

LECTURE NOTE
On
Mineral Processing

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Mineral Dressing

Mineral dressing → According to Gaudin, it is the processing of raw materials to yield marketable products and waste by means that don't destroy the physical and chemical identity of the minerals.

According to Taggart, mineral dressing is the sum total treatments to which minerals are subjected in order to separate and discard their worthless fractions by essentially physical and chemical means.

Ore dressing is mineral dressing applied to ores. Ore dressing operations remove substantial proportions of the gangue and thus upgrade the raw material.

Properties of minerals essential for mineral dressing →

Properties of minerals exploited	Process	Description
1. Brittleness	<u>comminution</u> (i) Crushing Crushing (ii) Grinding <u>Sizing</u> (i) Sorting or hand-picking (ii) Screening <u>Hydraulic classification</u>	Subdivision of mineral lumps and particles into smaller sizes. separation according to size
2. Size difference among particles		Settling in fluid
3. Relative difference in size and density among mineral particles.		Settling in fluid.
4. Relative difference in density among particles	<u>Concentrations</u> (i) Heavy media separation (ii) Jigging <u>Tabling</u>	Frictional movement along wet vibrating solid surface
5. Density, size, shape and coefficient of friction		Separation due to magnetic field in dry or wet condition.
6. Magnetic properties	<u>Magnetic separation</u>	Separation due to electric field.
7. Electrical conductivity	<u>Electrostatic separation</u>	Attachment of gas bubbles to mineral in aqueous pulp.
8. Surface properties	<u>Flootation</u>	
9. Non-specific properties	De-watering, Filtration, drying etc.	

Scope and Objectives of mineral dressing:-

In general, the scope of mineral dressing is two fold:

- (1) To eliminate unwanted chemical species from the bulk of the ore.
 - (a) Liberation of dissimilar particles from each other appearing in the bulk ore.
 - (b) Separation of chemically dissimilar particles
- (2) To eliminate particles of unsuitable size and structure, i.e. production of the ore particles of specific size range.
 - (a) reduction in size
 - (b) separation of particles of dissimilar physical nature.

Thus ore beneficiation involves size reduction or liberation as first step and Separation as Second step.

Advantages of mineral dressing →

- (1) To upgrade lean ores to rich ores.
- (2) Inexpensive as compared to hydrometallurgical, pyrometallurgical and electro-metallurgical operations.
- (3) Transportation charges are reduced substantially after mineral dressing (savings in freight)
- (4) Reduced losses of metal at the smelter - because of reduction in amount of metal bearing slag produced at the smelter.
- (5) reduction in total smelting cost - because of reduction in tonnage to be smelted.

Disadvantages of mineral dressing: →

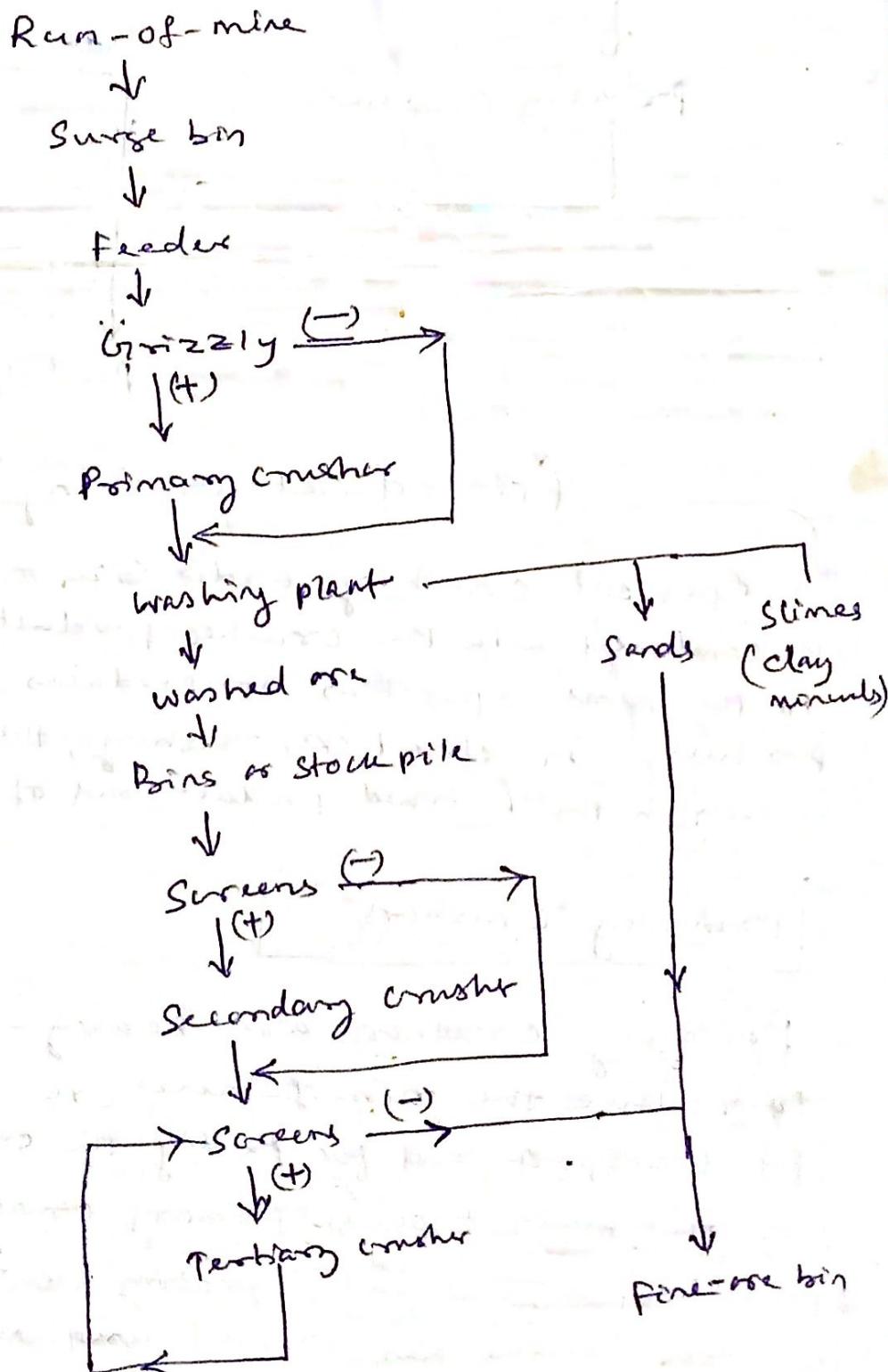
- (1) Losses incurred in dressing the ore.
- (2) Cost of the dressing operation.

