ARYAN SCHOOL OF ENGINEERING & TECHNOLOGY

BARAKUDA,PANCHAGAON,BHUBANESWAR,KHORDHA-752050

LECTURE NOTE

SUBJECT NAME- MINERAL DRESSING

BRANCH – MINING ENGINEERING

SEMESTER – 6TH SEM

ACADEMIC SESSION - 2022-23

PREPARED BY – SATYAJIT MOHAPATRA

-: MINERAL DRESSING :-

[Subject code-MNT-605]

[Branch-Mining engineering]

[Semester-VI (6th)]

- SYLLABUS AS PER SCTEVT 19-20 BATCH [MINING ENGIEERING]

MINERAL DRESSING

MNT-605

L/wk T/wk P/wk
4 0 0

Periods per week: 04
Total Periods
Lecture: 44

Total Marks: 100

Evaluation Scheme
Theory:

End Term Exam		**: 70**
Teacher Assignment		**: 10**
Class Test		**:20**

	Total	**100 Marks**

TOPIC WISE DISTRIBUTION OF PERIODS

Sl.No.	Topic	Periods: L
1.	Introduction	02
2.	Unit Operations	05
3.	Grinding	06
4.	Lab. Sizing	05
5.	Industrial Screening	05
6.	Gravity Concentration	06
7.	Heavy Media Separation	05
8.	Floatation	05
9.	Magnetic & Electrostatic Separators	05
		44

RATIONALE

In case of metalliferous mines, the ultimate goal is the extraction of metals. Prior to sending ores into the process of extraction, it requires dressing for removal of desirable gangue minerals as far as possible. So a Mining Engineer, specially attached to metalliferous mines should have some basic concepts about mineral dressing.

OBJECTIVES

On completion of the subject, students will be able to:

1. Comprehend physical & chemical properties of ores, know the application in mineral dressing.
2. Explain the principle of operation of Blake & Dodge jaw crushers, Gyratory Cone crushers, roll crushers.
3. Explain the principle of ball mill, open circuit & close circuit Grinding.
4. Explain the principle of lab.sizing.
5. Explain the principle of operation of industrial screening. Comprehend the principle of operation of classifiers & their application in the field.
6. Comprehend elementary idea about gravity concentration.
7. Explain the principle of operation of heavy media separation.
8. Comprehend elementary principle of floatation process.
9. Explain the principle & application of magnetic separators.

COURSE CONTENTS (Based on specific objectives)

1.0 Introduction

1.1 Describe the objective & scope of application of mineral dressing in surface & u/g mines.

2.0 Unit operations

2.1 Explain the principle of Blake & dodge jaw crushers, gyratory & cone crushers, roll crusher.

3.0 Grinding

3.1 Explain the principle of ball mill operation, open circuit grinding, close circuit grinding, dry & wet grinding.

4.0 Explain the procedure for size analysis & use of standard screen as also screening techniques employed.

5.0 Industrial screening

5.1 Explain the principle of industrial screening, type of screening (without calculation)

5.2 Explain the operation of classifier & their application.

6.0 Gravity concentration

6.1 Explain the general principles of wilfly table & its operation.

6.2 Develop elementary idea regarding the operation jigs.

7.0 Heavy media separation

7.1 Explain the fundamental principle of heavy media separation – Chance process.

6.0 Floatation

8.1 Comprehend elementary principle of froth floatation, practical utility of frother, collection, modifiers & depressants.

8.2 Describe & illustrate floatation cell.

9.0 Magnetic & Electrostatic Separators

9.1 Explain the principle of operation of magnetic & electrostatic separators.

9.2 Describe the application of separators in mineral dressing.

RECOMMENDED BOOKS

1. Principles of Mineral Dressing- Gaudin A.M.
2. Hand Book of Mineral Dressing Ores & Minerals – A.E.Taggart
3. Mineral Processing Technology – B.A.Wills

Chapter-1

1.0 INTRODUCTION :-

1.1 Describe the objective and scope of application of mineral dressing in surface and underground mines :-

SCOPE OF MINERAL DRESSING: -

To a large extent quarrying and mining operations are concentrating operations in that they are only on those portions of mineral deposits whose content of the material wanted is the highest available.

In a general way the scope of mineral dressing or ore beneficiation is twofold:

(1). It helps in eliminating *unwanted chemical species* from the bulk of the ore.

(2). It helps in eliminating *particles improper size and physical structure*. [which may adversely affect the working of smelters, roasters etc.]

1. To eliminate unwanted chemical species: -

To prepare the ore particle from chemical stand point, primarily involving the following steps:

(a). Liberation of dissimilar particles from each other appearing in the bulk ore.

(b). Separation of chemically dissimilar particles.

2. To prepare particles of unwanted size:-

This involves:

(a). *Reduction in size.*

(b). *Separation of particles of dissimilar physical nature*.

So, the first step in ore beneficiation is size reduction causing liberation. This is followed by separation of liberated particles as the second step in the process. These two steps are made to alternate to accomplish the desired end product most economically.

OBJECTIVE OF MINERAL DRESSING:-

Like other sciences, the art of ore beneficiation has started form historic time and has got modified, refined with the progress of scientific knowledge. In order to get satisfactory prospective of the status of the mineral dressing. It is described to review briefly the development of the art from its inception, fields of human endeavor, our information concerning the operation of the past is not so full as might be wished.

HISTORIAL OUTLINE [DEVELOPMENT]: -

(1). Hand Sorting:- This is a method of *choosing valuable ore lumps from worthless lumps* basing on the appearance, fracture cleavage and gross weight. This is still in use where cheap labour is available.

(2). Washing :- Washing in all probability is the next process that evolved. Water exerts a cleaning action and removes slimes. It is still in use with modification for washing and cleaning of coal and iron ores.

(3). Crushing: - It was discovered that valuable particles *generally occur in association with worthless particles in large lumps quite early*. So, to separate them it needs breaking of the large lumps. Thus, crushing is considered to the next step in the history of mineral dressing. It was carried out by using sledge hammers or brute force of the human operators.

(4). Tabling and Gravity Concentration:- The ideas of washing stretched further with the *particular use of specific gravity of the ore particles for concentrating them in terms of their specific gravity*.

(5). Jigging: - It was developed *by the Herz mountains of the Germany. Along with jigs, Vanners and shaking tables were also developed simultaneously.*

(6). Grinding: - Modern grinding machines were *developed much late along with stationary screens to produce fine ores required* for gravity concentration and froth flotation.

(7). Classification: - *Of late to separate fine size particles* classifiers came into picture.

(8). Development in Recent Years:- In recent *year magnetic separators, electrostatic separators, flotation and agglomeration techniques* have been developed to upgrade the ores.

[SOME USEFULL NOTES]

GENERAL OPERATIONS INVOLVED IN ORE DRESSING:

There are four measure steps involved in ore dressing-

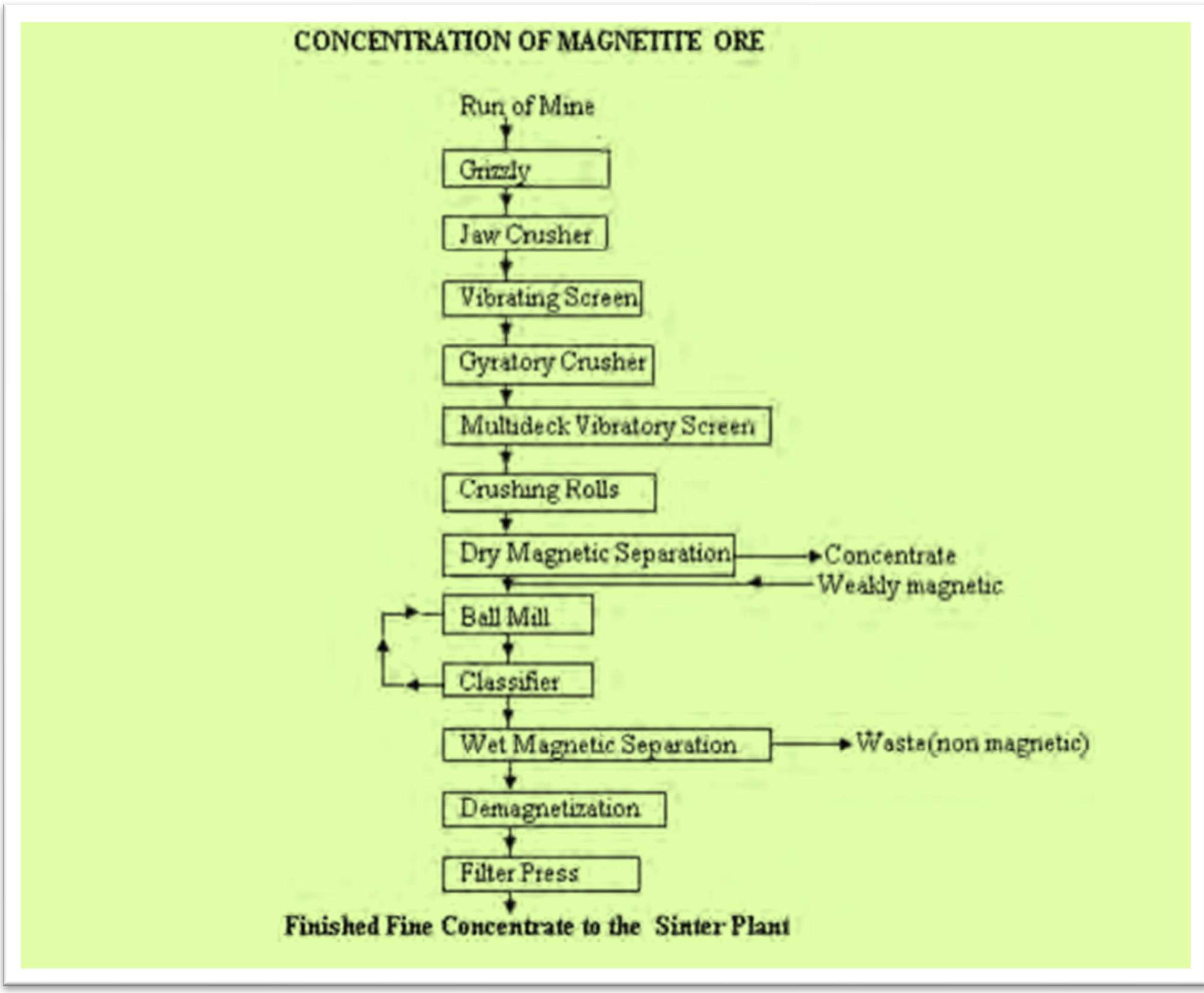
(1) Comminution.
(2) Sizing.
(3) Concentration.
(4) Dewatering.

(1) Comminution: - Comminution or size reduction can be accomplished dry or wet.
(2) Sizing: - This is the *separation of product material into various fractions depending* on their size parameter.
(3) Concentrating: -Concentration of valuable portion of the ore is obtained by the various means *which generally involve physical characteristics of the ore particles. Sizing, jigging, tabling, classification, magnetic & electrostatic separation are few* such examples. We may exploit an entirely different set of physio-chemical properties for concentrating the ore as it happens during froth flotation.
(4) De -Watering: - Where *aqueous medium is involved, water is to be* removed before smelting can take place.

This involves:

a) Removal of most of the water by the use of the thickener.
b) Then use of filter presses to prepare a damp cake of the concentrated ore.
c) Then drying the cake in a furnace.

*Usefull diagram..!



Chapter-2

2.0 Unit Operations: -

2.1 Explain the principle of Blake & dodge jaw crushers, gyratory & cone crushers, roll crusher:

- CRUSHERS: -

  Crushers are slow speed machine coarse size reduction of large quantities of solids. The main of crushers are Jaw, gyratory, Roll and toothed roll crusher.
  The first three operate or compressive force and crush very hard and brittle rock under primary and secondary crushing operations. The toothed sell crushers tear the feed part as well as crushes it. It works best on softer material like coal and slate.

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 coming from the secondary crushers.
4. Fine Grinding:
   The objective of fine grinding is to produce ultrafine material less than one micron.

Classification of the Size Reduction Equipment's: -
(In the Order of Finer Size Product)

(A)Primary Crushers:

1. Jaw crusher.
2. Gyratory crusher.

(B). Intermediate crushers:

1. Crushing rolls.
2. Cone crusher.
3. Disc crusher.

(C). Fine crushers or Coarse Grinders:

1. Ball Mill.

(D). Fine Grinders:

1. Rod mill.
2. Pebble mill.
3. Tube mill.
4. Hammer mill with internal classifier.

Primary crushers are of two types: -

1. Jaw crusher.
2. Gyratory crusher.

Classification of ***Jaw Crushers: -***

From capacity and working mechanism point of view jaw crushers are three types such as:

1. Blake jaw crusher.
2. Dodge jaw crusher.
3. Universal crusher.

➢ **Principle of Blake Jaw Crushers: -**

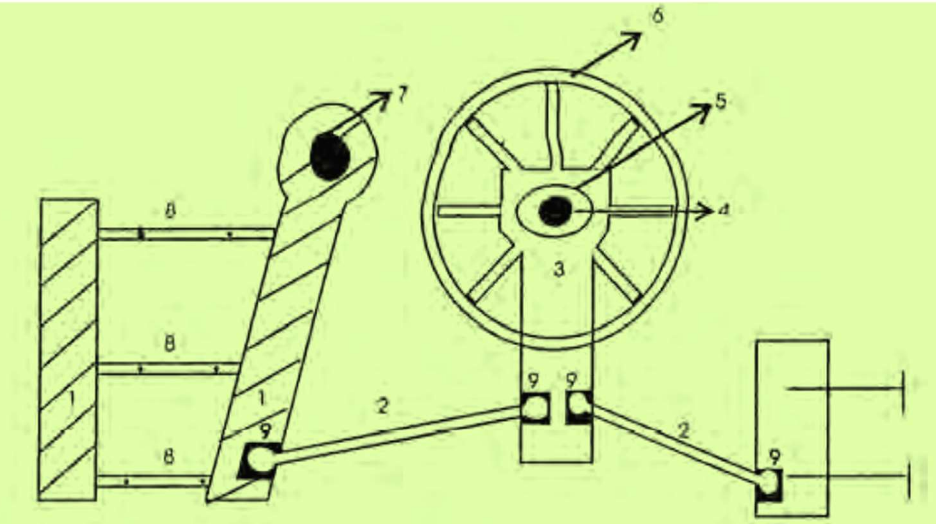
It is a primary crusher used most widely. It has its moving jaw pivoted (hinged) at the top as in the figure2.1a. Though the working principles of Blake and Dodge crushers may be different from constructional point of view they are almost identical excepting two notable differences which will be discussed afterward. ***The Blake crusher may be classified as single toggle or double toggle type.***

Working principle of Blake jaw crusher :-

The working principle of jaw crushers is based on the reciprocating **movement** of the movable jaw that compresses and crushes the rock or ore between itself and the fixed jaw, as the material enters the zone between the jaws.

Constructional Features: -

As the name suggests a jaw crusher has two jaws set to form a V-shape at the top through which feed is admitted into the jaw space. One of the jaws is fixed to the main frame of the crusher almost vertically while the other one is movable. The swinging jaw, *driven by an eccentric, reciprocates in a horizontal plane and makes an angle of 20- 30 degrees with the stationary jaw.* It applies a huge compressive force on the ore lumps caught between the jaws. The schematic figure of the Blake crusher is shown in the figure2.2.



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]

On the jaws, replaceable crushing faces are fixed by nut & bolt arrangement. The crushing faces are made of *Hadfield manganese steels*. When extensive wear is observed on any of the faces it is replaced with a new one. The crushing faces are rarely flat. They are usually wavy surfaces or may carry shallow grooves on them. The jaw running speed vary from 100-400 rpm.

Characteristics of Blake jaw crusher:-

1. Reduction Ratio:-

Blake crushers are the primary crushers. As the moving jaw is pivoted at the top it makes minimum and maximum swing at the top and bottom respectively. The maximum distance travelled by the moving jaw is defined as *throw* of the crusher. Blake jaw crushers have fixed *gape*. The width or length of the feed receiving opening is somewhat greater than the gape. The *set* determines the product particle size. Depending upon the *gape & set* the size reduction ratio (*R.R.*) generally available varies from 4-7. For a crusher the *R.R.* is defined as the ratio between average feed size to average product size. Mathematically: -

$$\text{Reduction Ratio } (R.R) = \frac{\textbf{Average Feed Size}}{\textbf{Average Product Size}}$$

This is a very important parameter for determining the energy consumption in the crusher. Keeping all other variables fixed, higher the

reduction ration (*R.R.*) higher is the energy consumed by the crusher.

2. Capacity: -

The capacity of the jaw crusher mainly depends on the length and width of receiving opening and the width of discharge. As per Taggart, the empirical formula for capacity of jaw crusher is:

***T = 0.6LS* where,**

***T* is the capacity expressed in tons per hour.**

***L* is the *length or width* of the receiving opening in inches.**

***S* is the *set* or width of discharge opening in inches.**

The above empirical relation is quite accurate except for smallest and largest jaw crushers.

The capacity of a jaw crusher may be as high as 725tons per hour for 2250x1680mm jaw size.

