum surface. According to the principle of mutual repulsion of similar electrical charges, better conducting materials are repelled away from the roll surface and fall with a trajectory determined by the size & shape of the particle and the speed of the rotating electrified drum. The poor conducting particles move along the roll surface and have a free fall under the force of gravity. The working of an electrostatic separator is shown schematically in the figure.




Electrostatic separator.

## RequirementsfortheProperWorkingofanElectrostaticSeparator:

1. Forelectrostaticseparation,feedmaterialsmustbedriedpriortoseparation.

2. Foreffectiveseparationdryminerals grainsaretobefedas alayerofoneparticledeepat the top of the rotating electrified roll. This is achieved by using a vibrating feeder.

3. Foreffectivehightensionseparation,feedmustbecloselysizedintherangeof1.0 -0.1 mm free from fines. Quite often the feed material the feed material is to be heated above room temperature for effective separation.

## Use

1. Itisemployedtoseparateconductingoresandmineralsfromnon-conductingmaterialsin ceramic industries.

2. Thisisappliedforbeneficiatingrutilebeachsandsfromnon-conductingsilicasandinrare earth plants. *

# UNIT–IV: ADVANCED TOPICS IN MINERAL DRESSING

## ADVANCED COMMINUTION TECHNIQUES

Comminution means reducing the size of ore particles by crushing and grinding. Its main purpose is to **liberate valuable minerals from gangue** so that subsequent separation becomes easier. Conventional grinding can consume a large amount of energy; therefore, advanced techniques aim to improve energy efficiency, liberation and throughput.

### High-Pressure Grinding Rolls (HPGR)

**Principle:** HPGR consists of two counter-rotating rolls. Ore is fed into the gap between them and subjected to very high compressive pressure. Particles break mainly by inter-particle compression rather than by impact from a grinding medium.

**Working:**

- Ore enters the feed zone between the rolls.
- One roll is driven while the other is mounted so it can move slightly against hydraulic/pneumatic force.
- High pressure creates cracks and fractures through the particles.
- The product leaves as a compacted cake containing fine particles and fractured coarse particles.
- The cake can be de-agglomerated and classified; the appropriate fraction may proceed to further grinding orconcentration.

**Advantages:**

- Lower specific energy consumption than many conventional grinding circuits.
- High throughput and good reduction ratio.
- Creates micro-cracks, which can make later grinding easier.
- Can improve mineral liberation at a given product size.
- Dry operation is possible, reducing water use in suitable applications.

**Limitations:**

- High capital cost and need for careful roll-gap/pressure control.
- Wear of roll surfaces is important when processing abrasive ores.
- Product may require de-agglomeration and classification.

**Applications:** iron ore, copper ore, gold ores, cement raw materials and other competent ores.

### Ultra-Fine Grinding (UFG)

Ultra-fine grinding reduces particles to very small sizes, commonly into the micron and sub-micron range depending on the technology and application. It is used when valuable minerals remain locked in very fine

intergrowths after conventional grinding.
**Principle:** Fine grinding media and high-energy agitation generate repeated impact, attrition and shear forces. Stirred media mills are commonly used for producing very fine products.

**Benefits:**

- Improves liberation of finely disseminated minerals.
- Increases surface area, which can improve leaching and some flotation responses.
- Can improve recovery of valuable minerals that cannot be liberated by coarse grinding.

**Problems:** energy requirement rises rapidly as the target size becomes finer; overgrinding can also produce excessive slimes that may reduce separation efficiency.

**Microwave-Assisted Comminution**

**Principle:** Microwave energy heats minerals internally according to their electromagnetic response. Different minerals absorb microwave energy differently. Differential heating creates thermal stresses at mineral boundaries and may weaken the ore.

**Process:**

- Ore is exposed to controlled microwave radiation.
- Susceptible mineral phases heat faster than less-absorbing phases.
- Thermal expansion and contraction create internal stresses and cracks.
- The weakened ore requires less mechanical effort for subsequent crushing/grinding.

**Advantages:** potential reduction in grinding energy, improved liberation and selective weakening of some ores.
**Limitations:** equipment cost, energy-transfer efficiency, penetration-depth limitations and dependence on mineral composition and moisture.

## ADVANCED GRAVITY SEPARATION: MULTI-GRAVITYSEPARATOR (MGS)

Gravity separation separates particles mainly according to differences in density, with particle size and shape also affecting performance. The **Multi-Gravity Separator (MGS)** is designed to improve gravity separation of fine and very fine particles.

**Principle:** MGS combines gravitational force with enhanced centrifugal effects and a shaking motion. A thin film of slurry flows over a slightly inclined rotating drum/conical surface. Heavy particles move differently from light particles and are collected separately.

**Working:**

- A feed slurry is introduced onto the rotating, inclined surface.
- The drum rotates and generates an enhanced effective gravitational/centrifugal field.
- Shaking motion assists stratification and separation.
- Heavy particles tend to remain closer to the surface and move toward the concentrate collection zone.
- Lighter particles are carried away by the flowing water toward the tailings zone.

**Advantages:**

- Effective for fine heavy minerals.
- Can achieve better fine-particle separation than simple gravity devices.
- Relatively low reagent requirement.
- Useful for upgrading mineral concentrates and recovering fine valuable minerals.

**Applications:** chromite, tin, tungsten, gold, mineral sands and other high-density valuable minerals.

**Limitations:** performance is affected by particle size distribution, slurry density, feed rate and the density difference between valuable mineral and gangue.