Operating steps in ore dressing: →

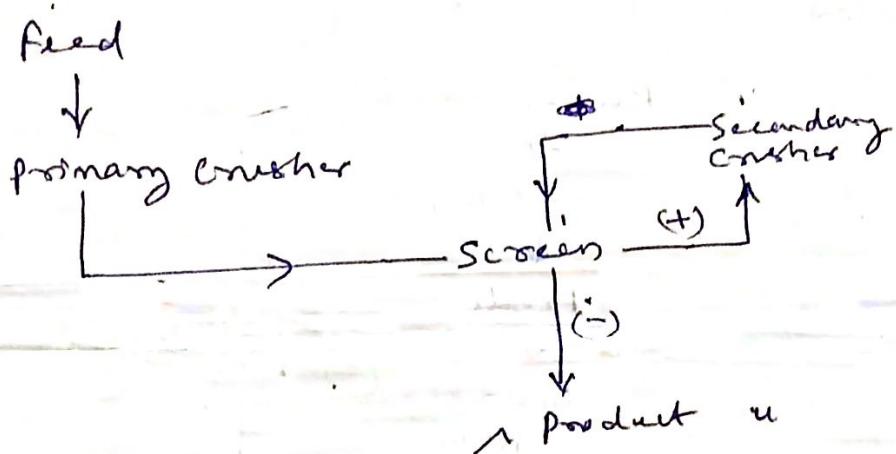
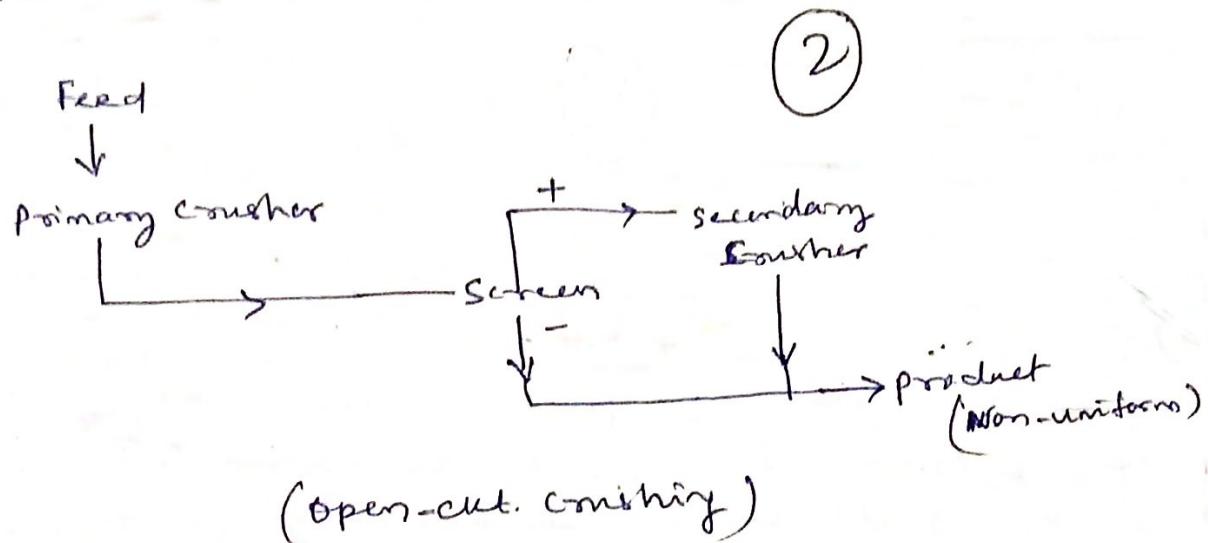
The four principal operations are

- (1) Comminution:— Comminution means reduction to a smaller size. Depending upon the size of the material to be comminuted, the operation is regarded as crushing or grinding. Crushing is almost always conducted on dry ore and grinding may be wet or dry.

Crushing - Crushing is the first mechanical stage in the process of comminution in which the main objective is the liberation of valuable minerals from the gangue. Generally it is a dry operation. A basic flow sheet for a crushing plant is shown below:



Crushing may be open or closed circuit depending on the product size.