3. Energy Consumption and Efficiency: -

Energy consumption in a jaw crusher varies considerably. Largely it depends on following factors:

***a.* Size of feed**

***b.* Size of Product**

***c.* Capacity of the machine**

***d.* Properties of rock such as hardness, specific gravity, etc.**

The jaw crushers are quite inefficient machines. The efficiency can be modified a little by analysing the modes of energy utilization in a crusher. Proper lubrication and reduction in frictional losses can only increase the efficiency of the crusher. Further the physical properties of the ore which affect the efficiency of crushing is:

1. Specific gravity of the ore.

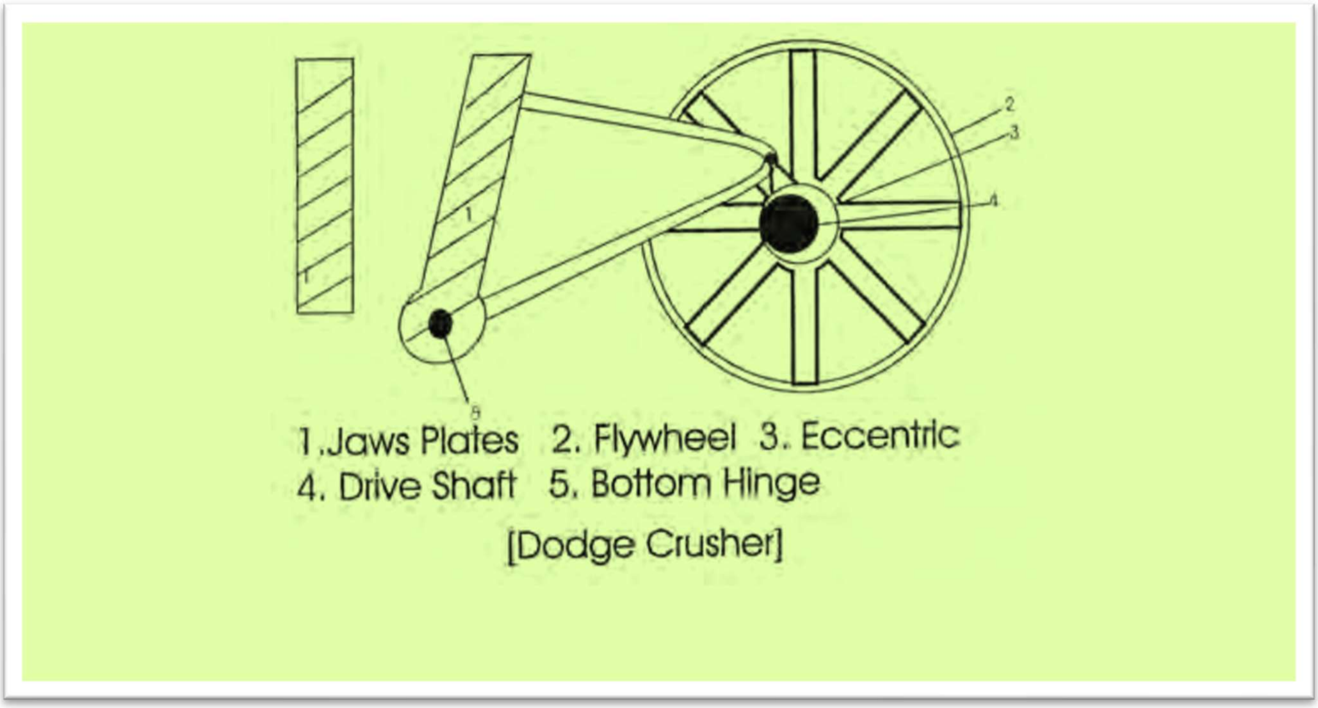
2. Hardness of the ore.

3. Moisture content in the ore.

4. Structural weakness planes of the ore.

DODGE CRHUSHER: -

In Dodge crusher the moving jaw is pivoted at the bottom in place of the top as in case of Blake crusher. Hence the maximum swing of the moving jaw is obtained at the top. The *gape* is a variable while width of discharge opening (*set*) is fixed. Due to the fixed *set*, the product is more uniformly sized as compared to the product from the Blake. The crusher has got fewer mechanical parts as compared to Blake crusher. The moving jaw is activated by a lever It is activated by a lever-eccentric arrangement mounted onto the main shaft as compared to the toggle-pitman combination in case of Blake crusher. Dodge crusher is shown schematically.



The inherent problem with this crusher is its tendency to choke frequently and that is why it is used less widely. This crusher is usually made in smaller size than the Blake crusher because of high fluctuating stresses working on the machine members. The major advantage of this machine is its power to effect larger size reduction because of larger-opening at the top with a fixed set. The advantage of uniform product size is the most significant where a single crusher is used as the only comminution machine. In industries where elaborate screening is available Blake crusher is preferred because of its higher capacity and more balanced mechanical design. The Dodge crushers are usually used in
college and research laboratories.

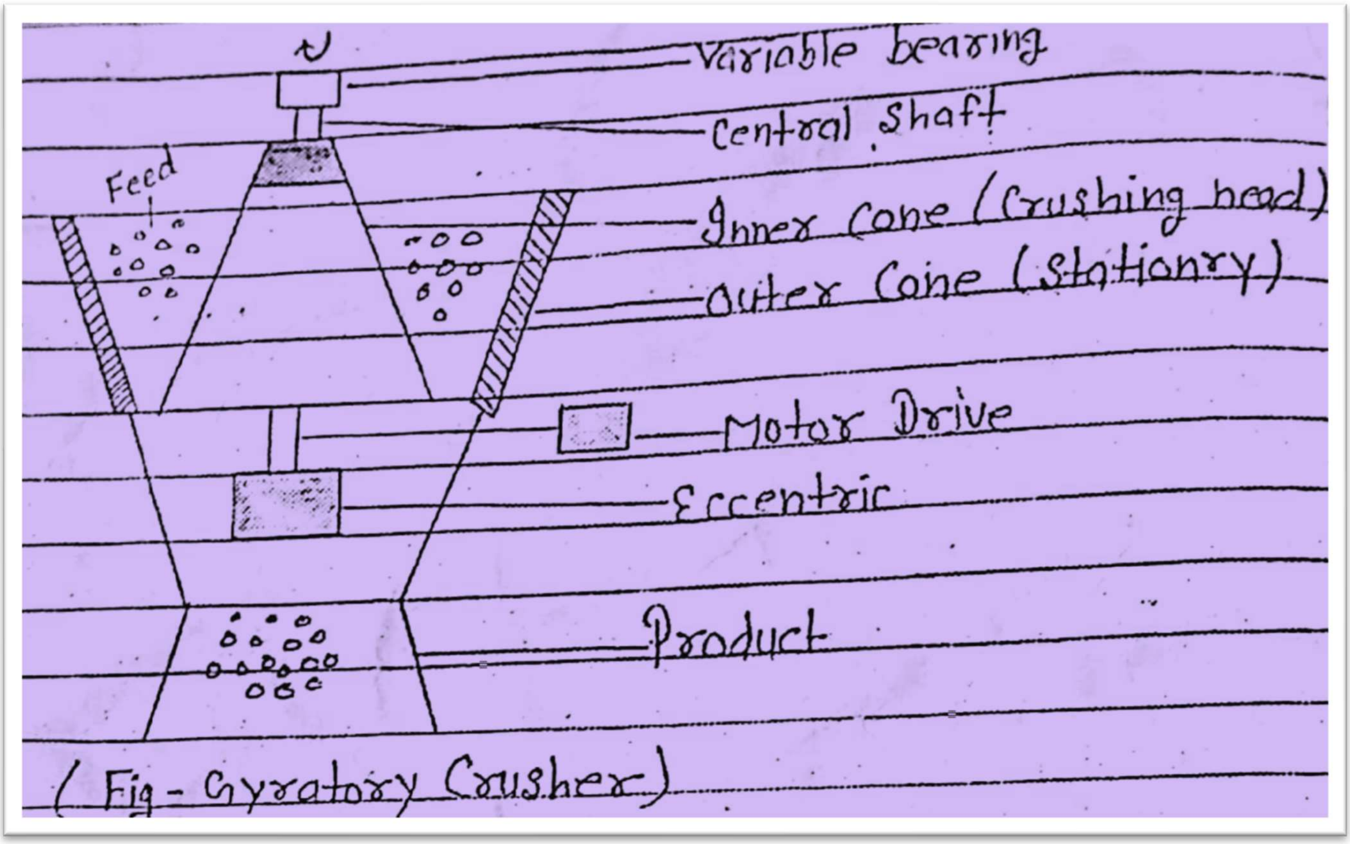
Comparison between Blake & Dodge Crusher: -

Blake Jaw Crusher	Dodge Jaw Crusher
1. It has got two toggles.	1. It has one toggle in the form of a Lever.
2. It has one pitman.	2. It has no pitman.

3. The movable jaw is pivoted at the top, so has a variable product discharge opening while feed receiving opening is fixed.	3. The movable jaw is pivoted at the bottom so the discharge opening is fixed. The set is fixed, while the feed receiving opening varies. This result in almost uniform sized product.
4. No choking takes place here as it has variable discharge. It operates on principle of forced feed.	4. Choking is a very common problem as the set is quite small compared to receiving opening.
5. This crusher is mechanically more balanced and has fewer breakdowns. Further it is built for much larger capacity.	5. Mechanically the design of this crusher is inferior. So, it is built only to lower capacity. This machine has more breakdowns as compared to the other.
6. Product size distribution is large & produces more fines.	6. Product size distribution is more uniform.
7. Blake is preferred at large industrial setups where elaborate screening facility is available along with other comminution machines. out.	7. A dodge is preferred where jaw crusher is to be used as the only comminution equipment.
8. This machine is of higher cost for same output.	8. This machine is cheaper for same output.
9. Because of forced feed lubrication it yields a coarser product.	9. As choke feeding is possible, it can yield a much finer product.

GYRATORY CRUHER: -

Gyratory crushers have been developed recently in order to supply a machine with a larger capacity than jaw crushers.



Mechanical element of gyratory crusher :-

It consists of two substantially vertical truncated conical shells. The outer shell has its apex pointing down while the inner cone has its apex pointing up.The outer conical shell is fixed rigidly to the main frame while the inner cone or the crushing cone is mounted on a heavy central shaft also known as spindle. The upper end-of the shaft is held in a flexible bearing while the lower end is driven by an eccentric so as to describe a circle. Because of this eccentric rotation, the inner cone thus rotates inside the outer cone alternately approaching and receding from all the points on the inner periphery of the outer shell.

The best-known gyratory crushers are: -

1. *Suspended spindle gyratory* crusher.
2. *Parallel Pinch* or Telsmith gyratory crushers.

1. Suspended spindle gyratory crusher: -

The Crusher Consists of an outer frame Carrying a Wearing Surface Known as Concaves and an inner Crushing head mounted on a Spindle. This spindle is made to gyrate from a fixed fulcrum at the point of Suspension by an eccentric Sleeve. driven from a horizontal drive shaft.

2. Parallel Pinch gyratory crusher: -

The essential difference between this and the Suspended-Spindle-type Crusher is that the motion of the Crushing head, instead of generating and acute Come with its apex at the point of Suspension generates a Cylinder So that the extent of the pinch exerted on the rock to be Crushed is the Small at all Point along the face of the Crusher head.

Characteristics of Gyratory Crusher: -

1. At any cross section there are in effect two sets of jaws opening and closing alternatively like a conventional jaw crusher. Hence gyratory crusher can be regarded as a series combination of infinitely large number of jaw crushers of infinitely small width. Hence the capacity of the gyratory crusher is much greater than that of a jaw crusher having equivalent gape size.
2. It has more regular power draft due to continuous crushing action.
3. With respect to the reduction ratio, at fixed power consumption and equivalent capacity, both jaw and gyratory crusher are at par.
4. The rule of installing a gyratory crushers or jaw crusher is given by Taggart as follows:

If the hourly tonnage to be crushed divided by square of gape expressed in inches yields a quotient less than 0.115 than use a jaw crusher or else use a gyratory crusher.

Mathematically: -

Mathematically:

If, $\frac{T}{Gape^2} > 0.115, select\ Gyratory\ crusher.$

And, $\frac{T}{Gape^2} < 0.115, select\ Jaw\ crusher$,

Where, T is expressed in tons per hour and $gape$ is expressed in inches. A

A comparison between Jaw crusher and Gyratory crusher :-

Jaw crusher	**Gyratory crusher**
1. The loading on machine components is intermittent and the power draft irregular.	1. Uniform loading on the machine components with regular power draft
2. Crushing action is intermittent.	2. Crushing action is almost continuous.
3. For a particular gape size, the capacity is less compared to gyratory crusher.	3. For the same gape size the capacity is much larger.
4. Its feed acceptance size is much larger compared to gyratory crusher.	4. Its feed acceptance size is much less compared to jaw crusher for some capacity.
5. Product particle size distribution varies widely &it has a reduction ratio less than that of the gyratory crusher.	5. More uniform sized product is obtained with a larger r.r.
6. Power consumption is higher for jaw crusher for a particular r.r. & capacity.	6. With the same r.r. & capacity, the gyratory crusher requires less power.
7. The crusher is less efficient compared to gyratory crusher It has an efficiency of 10 -20%.	7. It has an efficiency of 30 - 50%.
8. The wear on the jaw plates is not uniform which causes heavy wear on the plates at certain areas. The jaw plates are replaced frequently.	8. The wear on the crushing cone is quite uniform. If the bottom opening changes, the inner cone can be lifted up by the variable bearing to reduce the gap So the heads can serve for a longer time
9. Not much variation can be obtained with regards to product particle size.	9. Wide variation in product size can be obtained by varying the setting of the central shaft. The set can be varied as per requirement.
10. It has a low cost of installation.	10. It has a high cost of installation.
11. It is better for lower production rates.	11. It is better for higher production rates.

CONE CRUSHER :-

This type crusher is a newer development. They have gained wide popularity because of their economical operation in the intermediate range.

⇒ The principle of operation of the Cone Crusher is much like that of the gyratory Crusher, but with two exceptions. In the first place, the outside Crushering Surface, instead of flaring in from top to bottom as it does in a gyratory Crusher, flares out so as to provide an increased area of discharge for the crushed material Secondly, the outer Crushing Surface, Which becomes in the Cone Crusher an upper Crushing Surface, Can be lifted away from the lower Surface When an uncrushable obstruction enters the Machine. The Cone Crusher is a machine of very great Capacity if Compared with rolls or ever. With gyratory Crushers Set to deliver a product of Comparable fineness. ... provided With

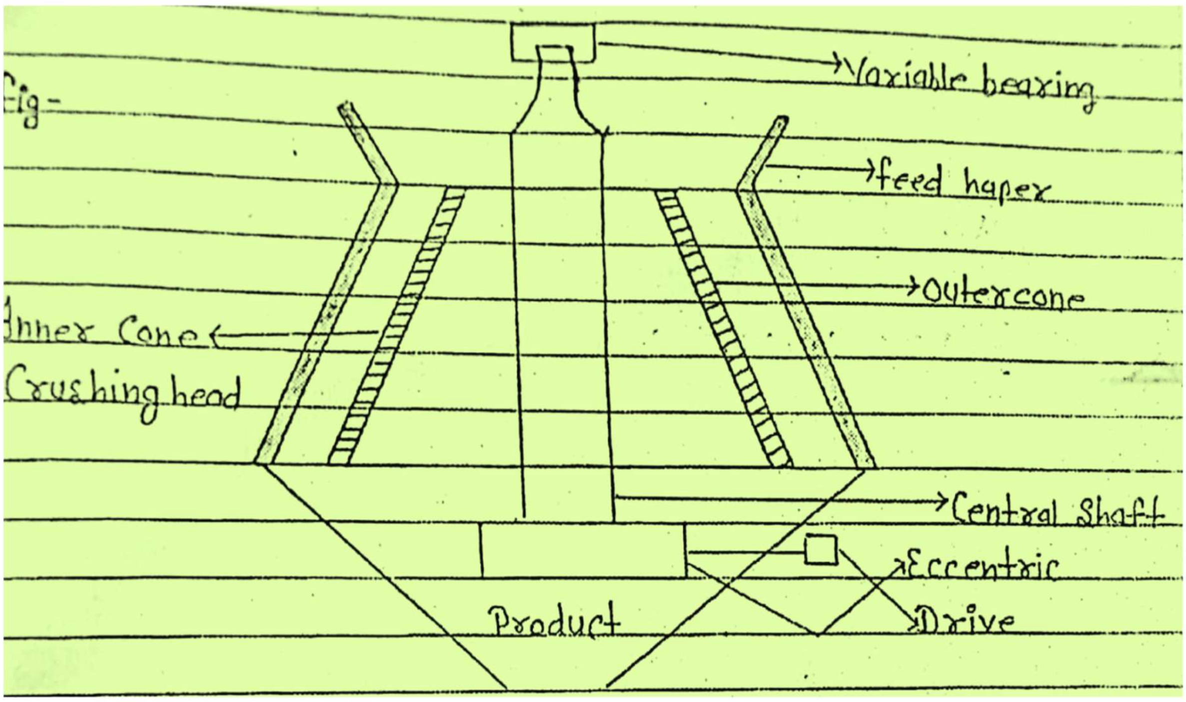


FIGURE OF CONE CRUHER

CONSTRUCTION OF CONE CRUSHER:-

The construction of this cone crusher is much similar to gyratory crusher (Figure) though the feed size is much smaller and the product is much finer. Here both the rotating inner cone & stationary outer cone apex point upwards. The outer stationary cone is fixed on to the main frame while the inner crushing head is mounted on a heavy central shaft rotating eccentrically. The material used as crushing heads is had field manganese cast steel containing at least12%Mn. The sectional view of a cone crusher is shown in the figure.

LIMITATIONS: -

1. It operates only on closely sized brittle material.
2. It has a low reduction ratio.
3. It needs extensive lubrication of all its moving part regularly.
4. It operates best in closed circuit grinding.