## ADVANCED FLOTATION TECHNIQUES

Froth flotation separates minerals based mainly on differences in surface properties. Reagents make selected mineral surfaces hydrophobic, allowing them to attach to air bubbles and rise into a froth.

### Microbubble Flotation

Microbubbles are very small air bubbles compared with conventional flotation bubbles. Their small size provides a large total surface area and can improve contact with fine particles.

**Working:**

- Air is dispersed into the pulp to form microbubbles.
- Hydrophobic mineral particles collide with and attach to bubbles.
- Particle-bubble aggregates rise to the froth.
- The froth is collected as concentrate while hydrophilic gangue remains mainly in the pulp.

**Advantages:** improved recovery of fine particles, high bubble surface area and potentially better selectivity under suitable conditions.

### Nanobubble Flotation

Nanobubbles are extremely small gas bubbles, generally in the nanometre scale. They have distinctive interfacial behavior and can influence particle-bubble attachment and flotation kinetics.

**Important effects:**

- Very high surface-area-to-volume ratio.
- Can persist in suspension longer than larger bubbles under suitable conditions.
- May promote attachment or provide nucleation sites for flotation.• Can be useful in recovering very fine or difficult-to-float particles.

**Microbubble vs Nanobubble:**

| Feature | Microbubble | Nanobubble |
|---|---|---|
| Relative size | Micrometre range | Nanometre range |
| Main benefit | Fine-particle flotation | Interfacial effects and ultra-fine particle recovery |
| Typical challenge | Generation/control of bubble size | Measurement, stability and scale-up |

## HIGH-INTENSITY MAGNETIC SEPARATION (HIMS)

Magnetic separation uses differences in magnetic susceptibility between minerals. Conventional low-intensity separators are mainly suitable for strongly magnetic minerals. **High-Intensity Magnetic Separation** produces a much stronger magnetic field and is therefore useful for weakly magnetic minerals.

**Principle:** When a mixture passes through a high-intensity magnetic field, magnetic or weakly magnetic particles experience a magnetic force and are attracted toward the magnetic region. Non-magnetic particles follow a different path and are collected separately.

**Working:**

- Feed is introduced into the magnetic separation zone.
- A high-intensity magnetic field is generated using suitable magnetic equipment.
- Magnetic/weakly magnetic particles are attracted and retained or deflected.
- Non-magnetic particles continue along their normal trajectory.
- Separate concentrate and tailings streams are collected.

**Applications:** separation or removal of iron-bearing minerals, upgrading silica sands, feldspar/quartz separation and beneficiation of weakly magnetic ores.

**Advantages:** useful for weakly magnetic minerals, can improve concentrate grade and can remove unwanted iron-bearing impurities.

**Limitations:** high equipment/energy requirements for some systems; separation depends strongly on particle size, magnetic susceptibility and liberation.

## SUSTAINABLE & ECO-FRIENDLY MINERAL PROCESSING

Modern mineral processing aims not only at high recovery but also at reducing water consumption, energy use, reagent consumption, emissions and waste generation. Sustainable processing tries to obtain maximum value from the ore with minimum environmental impact.

### Dry Beneficiation Technique

Dry beneficiation separates valuable minerals from gangue without using water. It is particularly attractive in water-scarce regions and can reduce the need for slurry handling and dewatering.

**Possible methods:**

- Dry magnetic separation for magnetic or weakly magnetic minerals.
- Air classification based on particle size and density-related behavior.
- Electrostatic separation based on differences in electrical properties.
- Dry density-based or sensor-assisted technologies where suitable.

**Advantages:**

- Greatly reduces process-water demand.
- Avoids or reduces tailings slurry formation.
- Reduces dewatering requirements.
- Can lower water-treatment and pumping requirements.

**Limitations:** dust generation, humidity sensitivity and difficulty in treating some very fine materials.

**Zero-Waste Processing**

Zero-waste processing is an approach in which waste generation is minimized and residues are converted into useful products wherever technically and economically possible. It does not simply mean that no residue ever exists; rather, the goal is to approach maximum resource utilization and minimum final disposal.

**Main strategies:**

- Maximize recovery of the primary valuable mineral.
- Recover secondary valuable minerals from tailings.
- Reuse process water through closed-loop systems.
- Use waste rock and tailings in construction or other suitable applications after safety and quality assessment.
- Recover useful heat or energy where feasible.
- Reduce reagent consumption and select less hazardous reagents.
- Use dry or filtered tailings where appropriate to reduce water-related risks.

**Benefits:** conservation of natural resources, lower environmental footprint, reduced land requirement for waste disposal, potential additional revenue and improved compliance with environmental requirements.

**COMPARISON OF THE ADVANCED TECHNIQUES**

| Technique | Main purpose | Key principle |
|---|---|---|
| HPGR | Efficient size reduction | High-pressure inter-particle compression |
| UFG | Very fine liberation | High-energy impact/attrition/shear |
| Microwave-assisted comminution | Weaken ore before grinding | Differential heating and thermal stress |
| MGS | Fine gravity separation | Enhanced gravity/centrifugal effect + shaking |
| Microbubble flotation | Fine-particle flotation | Attachment to small air bubbles |
| Nanobubble flotation | Ultra-fine flotation assistance | Nano-scale gas-liquid interfaces |
| HIMS | Separate weakly magnetic minerals | High magnetic field |
| Dry beneficiation | Water-free/low-water separation | Air, magnetic/electrostatic or other dry methods |
| Zero-waste processing | Minimize final waste | Recovery, reuse and recycling |

***THE END ***