(closed-circ. crushing)

In open-circ. crushing, under size material from the screen is combined with the crusher product and is then sorted to feed next operation. It produces non-uniform sized product. In closed circ. crushing, the undersize from the screen is the finished product and of uniform sized product.

Primary crushers

Primary crushers are heavy-duty machines, used to reduce the run-of-mine ore down to a size suitable for transport and for feeding the secondary crushers. There are two main types of primary crusher in metalliferous operations - Jaw and Gyrotatory crushers, although the roll crusher has limited use and considered as third one.

Jaw crushers -

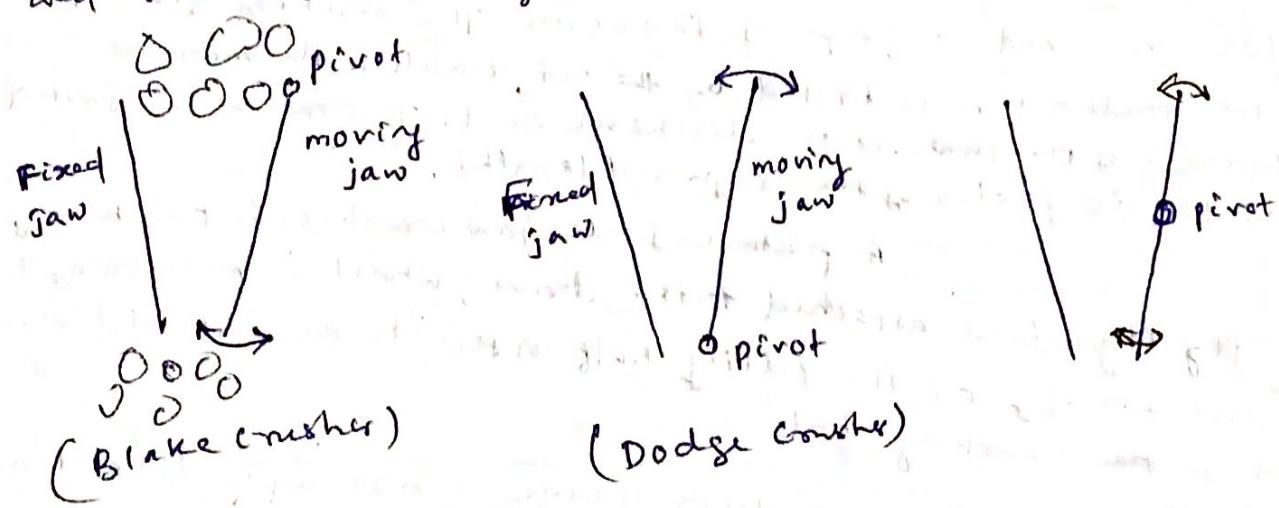
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The distinctive feature of this type of crusher is the two plates which open and shut like animal jaws. The jaws are set at an acute angle to each other and one jaw is pivoted so that it swings relative to the other fixed jaw. Material fed into the jaws is alternately gripped and released to fall into the crushing chamber. Eventually it falls from the discharge aperture.

Jaw crushers are classified by the method of pivoting the moving jaw.

In the Blake jaw crusher, the jaw is pivoted at the top and thus has a fixed receiving opening and a variable discharge opening. In the Dodge crusher, the jaw is pivoted at the bottom, giving a variable receiving opening and fixed discharge opening. The Dodge crusher is restricted to laboratory use, where a close setting is required, and is never used for heavy-duty crushing as it chokes very easily.

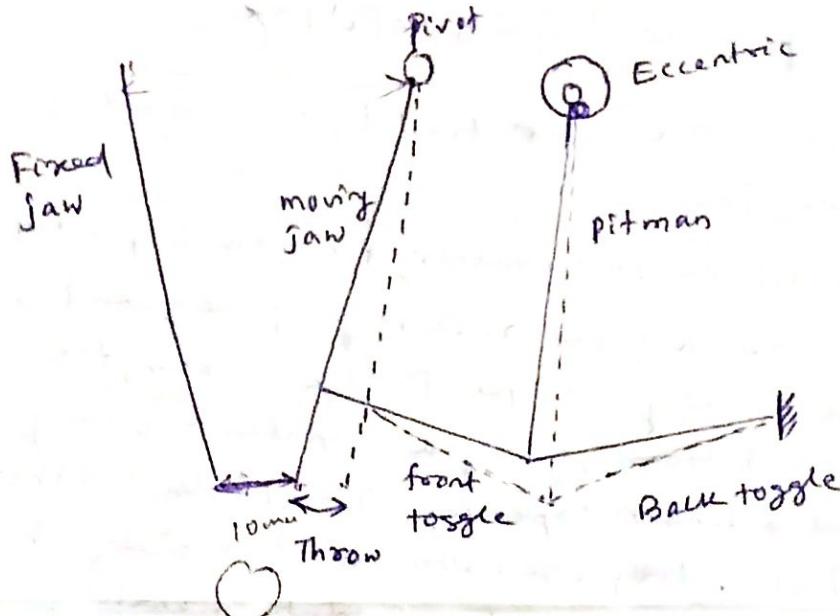
The Universal crusher is pivoted in an intermediate position and thus has a variable receiving and discharge opening.



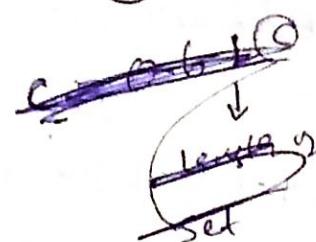
There are two forms of the Blake crusher - double toggle and single toggle.