ROLL CRUSHERS:-

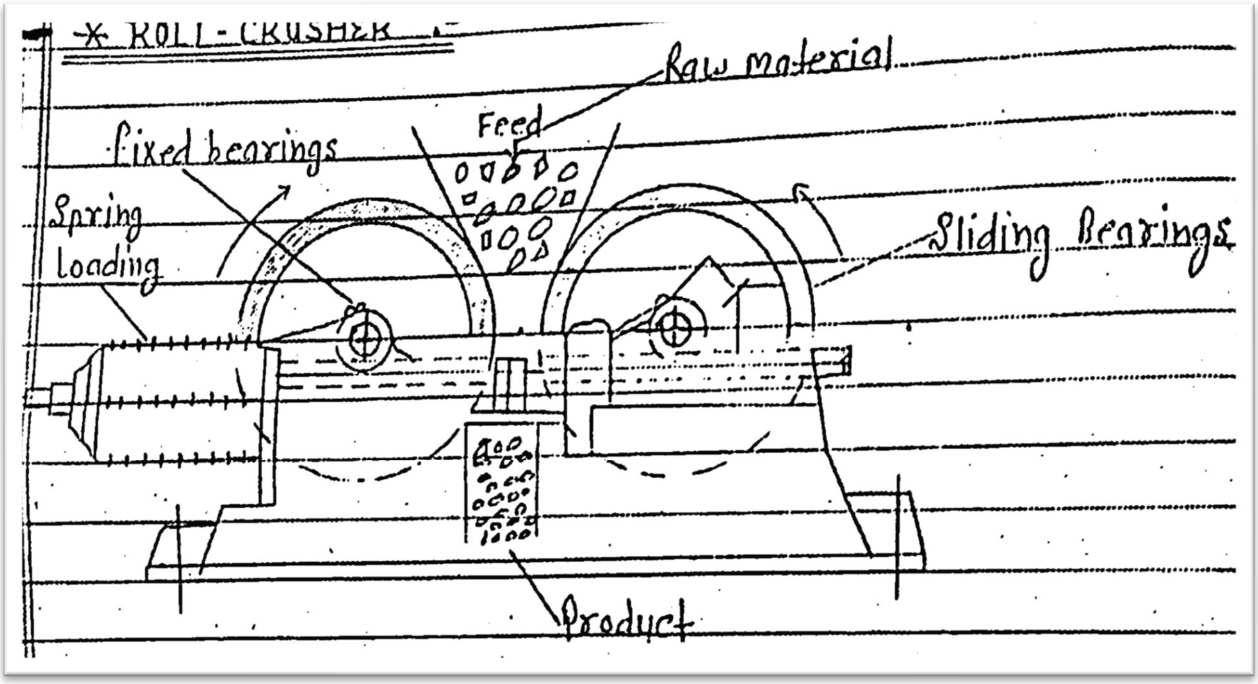


DIAGRAM OF ROLL CRUSHER

- This is an important class of intermediate comminution machine in the intermediate range of size reduction. Crushing rolls consists of pair of heavy cylindrical rolls revolving towards each other so as to nip a falling ribbon of rock and discharge it crushed below rolls. They were invented around 1850A.D.
- **Mechanical Design:-**
  - ✓ The two rolls are heavy and rigid ones. The material is cast steel and wear resisting. Both the rolls are positively driven towards each other by motors.
  - ✓ The heavy rolls turn on parallel horizontal plane having the roll centres at the same height separated by a distance, S. The feed caught between the rolls. are broken by compressive force and drop down below.
  - ✓ The rolls turn towards each other at the same speed. They have narrow faces but have large diameter so that they call nip moderately large lumps.
  - ✓ Figure. shows the crushing rolls schematically.

❖ Typical rolls are 600 mm long with 300 mm diameter.
❖ Roll speed ranges from 50 - 300 rpm.
❖ The feed size varies from 12-75mm & the product size varies from 12 to 20 mm.

- The product size mainly depends on the roll separation distance d.

Characteristics of the Crushing Rolls:-

1. It has a reduction ratio (r.r) is around 3 - 4 only which is very low compared to other size reduction equipment's.
2. It yields a uniform sized product.
3. The product of the crushing rolls contains fewer fines as the mystification time is limited and no repeated crushing takes place.

USES OF CRUSHING ROLL :-

- ✓ 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 coal because of lower residence time of the feed as lower residence time reduces the effect of heat on the feed material.

CHAPTER-3

Grinding :-

3.1 Explain the principle of ball mill operation, open circuit grinding, close circuit grinding, dry & wet grinding.

- **PRINCIPLE OF BALL MILL OPERATION: -**

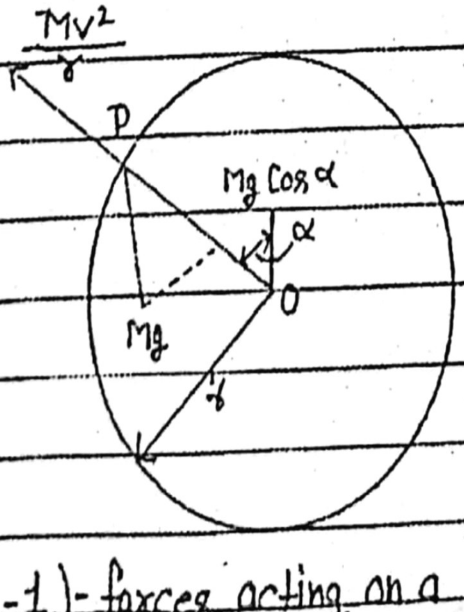
* Ball mills :-

Ball-mills are characterized by the use of steel or iron balls as the grinding medium. The balls mills used in practice are continuous machines, crushed rock being taken in at one end through a feeder and ground rock being discharged at the other end or through the periphery.

* Principle of ball mill operation :-

The path of balls is Compounded of a Circular Section and of a parabolic or near-parabolic Section as the balls are dropped. A ball at a distance r from the Center of the Mill revolving at n r.p.m abandons the Circular path for a parabolic path When the Centripetal Component of gravity exceeds the Centrifugal Component of angular acceleration.

Ex- According to Davis (Fig-No-1)



(fig-No-1)- forces acting on a ball at distance r from Center Of Mill

When

$$\frac{mv^2}{r} = mg \cos \alpha, \quad -(1)$$

In this relation

m = Mass of the ball

v = Linear Velocity

r = Radius of the mill

g = acceleration of gravity

(Fig - No - 2) -

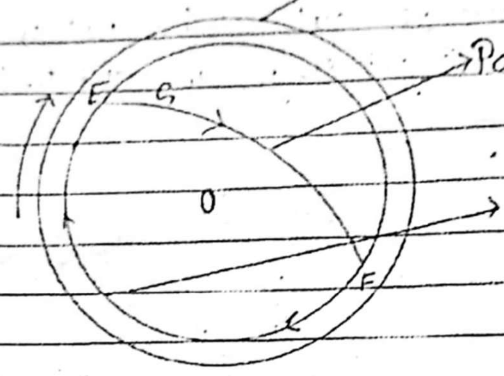


fig - No - 2 - Path of a typical ball in a ball mill.

(fig-No-3) →

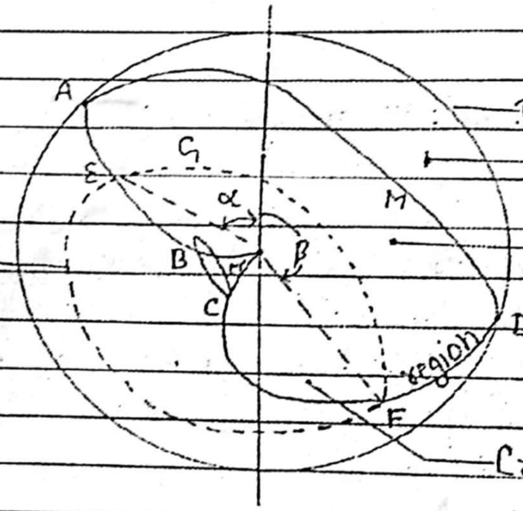


fig - No - 3 - Zones in a ball mill. (After Davis)

all expressed in Consonant units e.g. in c.g.s units
Hence, Since $v = 2\pi r n$,

$$\cos\alpha = \frac{4\pi^2}{g} n^2 r_0$$

The locus of the points E that delineate the beginning of the parabolic path (Fig No - 2) for various ball positions from center of mill to periphery is the

Scanned by CamScanner

Mechanical construction of a Cylindrical Ball mill:-

Ball mill has few important components as follows:
1. Cylindrical shell.
2. Inner surface or liners.
3. Balls or grinding media.
4. Drive.

1. Cylindrical Shell:-

It is the rotating hollow cylinder partially filled with the balls. The ore to .be crushed is fed through the hollow turnnion at one end & the product is discharged through a similar turnnion at the other end. The material ofconstruction for this hollow shell is usually high strength steel. The shell axis is either horizontal or at a small angle to the base. Large ball mills have a length of 4 - 4.25 mts, diameter of 3mts. They use hardened steel balls of size varying between 25-125 mm.

2. Inner Surface or Liners:-

As the grinding process involves impact and attrition the interior of the ball mills is lined with replaceable wear resisting liners. The liners are usually high manganese alloy steels, stones or rubber. Least wear takes place on rubber lined interior. As the coefficient of friction between balls and steel liner is specifically large, the balls are carried up taken to a higher height along the inner wall of the shell and dropped down onto the ore with a larger impact force resulting in a better grinding.

3. Balls (Grinding Media):-

The balls are usually cast steel unless otherwise stated. In some cases flint balls may be used. The diameter of the grinding media varies from 1-5inches. The optimum size of the ball is proportional to the square root of the feed size. The ball and liner wear are usually in the range of 450 – 1250 and 0.50 – 250 grams per ton of ore ground.

4. Drive:-

The mill is rotated by electric motors connected through reduction
gear box - ring gear arrangement.

Theory of Ball Mill Operation:-

Ball mills may be continuous or batch type in which grinding median the ore to be ground 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 along the inner wall of the shell nearly to 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.

Characteristics of Ball Mill Working:-

There are following working of ball mill :-
1. Speed and energy input interrelation in ball mill.
2. Ball load.
3. Reduction Retio.
4. Capacity.
5. Energy consumption.

1. Speed and Energy Input Interrelation in Ball Mill:-

Speed of the ball mill should be as high as possible without centrifuging. Initially the work input increases steadily as the speed of the mill increases. It reaches a peak at a particular speed and there after the work input decreases rapidly with the increase in speed. This is shown schematically in the figure.

3. **Ball Load:-**

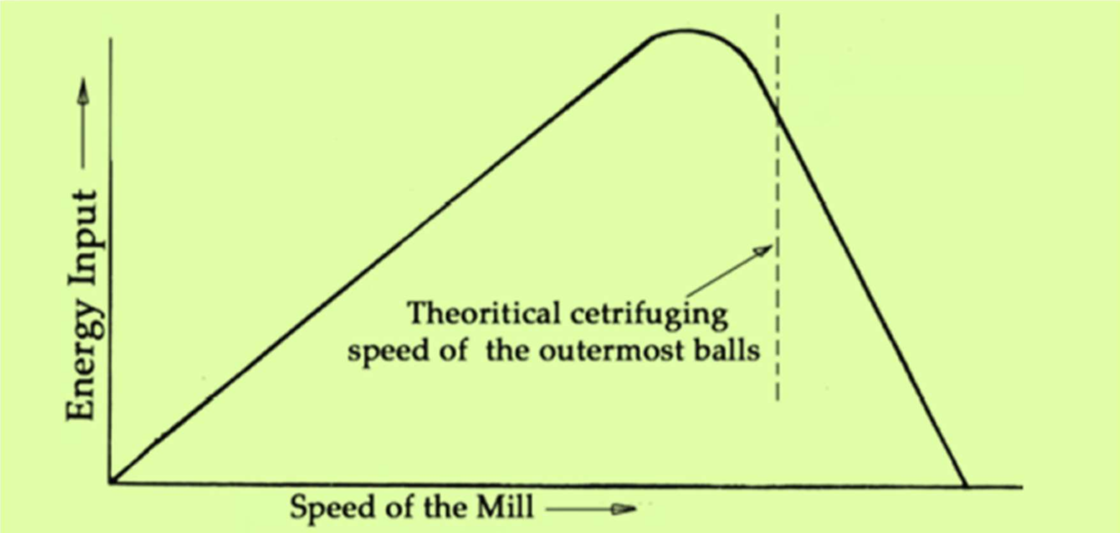
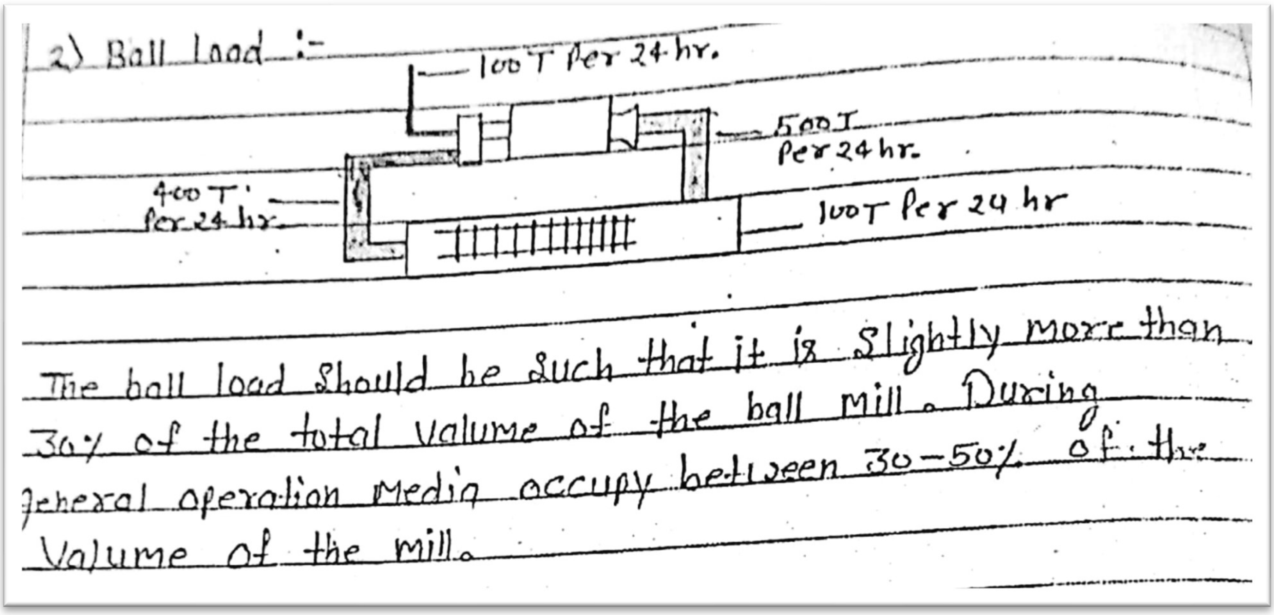


Fig. --- Ralation between Speed and Energy Input

1. It is defined as the volume that is occupied by the grinding media out of the total volume of the ball mill without ore or water in it. The ball load should be such that it is slightly more than 30% of the total volume of the ball mill.
2. During general operation media occupy between 30-50% of the volume of the mill. When a mill is operated for the first the time, balls of various sizes rather than single size are charged into the shell.
3. The Justification for the use of the various sizes is obvious. If balls of definite size are charged, the interstitial pores created by the uniform sized spheres will work as void spaces and ore particles of that particular void size if caught in the void will not be crushed further.
4. So as to avoid such problems balls of various sizes are used in the mill when it is installed and operated for the first time. During grinding the balls themselves get worn-off which reduces the ball load. The reduced ball load is replenished at regular intervals with new ball(s) of largest size only.
5. In fact the larger balls crush the feed material more effectively while the smaller ones are responsible for producing fines.The energy that the mill is made to consume is a function of speed of the ball mill, ball load, specific gravity of the ore and dilution of the pulp.
6. With the increase in ball load the energy input into the mill is increased gradually but not in direct proportion to the ball load till a maximum is reached. Thereafter the energy input decreases gradually to zero as it had increased earlier.

Shorter way :-



3. Reduction Ratio:-

The reduction ratio that can be obtained in the ball mill is large compared to reduction ratios obtained in primary or secondary crushers. It may range from 50 -100 for a ball mill-classifier circuit If the r.r. is high along with large capacity, it will be more economical to use ball mills in series. The first in the series may be with r.r of 20 while the last one may be a fine grinder having r.r of 5 resulting in an effective.

r.r of 20X5=100.

4. Capacity:-

The capacity the ball mill depends upon its size, hardness of the ore and the reduction ratio attempted. Ball mills yield 1-50 ton / hr of ore fines with 90% passing through 200 # screen.

5. Energy consumption:-

Average energy input into the ball mill is around 16 kWh / ton of ore ground.

Factors affecting the size of the Product in a Ball Mill:-

1. Rate of feed:-

Higher the rate of feed lesser is the size reduction since the residence time of the ore particles in the mill is reduced.

2. Properties of the feed ore:-

Under given operating conditions larger the feed larger will be the product. A lower reduction ratio (r.r) is obtained with a hard material.

3. Weight of the ball:-

Heavier balls produce finer product. Since the optimum condition is 50% ball load by volume, the weight of the balls is normally altered by the use of materials of different specific gravities.

4. Diameter of the ball:-

Smaller balls facilitate the production of finer material but they are not effective in grinding larger sized particles in the feed. The limiting size reduction obtained with a given size of balls is known as free grinding. As far as possible smaller size balls are to be used.

5. Slope of the mill:-

Increase in the slope of the mill increases its capacity of the mill. But a coarser product is obtained as the retention time of the feed in the mill is reduced due to higher slope.

6. Discharge freedom:-

Increasing the freedom of discharge of the product has the same effect as that of increasing the slope.

7. Speed of rotation:-

The mill should be operated at speed less than Nc. Usually it is operated at a speed,

Operational = 0.65 - 0.75 Nc

8. Level of Material in the Mill:-

Power consumption is reduced by maintaining a low level of material in the mill. If the level is increased the cushioning action is increased and energy is wasted in producing excessive fines. Total level of material in the mill should be 50% maximum out of which at least 30% should be the ball load.