In double toggle Blake crusher, the oscillating movement of the moving jaw is effected by vertical movement of the pitman. This moves up and down under

the influence of the eccentric. The back toggle plate causes the pitman to move sideways as it is pushed upward. This motion is transferred to the front toggle plate and this in turn causes the moving jaw to close on the fixed jaw. Similarly, downward movement of the pitman allows the moving jaw to open.



(4)



All jaw crushers are rated according to their receiving opening area, i.e. the width of plates and the gape, which is the distance between the jaws at the feed opening. For example, an 1830 x 1220 mm crusher has a width of 1830 mm and a gape of 1220 mm. The discharge size of the material is controlled by the set, which is the maximum opening of the jaws at the discharge end. This can be adjusted by toggle plates of the required lengths.

A feature of all jaw crushers is the heavy flywheel attached to the drive, which is necessary to store energy on the idling half of the stroke and deliver it on the crushing half.

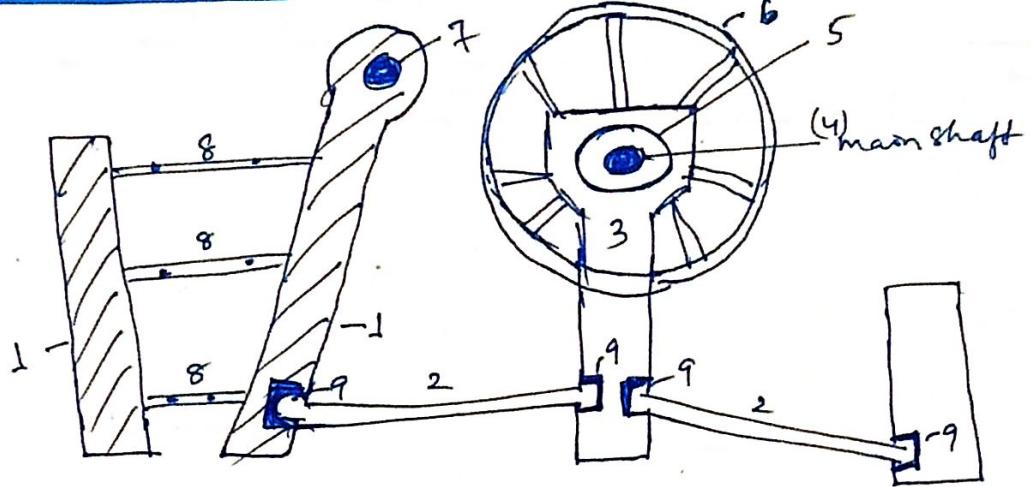
Jaw crushers range in size up to 1680 mm gape by 2130 mm width. This machine will handle ore with a maximum size of 1.22 meter at a crushing rate of approximately 725 t/hr with a 203 mm set.

CRUSHERS

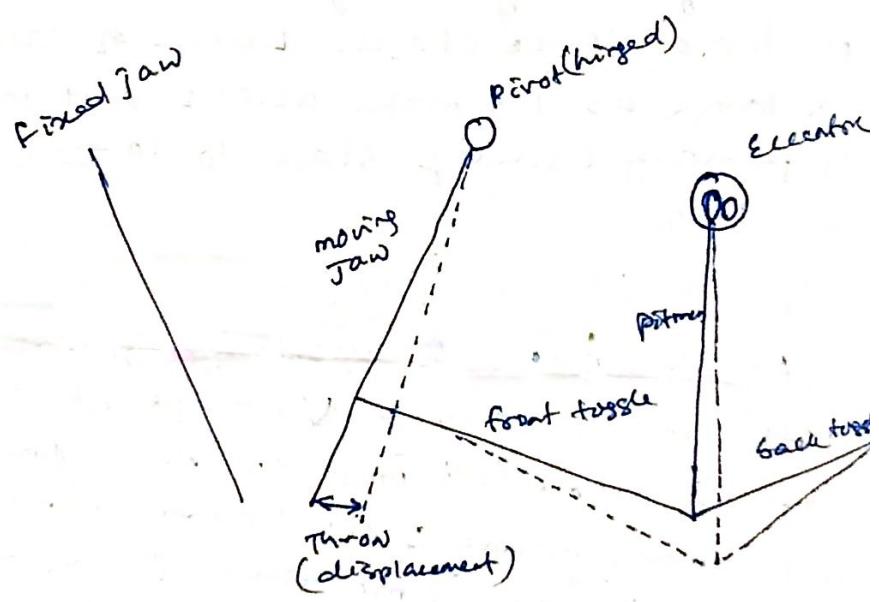
Crushing is the first mechanical stage in the process of comminution in which the main objective is the liberation of valuable minerals from the gangue. It is generally a dry operation and is usually performed in two or three stages. Lumps of run-of-mine ore can be as large as 1.5 meter across. and these are reduced in primary crushing stage to 10-20 cm in heavy duty machines.

① Blake Jaw crusher

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 jaws. One of the jaws is fixed to the main frame of the crusher almost vertically while the other ~~is~~ one is movable. The movable jaw reciprocates in a horizontal plane and makes an angle of 20-30° with the stationary jaw. and is driven by an eccentric so as to that applying a great compressive force on the ore to that caught between the jaws. The movable jaw of the Blake crusher is pivoted at the top so that maximum displacement is at the bottom while the top end opening is almost constant. On the jaws, replaceable ~~wearing~~ crushing faces ~~are~~ are ~~not~~ fixed by nut and bolt arrangement. The crushing faces are made from Hadfield manganese steel. The initially large lump is caught at the top and is broken, the broken fragments drop to the narrower bottom space and is again ~~again~~ again recrushed when the jaws close in next time. This action continues until the feed comes out at the bottom.