Advantages of the Ball Mill:-

1. The mill can be used both for wet and dry grinding.
2. The cost of installation of a ball mill is low.
3. The ball mill can use an inert atmosphere to grind explosive materials.
4. Media used for grinding is relatively cheap.
5. The mill is suitable for grinding materials with any degree of hardness.
6. It can be operated in batches or continuously.
7. It is used for both open and closed circuit grinding effectively.

Open circuit grinding :-

The usual meaning of grinding here is comminution and has nothing to do the product particle size. In many mills the feed is broken into particles of satisfactory size by passing it once through the mill. *When no attempt is made to return the oversized 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. Such* ***a method of size reduction at various stages till the desired product is obtained is termed as open circuit grinding.***

E.g. A bright example is dodge crusher operating on choke feeding.

Close circuit Grinding :-

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 termed as closed circuit grinding.***

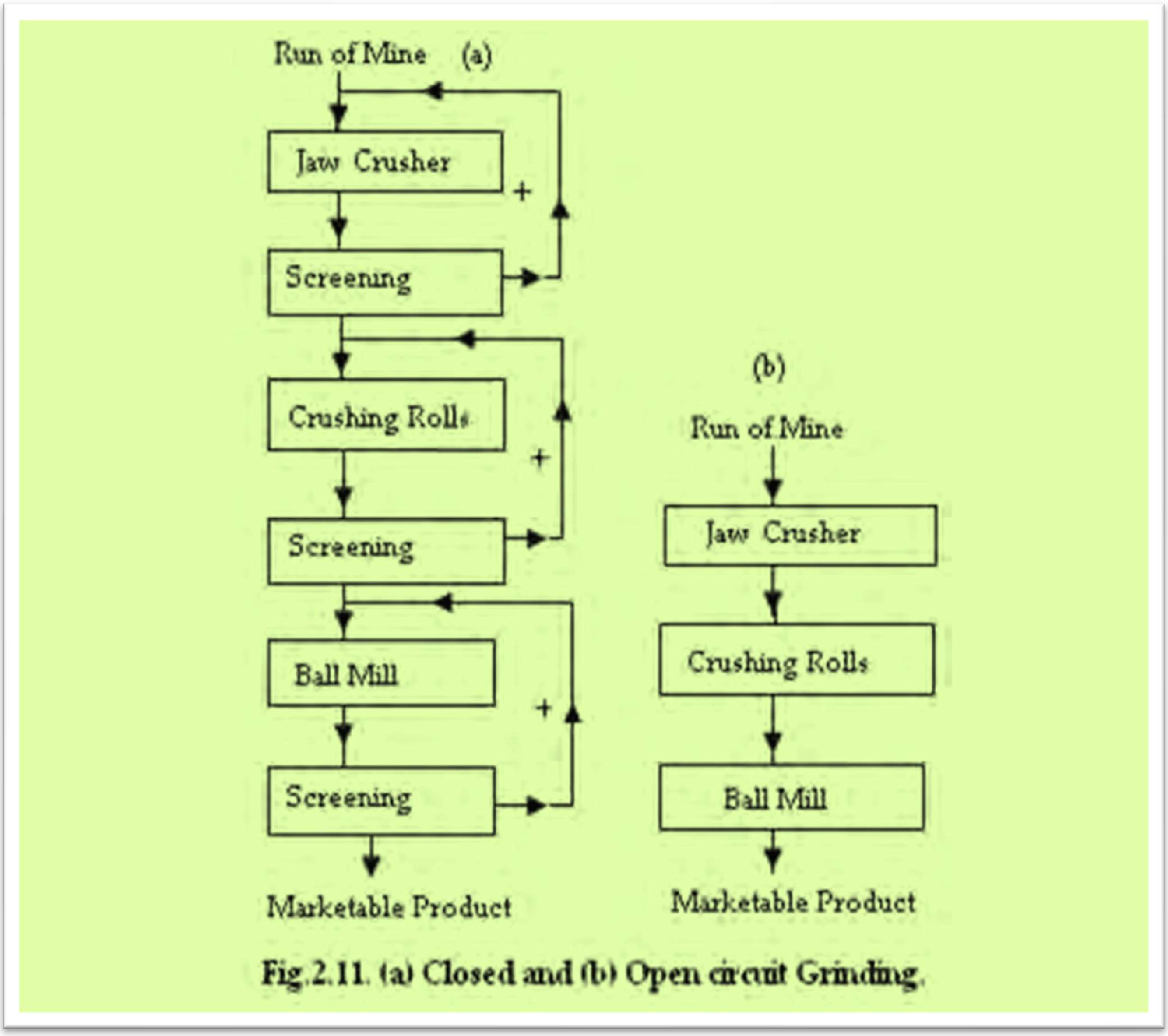


Figure (a) for closed and (b) Open circuit grinding.

Dry and wet grinding :-

It is to be noted that ball mills can he operated dry ***or wet. Mills are usually employed to grind ore in wet condition. But for some specific purpose*** essentially in chemical industries dry grinding is employed.

During ***dry grinding the mills are connected with pneumatic classifiers in closed circuit to produce extremely fine powder***. Pulverized coal is obtained in this manner.

Advantages of Wet Grinding Over Dry Grinding:-

Though wet grinding is generally applicable in low speed mills there are number of advantages of wet grinding over dry grinding: -

1.Wet grinding facilitates better removal of the product, eliminates dust problem, lessen the noise and heat produced though the wear may actually increase by 20 %.
2. Power consumption is lowered by10-30% over dry grinding per ton of product.
3. The capacity increases per unit volume of the mill.
4. This grinding makes wet screening possible for producing materials in narrow size range.
5. Dust problem is eliminated.
6. Wet grinding makes handling & transportation of product easier.
7. Sticky solids are more easily handled.

CHAPTER-4

4.0 Explain the procedure for size analysis & use of standard screen as also screening techniques employed.

- **SIZE ANALYSIS :-**

Size analysis of various products of a crushing mill constitutes a fundamental part of the laboratory testing procedure. It is of great practical importance to make a correlation between the particle size and degree of liberation. Further it is to be understood that, particle size has a great role to play during reactions between solidly - liquid or solid-gas. 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.

[SOMETHING USEFULL]

Particle Size & Shape:-

The shape of the particle plays an important role in the size determination. 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 often used to describe an irregular particle is the equivalent diameter. There can be various shapes to describe a particle as discussed below:
1. Acicular: Needle like particles.
2. Angular: Sharp edged polyhedrons.
3. Crystalline: Particles of regular geometric shapes.
4. Fibrous: Regular or irregular thread like particles.
5. Dendritic: Particles having branched crystalline structure.
6. Flaky: Plate like particles.
7. Granular: Equidimensional irregular shaped particles.
8. Irregular: Lack of any symmetry in the particles.
9. Nodular: Particles having rounded irregular shape.
10. Spherical: Globular particles.

- **PROCEDURE OF SIZE ANALYSIS: -**

Common Methods of Size Analysis:-

Particle size is usually defined as the narrowest regular aperture through which mineral particle passes through. Through this definition is applicable to polyhedrons it is not valid for rod shaped narrow particles. Particle size can be determined by various methods as described below :-

(1) Microscopic Measurement.
(2) Elutriation.
(3) Sieve Analysis.

Table 3.1.Methods of Particle size Determination:

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

(1) Microscopic Measurement:-

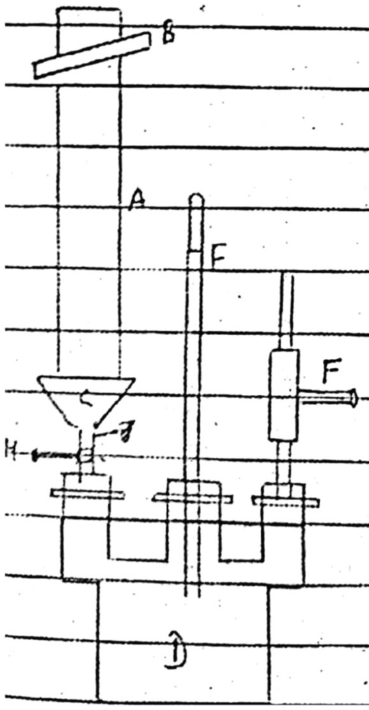
For measuring the particle size under microscope, it is customary to sprinkle them on a slide and to measure their diameter in random directions or in any two perpendicular axes within the plane of vision. In both the cases the smallest dimension is neglected.

(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 to that which the particle would attain when falling in still water.

This works on the principle of Stoke’s law of settling.

In elutration, the material to be Separated is again Suspended in the fluid medium but this time fluid medium instead of being at rest is Caused to ascend at a rate exactly equal to the Chosen Settling Velocity.



A) elutriator Column,
B) overflow launder
C) Leter Chamber
D) bottle
E) thermometer
F) grd
H) Clamps.

(3) Sieve Analysis: -

This is the most important method of sizing the mineral particles. This is widely used to determine the efficiency of size reduction operations and also used as a yardstick for assessing the fineness of a ground product. As sieve analysis has been the most important method of size analysis it has become pertinent to discuss about the standard screens or sieves used worldwide for the purpose.

Screen Analysis:-

Screen analysis is the experimental method to determine the average size of the crushed product. The product from jaw gyratory or any other crusher is hardly uniform in size. In fact, the product consists of particles of various sizes and it is impossible & impractical to know the size of each product particle. Hence, an average size of the product is determined by sieve analysis method as
it proves to be the quickest and most reliable method.

* Screening Technique :-

Testing Screens are circular shells of brass 8 in. in diameter and about 2 in. high. The screen cloth is placed in the bottom of the shell so that material can be held on the screen. The screen are built to nest in each other in order of decreasing size, a complete set includes a cover and a bottom pan. In screening by hand, the material is placed on the coarsest screen, used alone with a cover and a bottom. This operation is repeated for a given length of time after which the undersize is removed and the operation resumed to determine whether more material will pass through the sieve. for ~~par~~ practical purposes, however, after a certain length of shaking, there is very little material going through the screen so that a practical end point may be considered to have been reached.

****

CHAPTER-5

5.0 Industrial screening

- ✓ 5.1 Explain the principle of industrial screening, type of screening (without calculation)

5.2 Explain the operation of classifier & their application.

- **Industrial screening: -**

  Screening has only been discussed on a laboratory scale but for industrial need, the screening has to be carried out in a much larger scale. ***Thus, large scale screening is termed as industrial screening which differs from the***

***laboratory** screening practices in many ways. It is important to know the methods those* are available and also the factors which affect the process of industrial screening.

Screening can be practiced from a dividing size of several inches to a dividing size as fine as about 0.1 mm. Likewise, Classification can be practiced from a dividing size as coarse as 2 or 3 mm. to as fine a dividing size 0.02 to 0.03 mm. It is often stated as a mineral-dressing rule that for sizing coarser than 20 mesh screens are preferable, and for sizing finner than 35 mesh classifiers are preferable. Although this is a good general rule, it must be applied with the realization that there are many exceptions. for example, products that must be dry like talcum powder, aluminum powder, It studying industrial screening consideration must be given to the type of screening surfaces and to the type of machine that is employed with these various screening surface.

Principle of industrial screening :-

Mechanical screening, often just called screening, is the practice of taking granulated ore material and separating it into multiple grades by particle size. This practice occurs in a variety of industries such as mining and mineral processing, agriculture, pharmaceutical, food, plastics, and recycling. [principle from google]

Purposes of Screening: -

1. To prevent the entry of undersized material to the crushing machines so as to increase the capacity and efficiency of comminution.
2. To prevent oversized material from passing to the next stage in closed circuit crushing or grinding.
3. To prepare closely sized feed for next stage of unit operation such as gravity concentration.
7. To prepare closely sized end product as per specification and requirement.

Mechanism of Screening: -

The material passing through screen openings is known as under flow or under sized while the material retained is known as over flow or oversized. So, the basic fact

attached to screening is the passage of under sized material through the screen. There are several factors affecting this passage. The factors are:
1. The absolute size of the screen openings.
2. The relative size of the particle to that of the screen aperture.
3. The percentage of open area available on the screening surface.
4. The angle at which particle strikes the screening surface.
5. The speed with which the particle strikes the screening surface.
6. The moisture content of the material to be screened.
7. The opportunity offered to each particle to hit the screening surface that is the probability that a particle will hit the screening surface before it is taken away by overflow.

Screening Surfaces:-

Screening surfaces are the surfaces through which screening takes place. Screening surfaces are categorised according to the mode of their manufacturing classified. There are three types of screening surfaces: - (1) Parallel Rods.
(2) Punched Plates.
(3) Woven Wires.

(1) Parallel Rods: -

Such a surface is usually made-up-of steel bars, rails, channels and etc.It can also be made from wood and bamboo.

(2) Punched Plates: -

The surfaces are punched steel sheets or plates of various patterns. The openings are normally circular, rectangular, hexagonal and slot like.

(3) Woven Wires: -

The screening surfaces are woven carefully by gauged wires. These wires are generally made up of steel, bronze, copper & monels. The screen surfaces are shown schematically in the figure.

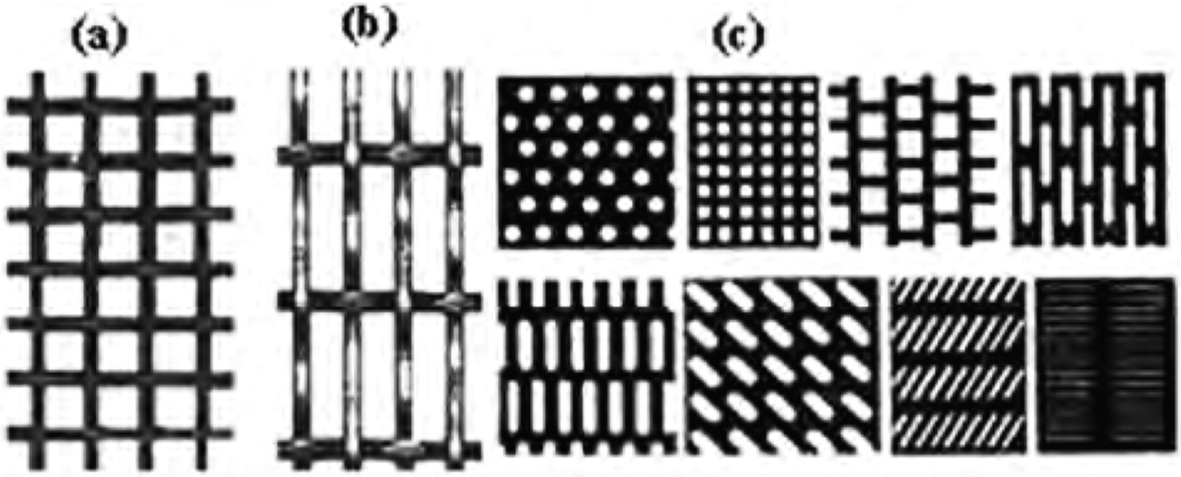


Fig.4.1. Screening surfaces; (a) Woven wires,(b) Parallel Rods, (c) Punched plates

Types of Screens:-

The screens are classified as: - (1). Stationary Screens.
(2). Moving Screens.

(1) Stationary screens: -

(1) These screens are of limited use but are not totally obsolete. These screens are grizzlies. They consist of parallel rods, bars or woven wire mesh set at an angle to the ground. They have heavy screening surfaces.
(2) The bars are usually held together at right angles to their length and are spaced at the desired distance sleeves on the bolts.
(3) They are usually employed in case of coarse crushing. A slope is generally provided so that the material fed onto the screen surface would roll down facilitating better screening. A typical stationary grizzly is shown in the figure.
(4) The major disadvantage of this type of screen is clogging. Rails are used under severe service conditions with openings greater than five (5) inches.

Fig.4.2. Stationary grizzly.

(2) Moving Screens: -

Moving screens are; -

1. Moving grizzlies.

2. Trommels or Revolving screens.
3. Shaking screens.
4. Vibrating screens.

(1). Moving Grizzlies: -

The grizzly is made up of rods and bars but have movements ascompared to stationary grizzly. In moving grizzlies' alternate bars or rods alternatively rise and subside, so that the feed material moves forward gently with sufficient turning over. There are different grizzlies such as:

a. Moving-bar grizzly.
b. Chain grizzly.
c. Travelling grizzly.
d. Disc or Roller type grizzly.
e. Vibrating grizzly.
f. Shaking grizzly.

Advantages of Grizzlies: -

(a). Low floor space is required for installation.
(b). They act as feeders to intermediate crushers.
(c). Result in better screening than stationary screens.

(2). Trommels or (Revolving) Screens: -

Trommel consists of rotating cylindrical, prismatic, conical or pyramidal sells of punched plates or thick woven wires. A trommel has one or more shells which are arranged in a concentric manner. When the trommel has only one shell, it is known as simple trommel. With more than one shell it is known as compound trommel. In case of compound trommels screen opening aperture gradually decrease from the innermost screen to outermost screen. The trammel is *commonly 3 - 4ft in diameter and 5-10ft. in length.* The Shells lire driven by a central shaft attached to them by 4 or 6 armed spiders.

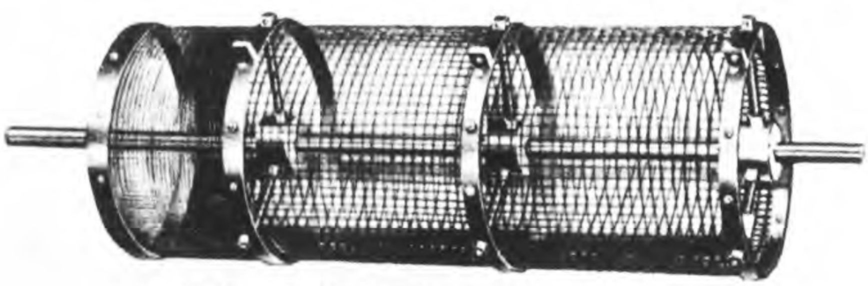


Fig.4.3. Schematic figure of a trommel.

Advantages of Trommels:-

1. It requires smaller floor space.
2. It has a larger capacity per unit screening area.
3. It is cheap to operate.
4. Several fractions are obtained in one go.

5. Screening operation is quite efficient, can utilize both wet and dry screening.

3. Shaking screens: -

It essentially consists of a shallow rectangular box where the length is at last 2-4 times the width. It is open at one end and is fitted a screen bottom. It is shaken by means of a suitable mechanism. Speed, slope and length of the stroke should be adjusted to produce rapid stratification of the feed with a forward motion so that minimum blinding of the screen surface is resulted. It is widely used in case of screening of coal. It looks very similar to the vibrating screen.

4. Vibrating Screens:-

Vibrating screens are recent development and have made most of the other screening practices obsolete. It is essentially a flat plane screening surface made from punched plates or wire woven which is secured rigidly on a steel frame. This frame is attached to certain mechanical device which imparts a reciprocating up and down motion to the screen in the direction either normal to the screen surface or at a high angle to the screen surface. These screens can be driven electrically or mechanically. The particles passing through the screen is the under flow and particles retained on it are discharged as overflow continuously at the other end.

- **Multi Deck Vibrating Screens:-**

When only one screen is used in the vibrating setup it is called single deck vibrating screen. But similar to compound trommel, multiple numbers of screens can be used in the set up. Then it will be called a multideck vibrating screen. In case of multideck vibrating screen a number of screens are used one over the other, fixed rigidly to the main frame. The coarsest screen is at the upper most position and the finest screen is at the bottom most position. So, by using this technique we get number of oversized material fractions on each screen. Sometimes the vibrating screens are placed in an inclined fashion so as to facilitate automatic discharge utilizing the natural force of gravity.

- **Advantages of Multideck Screens:**
  1. It requires minimum floor space.
  2. It operates continuously.
  3. The problem of screen blinding in this screen is less.
  4. The screen surface can be repaired easily compared to trommels.
- **Disadvantage of Multideck Screens:**
  1. There is heavy wear of screen cloth or material in vibratory screens.

- **Comparison between Shaking & Vibrating Screens:-**

1. Shaking screens have number of advantages over most of the vibrating screens in terms of cost of operation& installation.
2. Shaking screens can be set almost flat during operation.
3. But they are more prone to heavy wear and require more frequent and expensive repairs compared to vibrating screens.

- **Operating Characteristics of Screens:-**

The operating characteristics of any industrial screen are:-

(a). Capacity.
(b). Efficiency or performance.
(c). Operating cost.

(a) Capacity :-

Capacity of the screen depends upon: -

1. The area of the screening surface.
2. The size of the opening.
3. Characteristics of the ore such as specific gravity, moisture contents, temperature, proportion of fines particularly slime or clay in the product.
8. Type of screening mechanism used.

Capacity and efficiency are interrelated up to a particular extent. If the capacity is to be large; the efficiency has to be low. If the efficiency is to be improved capacity has to be sacrificed. Because of the direct dependence of screening capacity upon the area of screening surface and upon the screen aperture, it customary to express the capacity in the term of tons per square foot per millimetre screen aperture per 24 hours.

- A comparison is made regarding capacities of various industrial screens in the table below: -

Table 4.1. Capacity Comparison of Various Industrial Screens:

Type of Screen	Capacity Range (Ton/sq.foot area/millimeter aperture/24 hr.)
Grizzly	1-5
Trommel	0.3-2
Shaking	2-8
Vibrating	5-20

- **Performance or Efficiency of Screens:-**

It is difficult to quantify the screen efficiency. According to mechanical engineering efficiency is defined as the ratio of energy output to the energy input during execution of a particular work. But in case of screens the efficiency that is measured is not the mechanical efficiency in exact sense. Screen efficiency defined here is a measure of effectiveness of the screening operation as compared to a perfect screening operation.

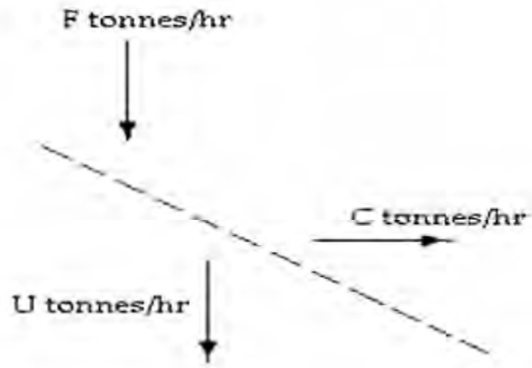


Fig 4.4. Mass balance on a Screen

The percentage efficiency E can be expressed as.

$$E = \frac{10{,}000\,U}{uF}$$

In which.
U = tonnage passing through the Screen.
F = tons of feed
u = is the Percentage of Undersize in the feed as determined by test Screening.

- **Operating Cost of Screens: -**

The operating cost of screens is small. For stationary screens, power cost is nil but there are other costs like attendant, replacement and repair. In addition to these costs moving screens have a cost for the power consumed during their operation.

5.2 Explain the operation of classifier & their application:-

- **Classification: -**

Classification is a process by which particles of various sizes, shapes and specific gravities are separated into separate groups by allowing them to settle in a fluid medium. The coarse and heavier grains settle faster than the finer and lighter grains. Usually, air or water is used as the fluid medium. Classification may be regarded as a mineral beneficiation process based primarily on Stokes 'law of sedimentation.

Factors affecting classification:-

1. Specific gravity:-

For particles of same size but different specific gravities, the particle having the highest specific gravity will settle fastest than any other particle.

2. Size:-

For particles of same specific gravity but different sizes, the largest one will settle fastest than any other particle.

3. Shape:-

Spherical particles settle faster than the narrower, longer and flatter particles.

4. Specific gravity of the fluid:-

In fluids of different specific gravities, the particle will settle fastest in the lightest fluid.

5. Air bubbles:-

Adherence of air bubbles to the solid particles would decrease the settling speed.

Classifiers :-

Basing on the above discussed ideas, classifiers are broadly classified into three categories: -

1. Sorting classifier:- It uses a relatively dense aqueous suspension as the fluid medium for classification.

2. Sizing classifier:- It uses a relatively dilute aqueous suspension as the fluid medium for classification.

3. Sizing classifiers:- It uses air as the fluid medium for classification.

Sorting Classifiers:-

Hindered settling takes place in sorting classifiers. The separation achieved by sorting is a sizing operation modified by specific gravity & shape of the particle. It is usually applied to coarser products. A dense suspension of 40 - 70% solids by weight is used depending on specific gravity, size of the particles to be sorted. The usual types of sorting classifiers are:

a. A simple launder classifier or *Evans' classifier*.
b. Richard's hinder settling classifier.
c. Richard's pulsator classifier.**
d. Hydrotator classifier.**

(a) Evans Classifier:-

Evans' classifier consists of a sloping launder, A. Opening to this launder several rectangular boxes BC are attached. To the rectangular boxes spigots, O are fitted which are capable of discharging out. Pipes are suspended from a main water pipeline into the rectangular boxes. Water is introduced into the boxes through these pipes and the flow is controlled by valve, F.

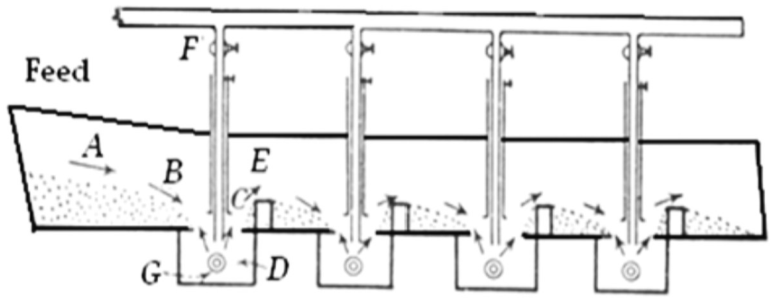


Fig.5.3. Evans Classifier.

The working of this classifier is quite simple. As water is introduced into the boxes, faster settling particles are discharged out through the spigot and slower settling particles overflow at E, to the next box in the launder. Baffles, E are fitted to the launder to restrict the return of particles to the same box from where they have been taken away as overflow.

(b) Richards Hindered Setting Classifier:-

It is a modified version of Evans classifier. In this classifier, cylindrical sorting columns replace the boxes of the Evans classifier. More interestingly water is introduced into the cylindrical sorting column from below through radial or tangential ports. Richards Pulsator classifier is characterized by the use of an intermittent or pulsating upward current of water designed to make settling totally hindered.

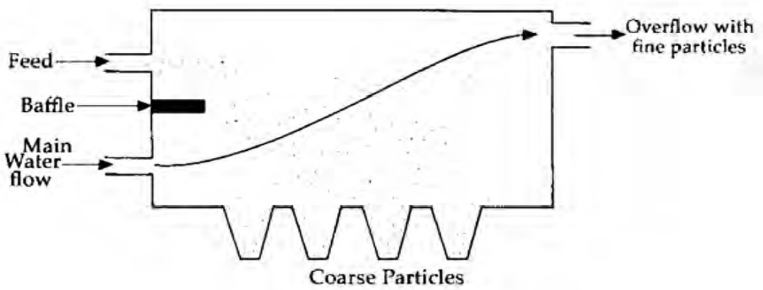


Fig.5.4. Richards Hindered Settler.

Sizing Classifiers: -

Sizing classifiers utilize free settling conditions to effect sizing as much as possible being unaffected by specific gravity & shape of the particles. These classifiers do not require any additional water besides that is present in the suspension undergoing classification. Sizing classifier may be subdivided into:

a. Settling cones having no moving parts and
b. Mechanical classifiers having moving parts.

They may use water or air as classifying medium. Classifier using air is known as pneumatic classifier where the settling speed is around 100 times faster as compared to the settling speeds in water classifiers.

Performance of Classifiers:-

1. Capacity:-

The capacity of a classifier is directly proportional to the following variables:

1. Cross- sectional area of the sorting columns.
2. The raising velocity of the fluid (water or air) in the sorting columns.
3. The percentage of solid in the classifier intake or feed.
4. Specific gravity of the solid.

The capacity of the classifier C (tons of solids per hour) is expressed by the formula:

C = aAvgr where,
A = The cross-sectional area in square feet.
v = Upward velocity or fluid feet per minute.
g = Percentage of solid by volume
r = Specific gravity of the solids.
a is a constant = 1.875 to obtain C in tons per hour.

2. **Efficiency**:-

It is difficult to quantify the efficiency of the classifiers. However the usual methods consist of screening of the classifier overflow & underflow and then calculate the efficiency using the formula:

$$E = 100 \times \frac{c(f-t)}{f(c-t)}$$

efficiency expressed in percentage, c, f, t is the content of minus X-mesh (-X #) material in the overflow, feed & underflow respectively. X being any size such that neither c nor t or f is zero.

3. Cost of operation:-

The cost of classification is strikingly less except for fine sized material. In large plants total cost of classification is around Rs. 15 per ton, but this depends largely on capital and inventory cost.

****

CHAPTER-6

6.0 Gravity concentration.

✓ **6.1 Explain the general principles of wilfly table & its operation.**

6.2 Develop elementary idea regarding the operation jigs.

Tabling :-

1. Tabling takes place on the Shaking or Wilfley table. The Shaking or Wilfley table essentially consist of a substantially plane surface called the deck. The table is slightly inclined to the horizontal from the left to right and shaken with an asymmetrical motion in the direction of the long axis.

2. Asymmetrical motion makes the stroke of the table faster in one of the directions and slower in reverse. Usually a slow forward with a rapid return is used during the operation of the Wilfley table.
3. This causes the mineral particles to crawl along the longitudinal cleats or riffles that are fixed on the table surface in the direction of the table movement. The wash water flows over the table at right-angles to the direction of jog.
4. A feed of 25% solids by weight is introduced through the feed box at the upper corner of the table and as the feed particles hit the deck they are fanned out by a combination of differential motion and transversely flowing water.
5. The jolt during the return stroke causes the heavier particles to work- down the bed to form the bottom layer. The lighter gangue materials are thrown into suspension and are discharged out over the edge of the table opposite to the feed box by the wash water.
6. The heavier minerals finally arrange themselves on the smooth unrifled proportion of the table when they encounter the full force of the wash water. The middling's are collected in that portion of the table intermediate between concentrate & tailings.
7. The reciprocating speed of the Wilfley table is usually 200-300 strokes/minutes with an amplitude or stroke length of 12-15mm. A finer feed requires a higher reciprocating speed but a smaller stroke length while a coarser feed requires larger stroke length with reduced reciprocating speed.
8. Hence the stroke length along with the reciprocating speed of the table can be adjusted as per the feed material to be classified on the table.

General principles of wilfly table & its operation :-

PRINCIPLE WILFLY TABLE :-

The shaking or Wilfiey table consist of a substantially plane surface (the deck), inclined slightly from the horizontal and shaken with an asymmetrical motion in the direction of the long axis. Asymmetrical motion means, the stroke of the table is faster in one direction and slower in opposite direction. [from google]

WILFLY TABLE :-

(49)

The Wilfley table use is still worldwide. The makers claim that at one time over 23,000 Wilfley tables were in use. The advance marked by the Wilfley table consists in the introduction of riffles, which increased the capacity and allowed treatment of coarser feed, and in the introduction of an effective and rugged head motion. The Wilfley table consist of a four-sided, nearly rectangular deck sloping adjustably toward one of the long sides.

This deck is actuated by a pitman and toggle type head motion (fig) when the toggle are nearly horizontal, an appreciable vertical movement of the pitman has practically no effect on the position of the outer toggle, but the opposite is true when the toggles are markedly inclined to the horizontal.

Construction of Wilfley Table:-

The constructional feature of a Wilfley table is shown schematically in the figure. The is made from wood or similar such material. The table surface is cleated specifically as shown in the figure.

surface is cleated specifically as shown in the figure.

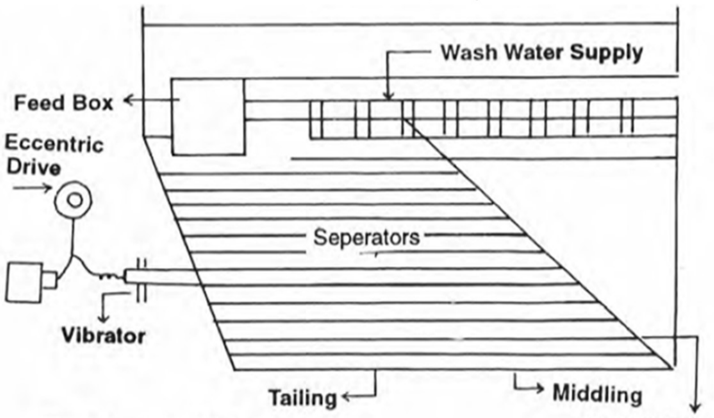
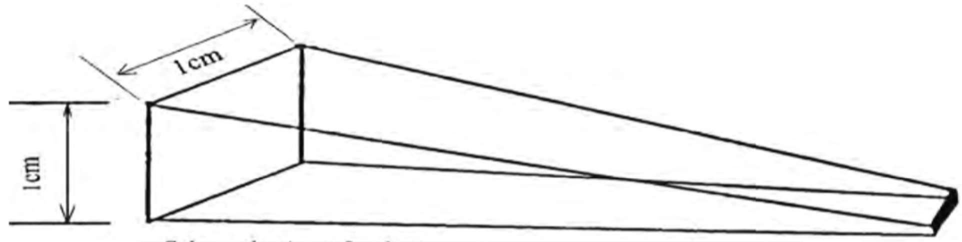


Fig. Schematic Wilfley table.

- Specific discussion on cleats or riffles is required as they require frequent replacement during the working of Wilfley table. The cleats are usually made up wood with a maximum height and width of one centimeter each as shown in the figure 8.4.



8.3. Schematic view of a Riffle or Cleat.

1. The cleats are tapered from one end to another. They are so placed that they form channels of around 1cm width and deep at the left-hand side end and the same tappers down to zero depth at the opposite end.
2. The cleats end along a diagonal line imagined on the Wilfley table which approximately divides the total surface area of the table in the ratio of 2: I. This means 2/3 of the total surface area of the table is cleated (riffled) and rest 1/3 portion is unrifled.
3. The inclination of the table is from left to right and from the back to front. Such inclination increases the ore handling capacity of the table.
4. However, the inclination should not be large as it hampers the classification efficiency. The normal inclination in both the directions is limited to 0-3 degrees. For majority of ores a slope of 0.75-1.25 degrees is used.

- However, the inclination should not be large as it hampers the classification efficiency. The *normal inclination in both the directions is limited to 0-3 degrees. For majority of ores **a slope of 0.75-1.25 degrees is** used.*

Table Surface:-

The surface of the Wilfley is lined with rubber or linoleum to restrict the wear of the wooden table surface and also increases roughness or friction of the table surface. Both riffles and the linoleum lining increase the capacity of the table.

Capacity of Wilfley Table:-

It depends on the table size and many other associated factors. However, for a table size of 4ft x 2ft the capacity is around 200 tons /24hrs.

Cost of Operation :-

a. Power 0.5 ---------- 0.8 Kw/hr
b. Repairing, cost of cleats & deck as and when required.

- **Important Use of Wilfley Table:-**
  1. It is widely used to concentrate cassiterite or tin ore.
  2. It is widely used to concentrate free milled gold ores.
  3. It is widely used for beneficiation of non-metallic like glass and sand.
  4. It is widely used for beneficiation chromite and tungsten ores.
  5. It is widely used to recover the part of galena and sphalerite in coarse aggregate of lead-zinc ores.