1. Jaw plates 3. Pitman 5. Eccentric
 2. Toggles 4. main shaft 6. Fly wheel
 7. Top hinge
 8. check plates
 9. bearings



(functional diagram)

In this machine an eccentric drives the pitman. The circular motion of the main shaft is converted to up and down motion of the pitman and finally the up and down motion ($\uparrow\downarrow$) is converted to to and fro motion (\leftrightarrow) with the help of two toggles. One of the toggles is fixed to the main frame and pitman and the other toggle is fixed to moving jaw and pitman.

The other important component of the Blake jaw crusher is the flywheel which is fitted on to the main shaft. The use of flywheel is quite important from the design point of view. As crushing action is only possible during the forward stroke of the jaws, ~~an~~ intermittent load works on the machine. To equalize this uneven load, flywheels are required on the main shaft.

Characteristics of Jaw crushers

1. Jaw crushers are usually intended for primary crushers.
2. They have relatively large gape (width of the receiving opening) and the length of the receiving opening is somewhat greater than its width.
3. All jaw crushers have an adjustable discharge ~~opening~~^{opening (set)} to produce different sized products.
4. The ratio of the maximum size of the particle in the feed to that of the product or the ratio of the average size of the particle in the feed to that of the product is known as reduction ratio. It varies from 4 to 30. In modern trends, it has to find a greater reduction ratio.
5. The capacity of jaw crushers are very high. Capacity of jaw crushers have been found by using Taggart's empirical formula

$$T = 0.6 LS \text{ tons/hr.}$$

Where T = capacity in tons/hr

L = Length of the receiving opening, in inches.

S = width of the discharge opening, in inches.

For small crushers, the capacity is high and vice-versa.

Comparison between Blake type Jaw crusher and Dodge Type Jaw crusher :-

Blake Jaw crusher

1. It is made in larger sizes.
2. It has one fixed and one movable Jaw.
3. The movable jaw is pivoted at the top.
4. The greatest amplitude of motion is at the bottom.
5. The width of discharge opening vary according to the motion.
6. Non-uniform size of product is obtained.
7. Mechanical advantages are more satisfactory.
8. It has two toggles.
9. It has one pitman.
10. The machine is heavier.
11. One or two flywheels are provided.
12. It is driven either flat or v-type belts.
13. power requirement is more.
14. The m/c is stronger.
15. Energy consumption is more.

Dodge Jaw crusher

1. Made in smaller sizes.
2. It has one fixed and one movable jaw.
3. It is pivoted at the bottom.
4. The greatest amplitude of motion is at the top.
5. The width of discharge opening is practically constant.
6. Closely uniform sized product is obtained.
7. Less satisfactory.
8. It has one toggle.
9. It has no pitman.
10. Lighter.
11. These are also provided.
12. It is driven either flat or v-type belts.
13. Less.
14. The m/c is weaker.
15. Less.

Bond's Law - The amount of work required is inversely proportional to the square root of the product diameter.

$$W \propto \frac{1}{\sqrt{D_p}} \quad \frac{E}{M} = K_b \frac{1}{\sqrt{D_p}}$$

2) Kick's Law - It can be stated as "the work required for crushing a given quantity of material is constant for a given reduction ratio irrespective of original size". Mathematically, this can be expressed as

$$\frac{E}{M} = K_k \ln \left(\frac{D_F}{D_p} \right)$$

Where E = energy required for crushing M kg of material

K_k = Kick's constant

$$\left(\frac{D_F}{D_p} \right) = R \quad (\text{reduction ratio})$$

D_F = feed diameter [6x]
 D_p = product diameter [size]

(Comminution energy depends only on the reduction ratio and independent of the original size of the feed
 E_{Fp} - energy required for reducing a 200 mm particle to 50 mm size will be the same as for reducing a 2 mm particle to 0.5 mm.

3) Rittinger's law - It states that "the work/energy required for size reduction is directly proportional to the new surface area created." Mathematically,

$$\frac{E}{M} = K_R (S_p - S_F)$$

~~S_p & S_F - new surface~~

Where S_p, S_F = specific surfaces of product and feed respectively.

K_R = Rittinger's constant.