6. It is widely used for cleaning fine coal.
7. It is widely used for beneficiation of some iron ores.
8. It is adopted as a pilot and guide to flotation plants.

6.2 Develop elementary idea regarding the operation jigs.

Introduction of Jigs :-

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 repeatedly affording an opportunity to a very thick suspension of mixed particles to settle for a short time.

The Jig:-

1. A jig is essentially a water filled box in which a bed of mineral grains is supported on a perforated surface or screen. Jigs are usually made up of wood or other materials. In place of one compartment there may be several compartments connected in series.
2. The tailing of one compartment works as feed for to the next consecutive compartment in the series. The amplitude of jigging is maximum in the first cell and minimum in the last cell.
3. When water is pulsed through the screen, the particles are brought into suspension in water and are allowed to settle under hindered settling conditions which are modified

greatly by differential acceleration (the theory of jigging has been discussed earlier.

4. If the settling periods are of very short duration, the separation of two materials according to the specific gravities may be possible almost regardless of the size.
   This explains how the jig can handle wide range of size distribution.
5. It is evident that with a feed of a wide size range, a very short settling time must be used for complete stratification.

Principles of Jigging:-

The three physical factors responsible for stratifications of particles during jigging are:

1. Hindered settling classification.
2. Differential acceleration at the beginning of the fall.
3. Consolidation trickling at the end of the fall.

1. Hindered settling classification:-

a) The essential difference in hindered settling in jigs and classifiers is that in jigging the solid - 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.

b) 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.
c) As the jigs produce a fluidized bed for few seconds, it offers an open bed alternatively and particle rearrangement takes place during that time period only.
d) Other parameters remaining same higher settling ratios are obtainable in jigs compared to classifiers. Figure 7.1 shows the effect of hindered settling during jigging.

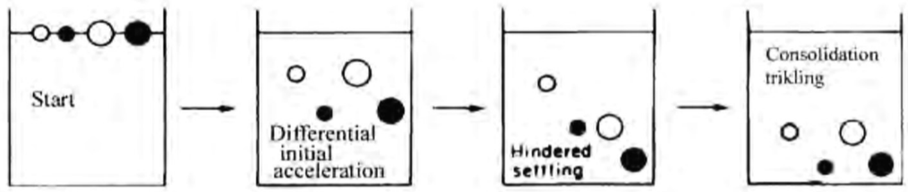


Fig.7.1. Effect of Hindered Settling During Jigging.

2. Differential Acceleration:-

In jigs particles are allowed to move and allowed to get rearranged during their accelerating time periods only. The heavy particles have a greater initial acceleration and speed than the lighter particles. So if the fall is repeated for short durations then the total distance travelled by the particle bears a resemblance to its initial acceleration than to its terminal velocity (Vt). Stratification of particles will takes place according to the specific gravity of the particle alone. The important issue is whether such short falls can be realized or not. Mathematically differential acceleration at the beginning of the fall can be derived as discussed below: -

Mathematical Derivation for Differential Acceleration:-

Applying law of sedimentation:

$$m. dv/dt = (m-m').g - R (V)$$

where, V is the velocity of the particle against the fluid motion.
m is the mass of the solid particle.
m' is the mass of the fluid displaced by the particle.
R (V) is the fluid resistance force working on the particle.

To separate small heavy from large light mineral particles a short jigging cycle is required. The effect of initial acceleration is shown schematically in the figure7.2.

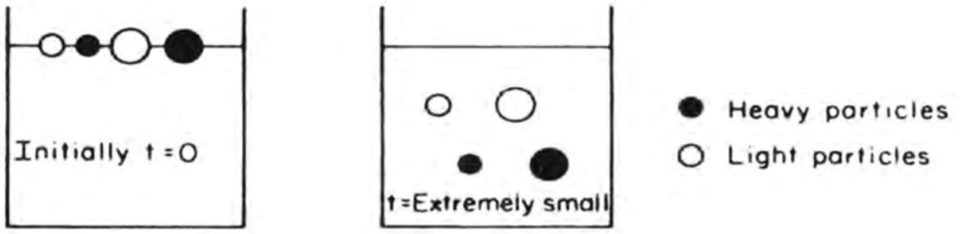


Fig.7.2. Effect of Differential Acceleration.

3. Consolidation Trickling:-

It is a fact that different particles of either same or different specific gravities do not travel the same distance during the settling period. So they appear at different heights in a stratified bed. Finer particles may appear on the top of a bed of coarse particles. The finer particles may run down through the interstitial pore spaces available in the bed of coarse particles under the influence of gravity & vibration. This particular phenomenon is known as consolidation trickling. In true sense consolidation trickling is opposite to jigging as it leads to an intermixing of smaller particles of lower specific gravity with coarser particles of higher specific gravity. The effect of consolidation trickling is shown schematically in the figure 7.3.

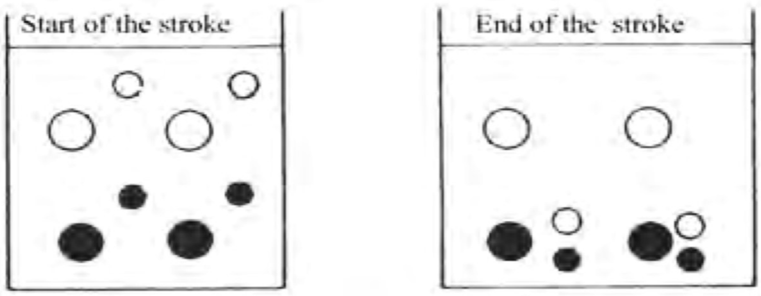


Fig.7.3. Consolidation Trickling.

1. To summarize, stratification during the stage when the bed is open is essentially controlled by hindered settling and initial differential acceleration.
2. During the suction stage, when the bed is tight the stratification is controlled by consolidation trickling. Hindered settling and the initial differential acceleration put the coarse-heavy grains at the bottom, fine-heavy & coarse-light grains in the middle and fine-light grains at the tap of a stratified ore bed.
3. Consolidation trickling reverses this process to some extent.

- **Advantages of Jigs:-**

1. Jigs are primarily used to concentrate coarse-minerals. In coal washing, up to 4 - 5inches coal pieces can be washed in Jigs. In case of ores, pieces up to I inch

size can 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. Excluding washing of coal it is used widely to beneficiate non-magnetic iron ores.
3. Jigs are cheap to operate and substantially fool proof and offers an easy access for inspection.

➢ **Limitations of Jigs:-**

1. Jigs are obsolete for sulphide ores.
2. It requires large amount of water during ore beneficiation.
3. Fines cannot be treated in jigs. Jigging is applicable to the ore that is too coarse for complete liberation.
4. Jigs do not provide a complete solution to any mineral beneficiation problem.

****

CHAPTER-7

7.0 Heavy media separation

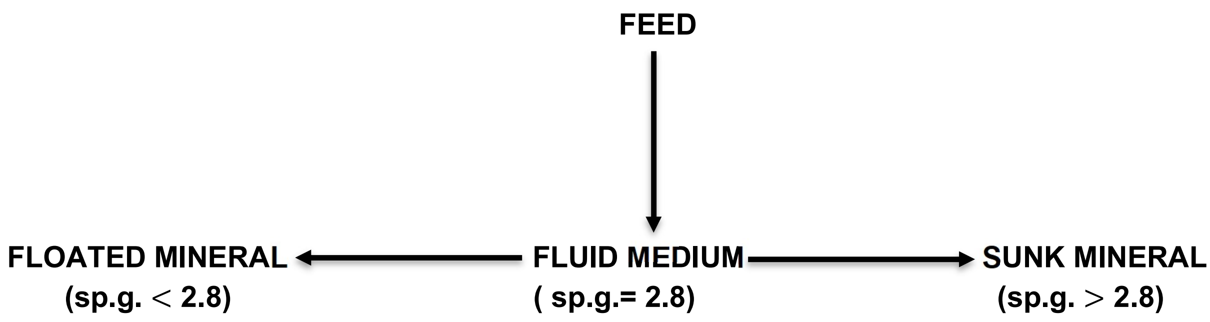
7.1 Explain the fundamental principle of heavy media separation – Chance process.

Introduction: -

1. If a fluid is available whose specific gravity is intermediate between two solids which are to be to separated, then one of the simplest process will be to suspend the mixed mass in that fluid.
2. 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.
3. Then a mechanical arrangement will be required to draw 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 gravity is 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 effective fluids heavier than water are required. The figure 6.1 explains the basic principle involved in H.M.S. [Heavy media separation]



*** Fig.6.1. Scheme of heavy Media Separation.**

Industrial Processes Using Heavy Suspensions Or Pseudo Fluids:-

Pseudo heavy fluids are manufactured by suspending quartz, ferrosilicon or galena in different proportions to have the requisite specific gravity. The processes are:-

1. Chance process.
2. Vooys process.
3. Wuensch process.

1. Chance Process :-

The parting fluid is a suspension of quartz or sand particles in water. The sand used here is in the size range of -40 to +80 #. The Chance Cleaner consists of a separating tank or a Cone Separator in which sand suspension moves up gently. An agitator is used for stirring the suspension to prevent packing. The overflow of clean coal and sand passes over to the cleaning screens which disband and dewater the coal. Spray water is used for desanding. The specific gravity of the fluid is adjusted by varying the proportions of sand and water. For cleaning anthracite coal, a heavier fluid is used than compared to the fluid used for cleaning bituminous coal. Figure 6.3 shows the Chance process schematically.

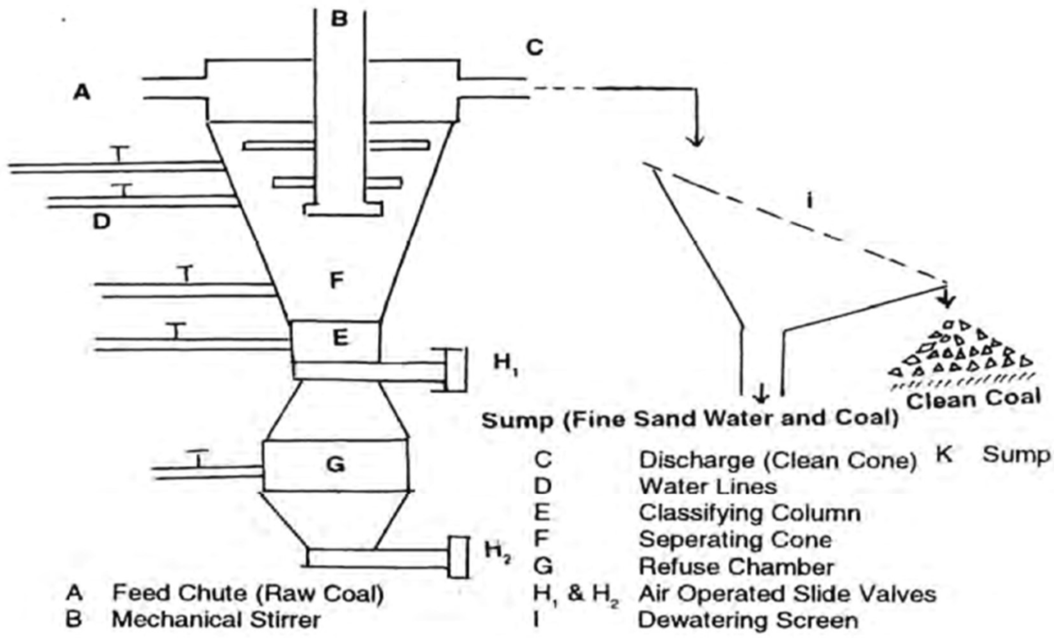


Fig.6.3. Schematic Chance Cleaner.

* Chance Process is in use for last 100 years for cleaning coal.

2. Vooys process:-

This process uses a suspension of finely grounded barite (-150 to +200#) in water. Specific gravity is adjusted to 1.47 to clean coal. Coal particles finer than 100- mesh are excluded. Since the solid particles used to manufacture the parting fluid are much smaller than what is used in the chance process, the coal that can be treated by Vooys process can also be much finer.

3. Wuensch process:-

This is a process for concentrating ores those contain lighter materials as waste (sp.g> 2.7). A mineral having specific gravity more than 5.25 must be used for making the suspension as suspensions containing more than 40% solid by weight are too plastic for partitioning work. It is preferable to use a suspension containing less than 30% solids by weight. It has been found out that galena is most suitable material to be used as it yields a heavy fluid with a specific gravity in range of 3 - 4.5 very easily at low concentration of solid. Since galena is relatively valuable the loss of medium must be reduced to a minimum level. The medium is purified periodically by flotation of galena. Sometimes ferrosilicon in water is also used as heavy fluid.

**** Heavy Media Separation Circuit:-**
A simple heavy media separation circuit would essentially consist of the followings: -

(i). A separating vessel in which heavy suspension is kept with a provision for introducing the feed and withdrawing the product continuously.

(ii). Means to clean the product separated, recover the media and recirculate it to the vessel for further utilization.

****

CHAPTER-8

8.0 Floatation: -

- ✓ **Comprehend elementary principle of froth floatation, practical utility of frother, collection, modifiers & depressants.**

8.2 Describe & illustrate floatation cell.

- ➢ **Introduction:**

1. Flotation is the most widely used method of wet concentration of ores for separating the valuable constituent of the ore from the worthless gangue.
2. The process is primarily a surface phenomenon based on the adhesion of some mineral particles to air and simultaneous adhesion of other particles to water in the pulp.
3. 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.

4. 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.
5. In such a case the adhesion is affected between a free water surface and the mineral particles. The particles involved in skin flotation are usually larger than the particles involved in froth flotation.
6. To obtain adherence of the desired mineral particles to the air bubbles, a hydrophobic surface film should be formed on the particle surface. Hydrophilic surface film must be created on the particles which are to be retained in the pulp phase.

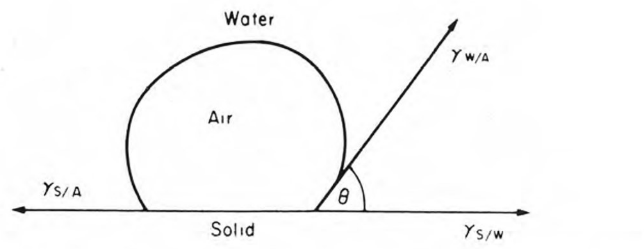
- **PRINCIPLE OF FROTH FLOATATION :-**

Physico-Chemical Principles of Flotation:-

Physio-chemical principles of flotation can be explained in terms of surface energy & surface tension, contact angle, polarity and adsorption.

Surface Energy or Surface Tension and Contact Angle:

At any interface there exists certain amount of energy called surface energy. The
surface forces at the bubble-mineral interface in an aqueous medium are shown
schematically in figure 9.2.



Contact angle between bubble and particle in an aqueous medium.

From the figure it understood that at equilibrium,

Polarity and Adsorption:-

All the minerals are classified into polar and non-polar type according to their surface characteristics. Non-polar surfaces do not attach readily to the water phase and are called hydrophobic minerals. Graphite, coal, talc and sulphur are nonpolar minerals and exhibit natural floatability and readily float on water. Minerals of polar type are hydrophilic and do not float naturally on water. These minerals have to acquire floatability to get floated up.

Another important idea in case of flotation process is the existence of a selective tendency on the part of some mineral particles to adhere to air and others to water. Much research has been done on this most recent and complex means of ore beneficiation which are summarized as follow:-

1. Most minerals if suitably protected from contamination adhere to water but not to air.
2. Paraffin & other hydrocarbons adhere to air in preference to water.
3. Some minerals adhere to air naturally and float. This may be due to surface impurities or due to inherent surface property of the minerals. Such a phenomenon is known as natural floatability and usually possessed by coal, graphite, sulphur and other hydrocarbons.
4. But for minerals to be separated by froth flotation, floatability is to be induced on the surface. This is known as acquired floatability. For the minerals to acquire floatability suitable chemical reagents are to be added to the pulp for changing their surface properties. The reagents vary in nature depending on the type of ore to be floated. The quantities to be used are extremely small but just sufficient to develop a continuous film around the mineral particles of at least few molecular level thicknesses.
5. Almost all the minerals can be made to adhere to air or water selectively by using suitable chemical reagents. But this selectivity can not be 100% efficient. This means when we are trying to float a particular mineral selectively, other mineral present in that pulp would also float up.
6. Change in the surface condition of the minerals (due to oxidation) will affect the floatability of such minerals considerably. 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, during reverse flotation the gangue is* separated into the float fraction while the valuable mineral is retained in the pulp.

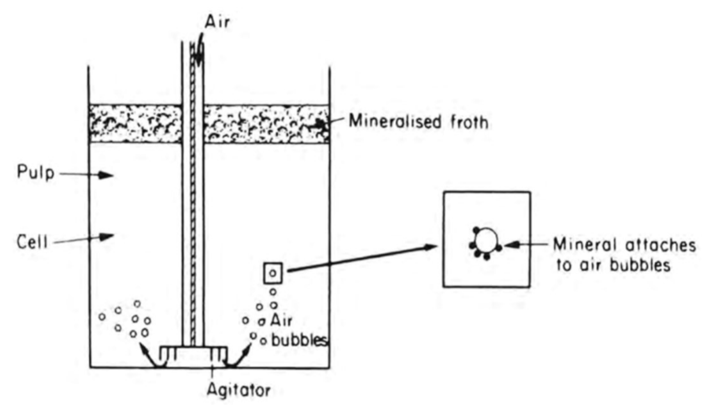


Fig.9.1. Basic Principles of Flotation.

Classification of Floatability:-

Floatability can be classified as:

1. Natural floatability.
2. Acquired floatability.

1. Natural floatability:-

It is generally agreed that hydrocarbons, coal, graphite, sulphur shows large degree of natural floatability. It is to be observed that substances showing natural floatability are non-polar substances. So minerals that are polar in nature lack in natural floatability.