$S_p - S_F$ = new surface created

Gyratory Crushers

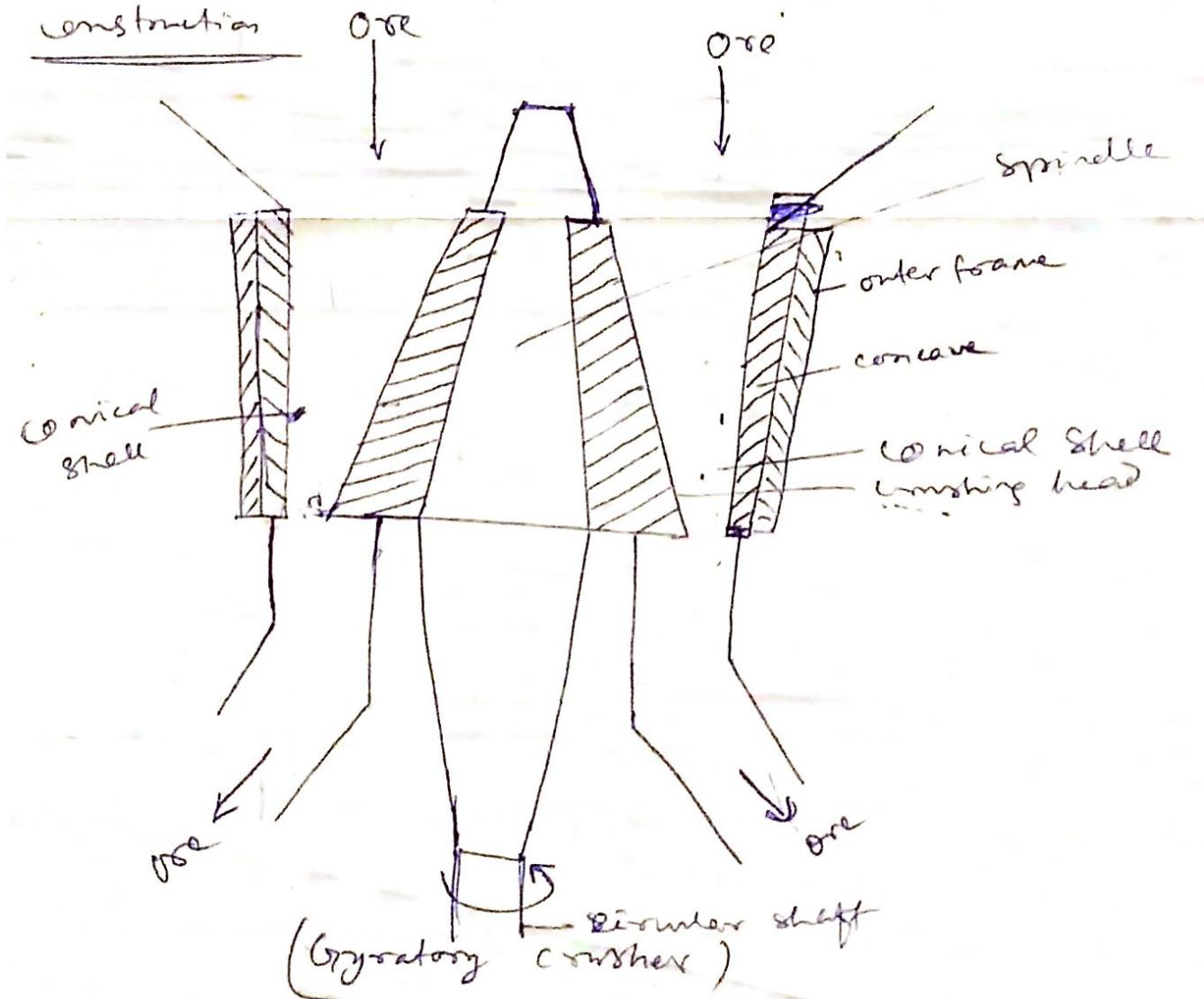
(9) 6

These are developed more recently course.

These crushers are intended to for size reduction of large and are of greater capacity than jaw crushers. The crushing action of gyratories is similar to the action of jaw crushers in that the moving crushing element approaches to and recedes from a fixed crushing plate. The gyratory crushers have a gape of 7 $\frac{1}{2}$ inch and weigh about 700 tons.

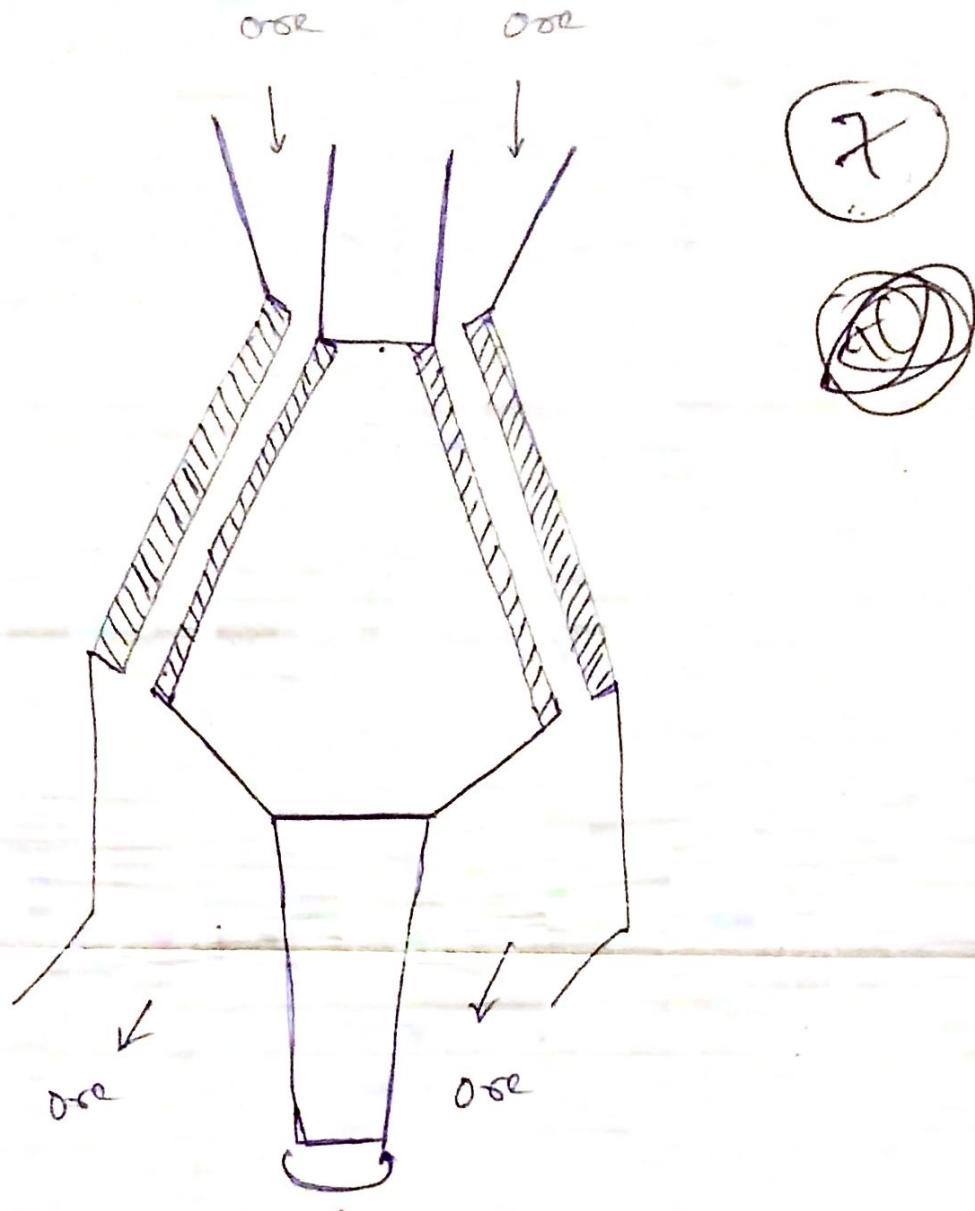
The capacity of gyratory crushers is much greater than that of jaw crushers.