2. Acquired floatability:-

By suitably coating the surfaces of one or another a group of minerals with a film that is non-polar, particles of the selected group can be made to act as if they are non polar throughout and made to acquire floatability. Acquired floatability is the result of the actions of a group of reagents called collecting agents or collectors. When the ground ore is mixture of several of minerals of similar nature, to separate them from each other, some minerals should be made more floatable compared to others. To acquire such selectivity specific reagents are to be added to the pulp and are termed as activators or depressors.

Flotation Reagents:-

Froth flotation being a physico-chemical process requires a number of chemical reagents for its successful operation. Broadly the flotation reagents can be classified under following categories:-

1. Frothers.
2. Collectors.
3. Modifiers.

1. Frothers:-

Frothers are heteropolar surface active organic reagents, capable of being adsorbed on the air-water interface. The adsorption of frothers at the bubble-water interface 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 repellence to the froth as required. A typical froth bubble is shown schematically in the figure 9.4.

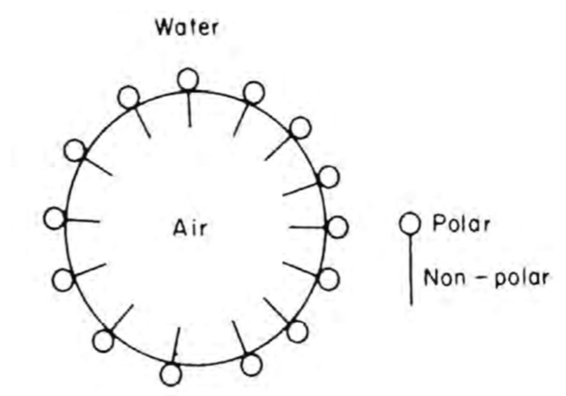


Fig.9.4. Schematic Froth Bubble.

The froth should be strong and stable enough to support the weight of the desired mineral attached to it and permits its separation from pulp*. On the other hand, the froth should break down readily after its removal from the flotation cell. Most widely used* *frothers are pine oil, isobutyl carbinol (MIBC), terpineol, aliphatic alcohols & cresol (cresylic acid).*

2. Collectors:-

The collector is said to be the most important reagent in flotation. Each collector molecule contains a polar and a non-polar group. It gets adsorbed on the mineral surface and forms a continuous heteropolar film all around the particle. 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.

1. Anionic Collectors:-

These are the most widely used collectors in froth flotation. If the nonpolar part of the collector, which imparts water repellency to the mineral surface, carries a negative charge on it, it is termed as an anionic collector.

Some typical anionic collectors are:

1. Potassium or sodium ethyl xanthate (Xanthogenates).
2. Dithiophosphates (Aerofloats).
3. Thiocarbamates.
4. Fatty acids.
5. Sulphonates.

2. Cationic Collectors:-

The characteristic property of this group of collectors is that the nonpolar water repellent group has a positive charge in place of a negative charge as in the case of anionic collectors. The most general cationic collector is the fatty amine acetate. Cationic collectors are very sensitive to the pH of the pulp.

3. Modifiers or Regulators:-

Sometimes it may be necessary to use a modifier before any collector can be made to function effectively. By means of a modifier, it is possible to accomplish the followings:

a. Utilize collectors under optimum conditions.
b. Prevent or control mutual mineral interaction.
c. Prevent or control action of atmospheric air or aquatic ingredients at the mineral surfaces.
d. Modify favourably or adversely the ability of some minerals to acquire floatability.

Due to the actions of the diverse chemical reagents tremendous flexibility is achieved with 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.

According to their function the *modifying agents* may be classed into one of the following categories: -

(i). pH regulator.
(ii). Activator.
(iii). Depressant or Depressor.
(iv). Dispersant.

(i). pH Regulator: -

In the modern froth flotation, alkaline circuits are used almost exclusively for sulphide ores. For any particular ore there is a definite range of pH (7 to 13) at which optimum results are obtained. For this reason proper pH control of the pulp is of great importance: The reagents commonly used to control pH & obtain the desired alkalinity are lime, soda ash and sulfuric 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. Sometimes 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 (CuSO4) which is used to activate sphalerite.

(iii). Depressant or Depressor:-

In some cases to induce selective flotation, it is required to prevent or suppress the flotation of a mineral over another. To achieve such a selective flotation, a class of reagents is added 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 subsequently inhibit the adsorption of collectors.

(iv). Dispersant: -

Sometimes the gangue may have the nature of flocculating along with the minerals. The extent of flocculation may be such that it interferes with the efficient flotation of the desired minerals. Then it becomes imperative to use a dispersant or deflocculator. Sodium silicate is used as a dispersant. Starch, casein and glue are used to disperse both gangue and carbonaceous materials associated with metallic minerals.

Regent quantity:-

The optimum quantity of various reagents used depends upon the ore being floated and there is no fixed rule to quantify the reagents necessary for a particular activity. However, it is important to remember that the consumption of reagents should be kept as low as possible due to their prohibitive cost. The optimum quantity of reagents to be used for a particular process is determined by trial runs. Average consumption of reagents is listed below:

Reagents	Amount (gms. per ton of ore floated)
Frothers	5 – 250
Collectors	10 – 1000
pH Regulators	10 – 2500
Depressants	10 – 500
Activators	25 – 2000

Operational Principles of Flotation:-

The success of the flotation operation depends on the following factors: -

1. Particle size.
2. Surface preparation of the minerals or conditioning.
3. Pulp density.
4. Temperature of operation.
5. Time duration of flotation.

1. Effect of particle size on froth flotation:-

Particles of various sizes do not float equally. From experiments it has been found out that flotation is most efficient for particles in the size range of 20-200#. Recovery falls off distinctly in the very fine and coarse range of the feed. The failure to float coarse particles arise from:-

1. Incomplete liberation.
2. Too small a contact angle.
3. Violent agitation required to form suspension.

The failures to float extremely fine particles are due to:-

a. Poorer chance for mineral - bubble encounter in the fine size range of the mineral.
b. The finer particles have an older surface than coarse particles. As the surfaces of the particles is affected by ions derived from other minerals, oxygen and water during fine grinding, they become unresponsive to reagents and lose their capacity to float.

2. Conditioning:-

Conditioning is nothing but mixing of ore with water & aeration prior to flotation in a cell. Usually a big tank is used for this purpose. Improper conditioning will have adverse effect on flotation.

3. Pulp density :-

For the mineral and gangue particles to get separated during flotation the pulp should be dilute enough to permit particle rearrangement to take place freely. A pulp density of 35% solids by weight shows the best result. Over dilution should be avoided as it results in larger consumption of water and reagents.

4. Temperature:-

For obtaining best result during flotation the pulp temperature is to be maintained between 12-20oC.

5. Time Duration of Flotation:-

The time duration of flotation has a strong bearing on the extent of recovery and grade of the concentrate floated. As time duration increases, the extent of recovery increases with a fall in the grade of the concentrate as shown in the figure 9.9.

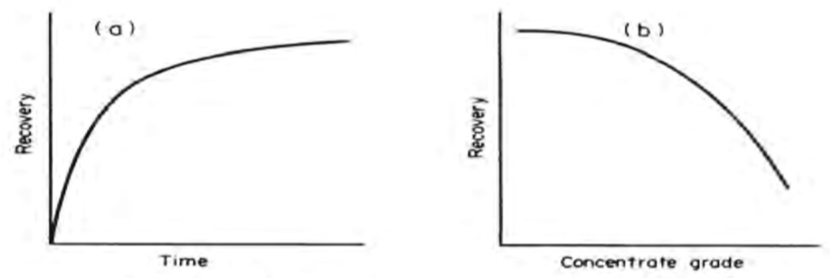


Fig.9.9. Time, Recovery and Concentrate Grade.

- ✓ **8.2 Describe & illustrate floatation cell :-**

Flotation cell 's :-

Two important flotation cell's are:

1. Pneumatic cell.
   [*In the pneumatic flotation cells compressed air is directly blown into the pulp*]
2. Mechanically agitated or Sub-aeration cell.
   [*while in the sub-aeration cell a rotating impeller serves as a pump which draws in air through the hollow shaft of the impeller and distributes the same into the pulp to produce the froth.*]

- In the pneumatic flotation cells compressed air is directly blown into the pulp while in the sub-aeration cell a rotating impeller serves as a pump which draws in air through the hollow shaft of the impeller and distributes the same into the pulp to produce the froth. In the laboratory, usually a rotating, hollow impeller type sub-aeration cell is used which is shown schematically in the figure 9.10.

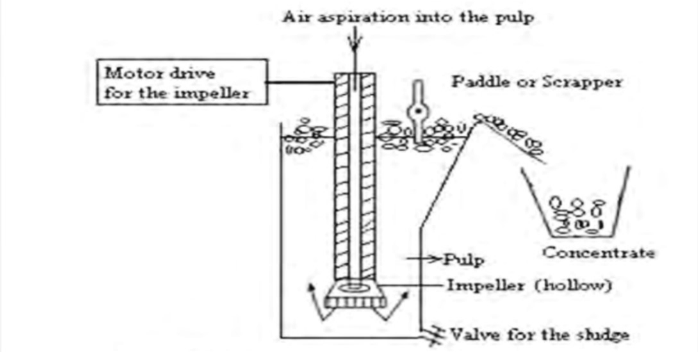


Fig.9.10. Laboratory model Sub-aeration Cell.

Industrial Model :-

In industries hardly a single cell is used for practical floatation work. Rather a series of 10-15 cells connected in series are used-simultaneously. They are connected in such a fashion that one cell receives the defrosted pulp from the preceding cell as its feed. The recovery of such process is usually more than 90%. An industrial pneumatic cell is shown schematically in the figure 9.11.

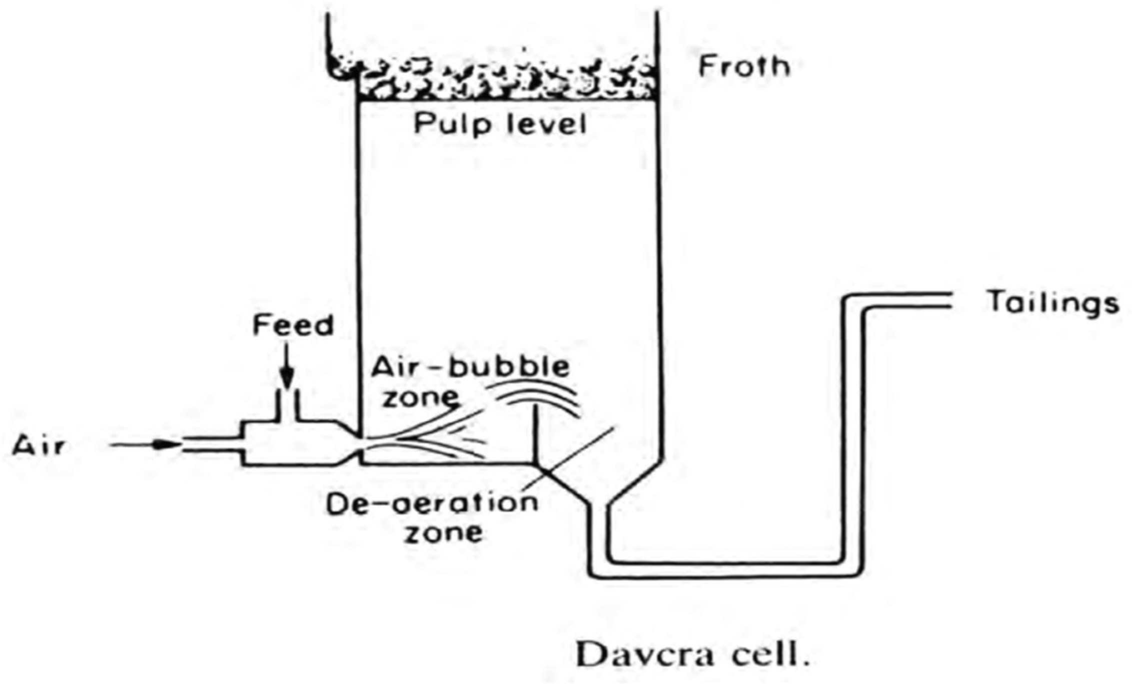


Fig.9.11. Davera Cell: Industrial Flotation Cell.

****

CHAPTER-9

9.0 Magnetic & Electrostatic Separators: -

- ✓ **Explain the principle of operation of magnetic & electrostatic separators.**

9.2 Describe the application of separators in mineral dressing.

Introduction: -

It is a fact that various metallic minerals exhibit magnetic properties. They are attracted by the magnet exhibiting specific attract ability. Basing on the degree of attract ability minerals can be classified as:-

1. Ferromagnetic.
2. Paramagnetic.
3. Diamagnetic.

1. Ferromagnetic Minerals:-

Few minerals such as magnetite and pyrrhotite are strongly attracted by magnets and behave as temporary magnets under the influence of magnetic fields. They are known as ferromagnetic minerals.

2. Paramagnetic Minerals:-

These are the minerals which are weakly attracted by the magnets. Minerals in this group are ilmenite, hematite, garnets etc.

3. Diamagnetic Minerals:-

Minerals such as quartz, calcite and many others are practically non magnetic or may even be diamagnetic minerals. These minerals are repelled by a magnetic field along the lines of forces to a point where the magnetic field intensity is much smaller. The magnetic nature of the minerals or ores can be exploited in an industrial sense to separate them into three different groups such as:

1. Highly magnetic.
2. Weakly magnetic.
3. Nonmagnetic or diamagnetic.

This method of separating minerals is broadly termed as magnetic separation. Magnetic separation has found largest application in concentrating ferromagnetic minerals particularly magnetite ores with less than 50% Fe to 70% Fe. It should be noted that subjecting the minerals to a magnetic field may result in magnetic concentration or separation.

- ✓ Magnetic concentration is the separation of valuable mineral from the gangue while magnetic separation is the separation of one mineral from another essentially based on the difference in the value of magnetic attract ability of the minerals.

Elements in Designing Magnetic Separators:-

The following facts are essential and to be considered during the designing of a magnetic separator:-

1. Production of a suitably converging magnetic field.
2. Easy regulation of magnetic field intensity.
3. Even feeding of ore particle as a stream or ribbon.
4. Controlling the passage speed of ore particles through the magnetic feed.
5. Avoidance of nonmagnetic materials within magnetic field as occlusion.
6. Suitable means to dispose the products.
7. Provision for production of a middling.
8. Elimination or reduction of moving parts to a minimum.

Types of Magnetic Separation:-

Depending on the magnitude of magnetic flux density, magnetic separation can be classified as follows:-

a. Low intensity magnetic separation.
b. High intensity magnetic separation.

A further subdivision within the group is possible depending on the medium in which separation is carried out. Depending on the medium of separation it classified as:
(i). Dry magnetic separation.
(ii). Wet magnetic separation.

*** Different Types of Magnetic Separators:-**

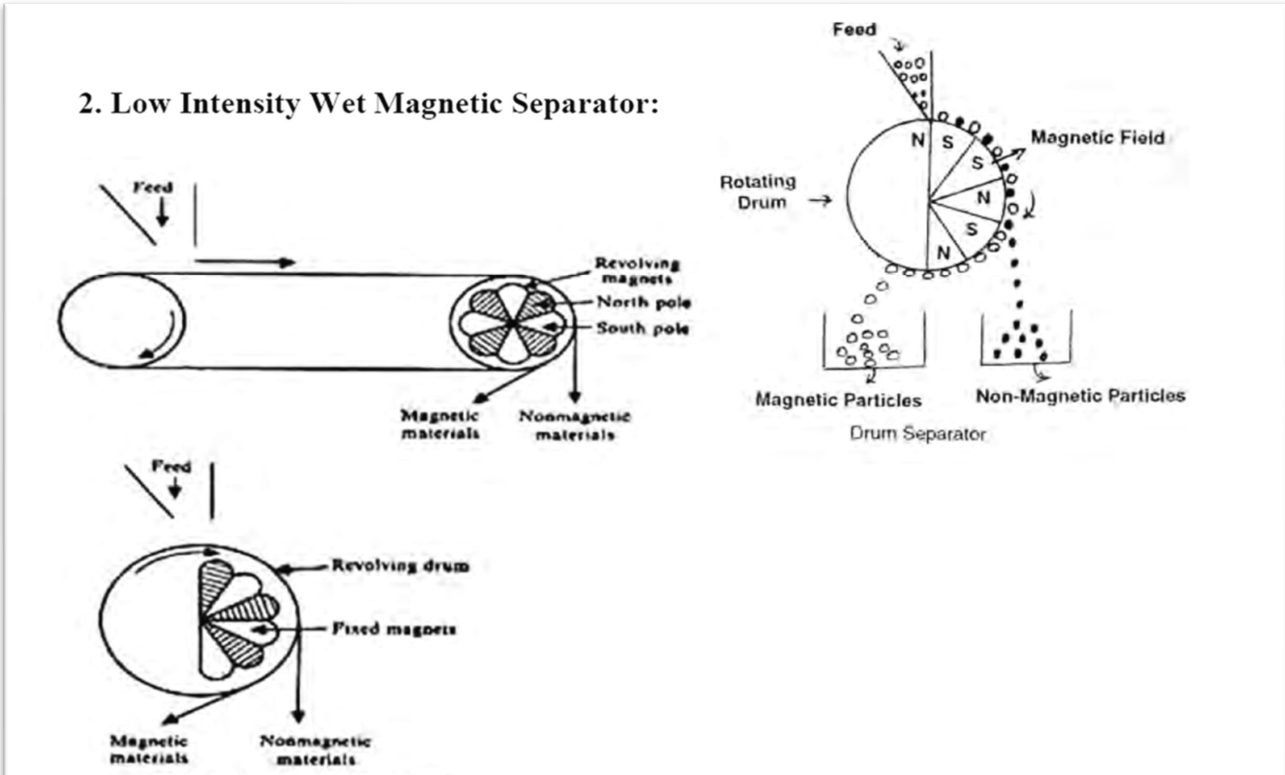
a. Low intensity dry magnetic separator.
b. Low Intensity Wet Magnetic Separator.
c. High Intensity Separators.

(a). Low intensity dry magnetic separator:-

This is type of separation is commonly applied to separate highly magnetic particles like magnetite, tramp iron from the non-metallics utilizing a low intensity magnetic flux. When ore is travel on an endless conveyor belt passing over a magnetic pulley, the non-magnetic particles follow a normal trajectory and are thrown clear but the magnetic particles are held firmly to the belt until it is carried out of the field and fall down when the belt just leaves the pulley.

(b). Low Intensity Wet Magnetic Separator :-

This is widely used today for concentrating of low-grade magnetite ore.
Wet type has the advantage of treating very fine ores almost in the slurry-form.
Fines are more readily-separated and higher grade product is obtained because water causes a better dispersion of particles and, presents the feed to the separator efficiently.



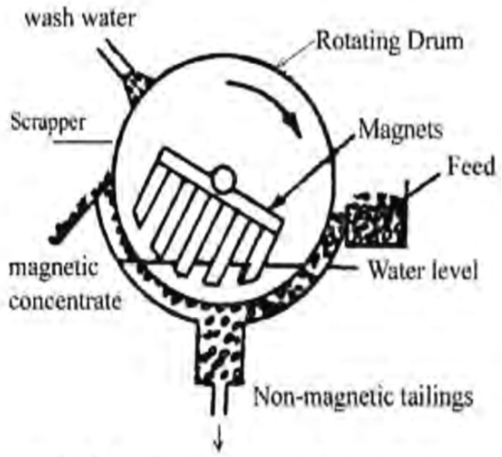
Dry magnetic separators.

⇒ * Edison Separator :-

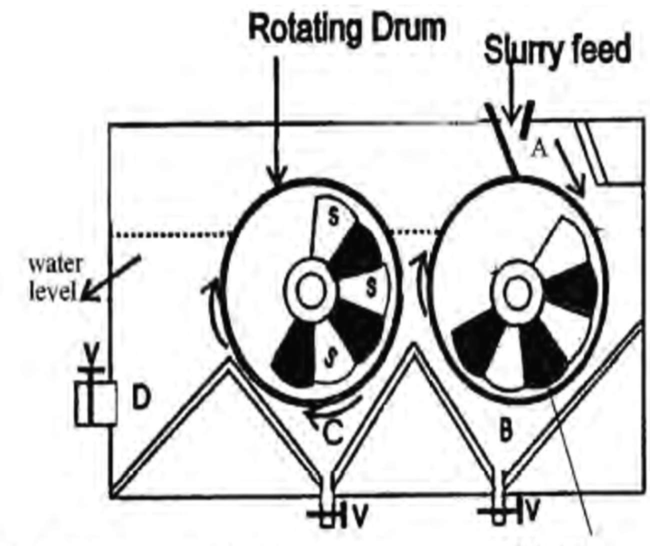
Reduced to one its elements, the Edison Separator Consists of a bar magnet. The ore as thin Streams falls in front of the poles, Susceptible being deflected inwards and nonsusceptible particles Continuing to fall, undeflected.

- **Ball-Norton drum separators :-**
  1. The Ball-Norton drum separators consist of one or two rotating drums of nonmagnetic metals. In the drum(s), a number of fixed magnets are arranged in such a fashion that consecutive poles are of opposite nature.
  2. Much of the magnetic field passes directly from one pole to the other inside the drum, and thereby get wasted. But enough flux lines come out of the drum to attract and hold the magnetic particles strongly.

3. The particles which are magnetic stick to the surface of the drum and travel along the periphery. They are finally removed-off from the drum surface by the help or a scrapper.
4. The non-magnetic particles just fall off at the edge of the drum during rotation as shown schematically in the figure.
5. In the two drum Ball-Norton machine the second drum revolves at a higher speed and has weaker magnets in side.
6. From the feed slurry, both highly magnetic and weakly magnetic particles get stuck to the surface of the drum in the first compartment while non-magnetic particles are removed as tailings at B.



Single Drum wet magnetic separator.



D is the concentrate, C is the middlings
B is the tailings.A is the feed,E are the fixed magnets,
V = the valves.

Fig. Two-Drum Ball-Norton wet magnetic separator.

(c) High Intensity Separators:-

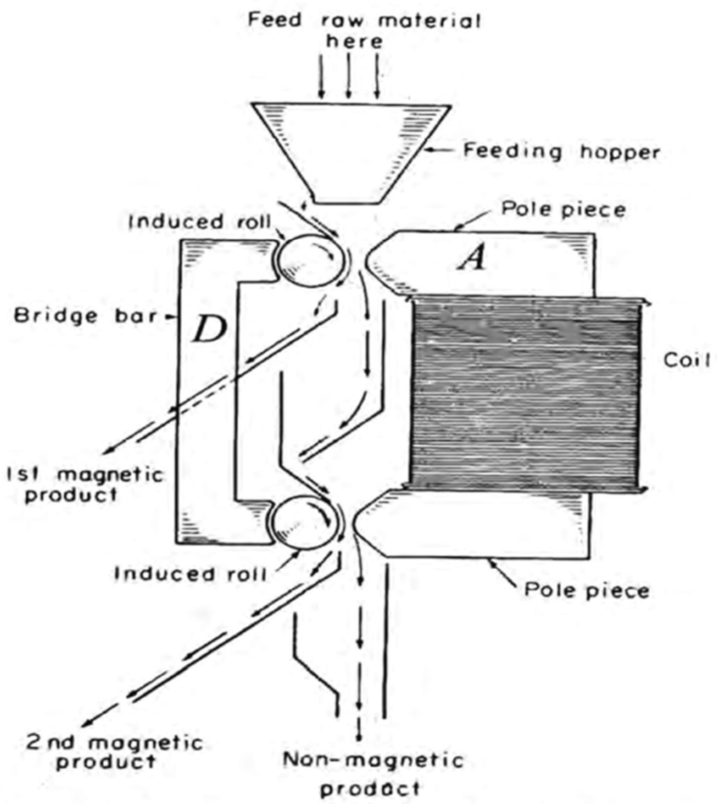
Very weakly paramagnetic materials can be separated from the ore by employing high intensity magnetic field of 2Tesla or more. The cross-belt pickup separator is a very popular separator of this kind. Further high intensity induced roll separators are widely used to treat beach sands, wolframite, tin ores and phosphate rock. *It is also known as Dings Induced Roll Separator.*

- **Dings Induced Roll Separator:-**

  The induced-roll Dings separator is shown schematically in the figure10.3 and mainly consists of:

  i. Horse-shoe magnet A.
  ii. An iron keeper D facing the magnet A.
  iii. Two rolls, one opposite each primary pole.

The separator is shown schematically in the figure103.



10.3. Ding's High Intensity Induced Roll Separator.

1. The magnetic circuit is thus completed inside iron excepting for very small clearances between the rolls and the iron keeper and also between the rolls and the poles.
2. The rolls are laminated to behave as a large assembly of secondary poles. The strength of those poles varies as the rolls revolve. It becomes zero twice per revolution.
3. As the ore particles pass over a roll, the magnetic particles are drawn onto the laminated roll and they fall down' only when they are at a position where the magnetic strength of the adjoining secondary pole is zero.
4. This means magnetic particles continue to move along the roll surface to a greater distance compared to non-magnetic particles & fall off much later. So the feed is separated into two fractions as it passes through the rolls.
5. For proper working of Dings separator closely sized feed is required and it operates best on materials above 75microns. The effectiveness of the separation on fine materials is severely reduced by the effects of air currents, particle-particle adhesion and particle-rotor adhesion.
6. This is applicable and most suitable for separating granular coarse materials of medium to low susceptibility. This is successfully used on materials like mica & MnO_2. [magnesium dioxide]

7. This has removed the constraint of particle size of the dry separation. The effectiveness of the separation is enhanced as finer grinding is possible leading to maximum liberation of the magnetic fraction.

Applications of Magnetic Separation:-

1. For removal of tramp iron in coarse and intermediate crushing circuits as a protection to the crushing machineries.
2. To concentrate magnetite ore.
3. To concentrate ores other than magnetite after converting iron ores to magnetite by magnetic roasting.
4. To remove small quantities of iron or iron minerals from the ceramic raw Materials.

ELECTROSTATIC SEPARATION:-

Electrostatic separation is a method of concentrating or separating minerals from each other 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 charges attract. It was first used to separate zinc ore from lead sulphide ore. However, it was abandoned after introduction of froth flotation. But recently it has got a new lease of life for separating non-metallic. Electrical concentration can be broadly classified into:-

1.Electrostatic separation.
2.High tension separation.

- **PRINCIPLE OF ELECTROSTATIC SEPARATION :-**

It works on the principle of mutual attraction of unlike charges and mutual repulsion of like charges (Coulomb's law). On the basis of electrostatic charge, a body is said to be positively 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:-

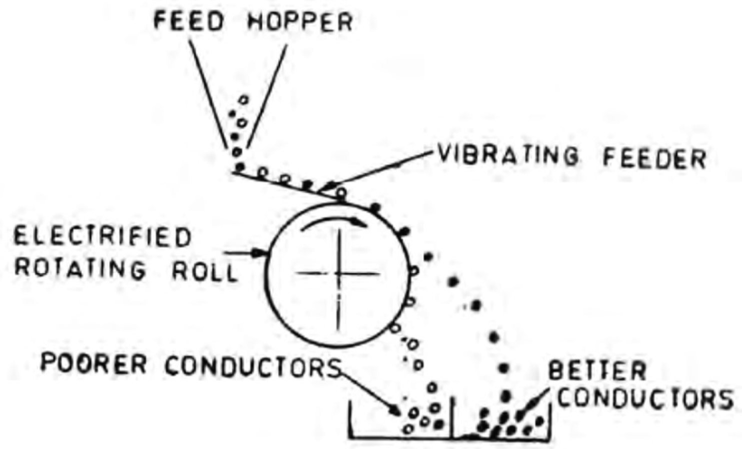
a. Conductor: When electrons are highly mobile in them (Metals).
b. Insulators: No mobility of electrons in them (plastics, rubber).
c. Semi-conductor: Higher mobility of electrons in them as compared to insulators but much less conductivity compared to conductors.

Electron mobility increases in all materials when they are placed inside an electrical field. Almost all the metallic ores and minerals gain electron mobility and develop excess electrical 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. Poor conductors.

(1) ELECTROSTATIC SEPARATOR SETUP: -

1. In electrostatic separation the feed material is brought near a revolving roll which is either permanently electrified or electrified by means of induction.
2. 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.
3. 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.
4. 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.

2. HIGH TENSION ELECTROSTATIC SEPARATION:-

1. Similar to high tension magnetic separation, there is also a high-tension electrostatic separation. During this separation the material grains are charged up electrically due to ion bombardment on them along with the induction from the electrified drum.
2. Ions are produced in the air gap between the electrically charged wire and the grounded electrified roll due to very high potential difference of few thousand volts maintained between them. The air around the wire becomes ionized and is attracted toward the grounded roll to discharge its ions.
3. Usually a potential difference of 30kV and above is applied to the wire electrode to make a corona discharge.
4. The wire electrode is also known as corona electrode. If the voltage difference is sufficiently high the ionized corona is visible as a luminous discharge.

5. On entering into the electric field, the conducting mineral particles are bombarded with gaseous ions and get charged negatively and thus get deflected away from the ground roll.
6. The non-conducting particles are not deflected and have a free fall as it happens in case of usual electrostatic separator. The working principle of high-tension separator is shown schematically in the figure 10.5.

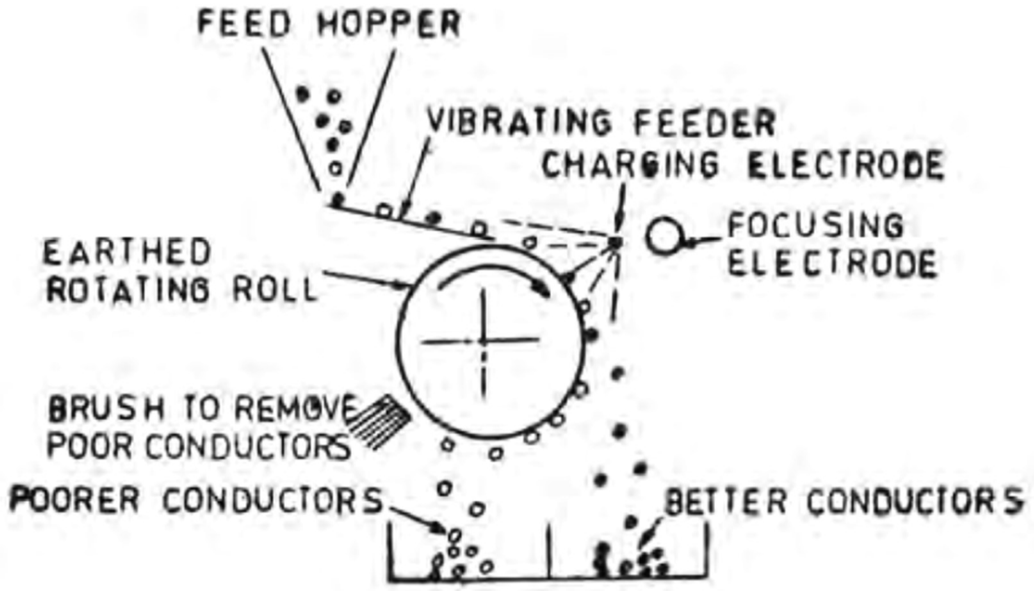


Fig.10.5. High Tension Electrostatic Separator.

7. The dry mineral grains are fed as a layer of one particle deep onto the electrified roll with the help of a vibrating and get separated as per the principle discussed earlier. High tension electrostatic separator is also known as Huff's separator.

➢ **Requirements for the Proper Working of an Electrostatic Separator:-**

1. For electrostatic separation, feed materials must be dried prior to separation.
2. For effective separation dry minerals grains are to be fed as a layer of one particle deep at the top of the rotating electrified roll. This is achieved by using a vibrating feeder.
3. For effective high-tension separation, feed must be closely sized in the range of 1.0 - 0.1 mm free from fines. Quite often the feed material the feed material is to be heated above room temperature for effective separation.

Uses electrostatic separator: -

1. It is employed to separate conducting ores and minerals from non-conducting materials in ceramic industries.

2. This is applied for beneficiating rutile beach sands from non-conducting silica sand in rare earth plants.

MISELLANOUS OF CHAPTER-9 : -

⇒ * Magnetite Ores :-

The principal ~~ais~~ aims in the Concentration of Magnetite ores are to increase the iron Content of the Concentrate and to reduce the sulphur and the phosphorus. Sulphur is usually present as pyrite and chalcopyrite, phosphorus as satite. Almost any degree of perfection of Separation is possible, Provided the liberation is adequate, because of the enormous Spread in magnetic properties of the magnetite on the one hand, and all the other minerals on the other. Accordingly, it is often preferable to make a poor Separation by Concentrating with dry cobbers at a Coarse size than to make a much better Separation by Concentrating with wet Separators at a fine size. From ore Containing 30 to 45 per cent magnetic iron, a Concentrate with 60 to 68 per cent magnetic iron and tailing with 1 to 4% magnetic iron can usually be obtained. ~~St~~ In that case, Concentration of the magnetic tailing by flotation or by gravity and flotation may have interesting possibilities.

⇒ * Other Iron Ores :-

Siderite, hematite, goethite, and limonite are usually Considered nonferromagnetic. By Controlled oxidizing ~~ros~~ roasting in the case of siderite or Controlled reducing ~~ros~~ roasting in the case of hematite, goethite, or limonite, the irron mineral is Converted into magnetite pseudomorphic after the parent

Mineral. According to the best figures, the Cost of roasting hematite ores is of the order of magnitude of 65 Cts. Per ton of feed, of which some 35% is for fuel. Artifical magnetite has as high a Permeability as natural Magnetite. In magnetic Separators; it responds therefore just as readily as natural magnetite. But artificial magnetite has a high Coercive force. It in a d-c Separator; on the other hand, artificial magnetite works well in an a-c Separator, whereas natural magnetite does not. Artificial magnetite has also one advantage over natural magnetite, It is porous and reduction in the blast furnace is more rapid. This is an expensive procedure which it is desirable to avoid if at all possible.

Ceramic Raw Materials :-

For the glass or Porcelain industry, Purity of Color of the product has definite commercial value. Iron discolors Ceramic products and must be reduced to a small fraction of one per cent (1%) if quality is to be attained. Metallic iron is usually removed by low intensity wet separators after the grinding or crushing of the raw materials. Iron minerals such as biotite and hematite ar usually removed by high-intensity Separators ~~operation~~ operating on dry, sized feed.

* Concentration of Weakly Paramagnetic Minerals :- (47)

These minerals usually have a Spei Specific gravity appreciably higher than the common gangue minerals viz, quartz, calcite, dolomite, and silicates low in iron content. As a result, magnetic concentration of weakly paramagnetic minerals is usually applied not to the ore but to gravity concentrates. There are of course exceptions, as in the concentration of manganese oxides in which the unconcentrated but sized and dedusted ore is treated directly in magnetic separators and in the concentration of the zinc ores from Franklin furnace N.J.

Typical applications include the following; Separation of cassiterite from tungsten minerals of monazite from rutile and gr garnets, of garnet from hornblende, of chormite from silicates, and the elimination of magnetic minerals from corundum, barite, or other concentrates. For these purposes, however, magnetic separation has been supplanted by flotation.

****