construction



A gyratory crusher consists of two vertical conical shells, the outer shell having its apex pointing down and the inner shell having its apex

pointing up. The outer shell is stationary and the inner shell is made to gyrate / rotate



Characteristics of gyratory crushers

- ① These are intended for coarsest crushing.
- ② The capacity of gyratory crushers is much greater than that of jaw crushers handling the same size of feed.
- ③ It has more regular power draft. (because of continuous crushing)
- ④ The reduction ratio of gyratory crushers is comparable with jaw crushers.
- (5) ~~If~~ quantity of ore to be crushed is large, then gyratory crusher is used.

The conical crushing head is supported on a spindle which hangs from a suitable bearing in the upper portion of the machine. The lower end of the spindle is a conular shaft, free to rotate in an eccentric sleeve. The crushing spindle is free to rotate, but as soon as feeding of the machine starts, rotation ceases.

~~(A)~~ Q,

Grinding | Fine crushing

(1)

Grinding is the last stage in the process of comminution. Any comminution process aiming at a product size ~~below~~ ^{below} 6 mm is known as grinding. Crushing reduces the size of the product to 6 mm, and below that size grinding is required.

Grinding is a slower process and usually carried out in a ball mill or any other equipment, like tube mill, rod mill, etc. These mills are closed chambers containing hard balls, ~~sheets~~, ^{beads, rods}, ~~pebbles~~, as grinding media respectively. It differs from crushing by the following points:

- (i) Grinding is related to fine materials.,
- (ii) It is a slower process
- (iii) The disintegration of particles is mainly due to impact, attrition and inter particle collision among the particles.

Depending upon the condition of the grinding, it is of two types.

(a) Wet grinding — When chemicals such as amines, ketones, fatty acids, alcoholic acids, water etc are employed at the time of grinding such that a better amount of product is obtained, it is called as wet grinding, otherwise it is called dry grinding.

Adv. of wet grinding —

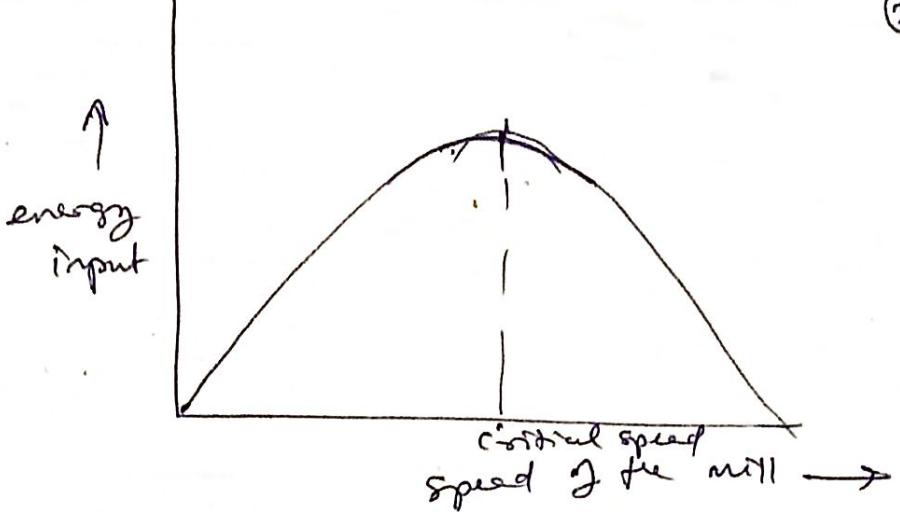
(i) Power consumption is lesser in wet grinding

(ii) Dust can be easily suppressed in case of wet grinding

(iii) 75-80% of the critical speed can be obtained which give the maximum amount of ground product where as in dry grinding it is 60-65%.

(iv) Fine production is less.

Critical speed — It is the speed of the mill beyond which energy ~~consumed~~ input decreases rapidly to zero and the solids are centrifuged on the mill shell and there is no work done by the mill.



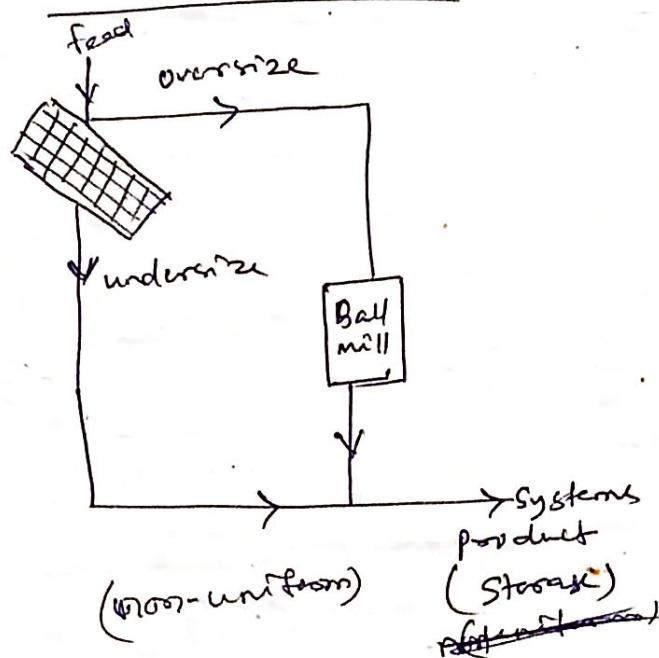
Disadv. of wet grinding

- (i) cleaning of the mill is difficult
- (ii) it is not preferred for short time operation
- (iii) Drying is a very costlier costlier process
- (iv) wear and tear of the machine is more

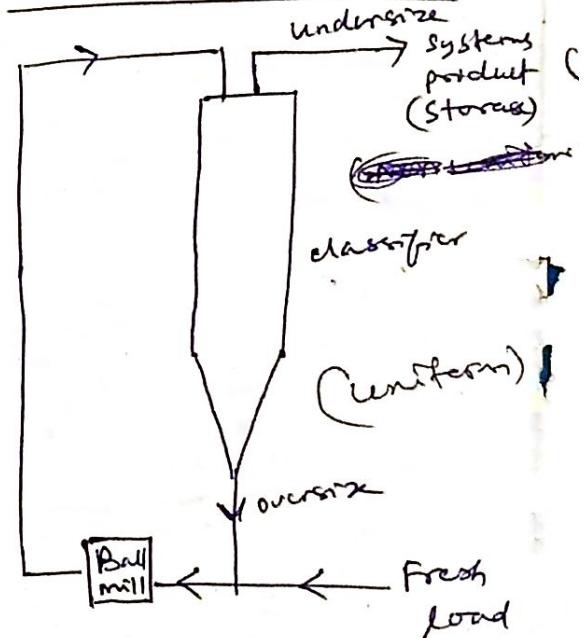
Depending upon the size of the product to be produced, grinding may be classified as

- (i) open ckt. grinding
- (ii) closed ckt. grinding.

(i) open ckt. grinding



(ii) closed ckt. grinding



1) As screening is done before grinding, non-uniform size of product is obtained.

2) The load to the mill is only the oversized material

1) As classification is done after grinding, uniform size of product is obtained.

2) The load to the mill is fresh load plus oversized material

Grinding equipment

(3)

Grinding is carried out in the following mills

(1) Arrestors — primitive mill used largely in Mexico.

(2) Chilean mills — were used extremely for secondary size reduction

(3) Raymond Bowl mills

(4) Ball mills ↗ cylindrical ball mills
cylinders conical Ball mills (Hardinge mill)

(5) Rod mills

(6) Tube mills

(7) Had set mills

(8) Compound ball mills.

Feeding Systems in comminution equipments

There are two methods of feeding material to a crusher

(1) Free Feeding.

(2) Choke feeding.

(1) free feeding (free crushing)

This involves feeding of material at a comparatively low rate so that the product can be easily escape out of the machine. The time of residence of the material in the machine is short and producing appreciable quantity of undersized (fines) is avoided. This reduces the chances of clogging of the machine.
The reverse of this is choke feeding.

WRITING SPACE

Grinding Equipment

Grinding is carried out by the following mills

1. Arrastres - primitive mills used largest in Mexico.
2. Chilean mills - were used extensively for secondary size reduction.
3. Raymond Bowl mills.
4. Ball mills ✓
5. Rod mills ✓
6. Tube mills ✓
7. Hadgel mills.
8. compound ball mills

1. Ball mills

Ball mills are horizontal rotating cylindrical or cylindro-conical steel chambers, approximately slightly more than half full of cast iron or cast steel or steel balls of various or uniform sizes. These cast iron or steel balls are used as for grinding medium. The size reduction is accomplished by the (i) impact of these balls as they fall back after being lifted by the rotating chamber, (ii) rubbing among rolling balls (iii) collisions among the ore particles (iv) frictional forces at the lining of the mill. The length of the cylinder is about equal to the diameter. Most ball mills are continuous in operation however laboratory ball mills are either intermittent or continuous. They may be operated dry or wet.

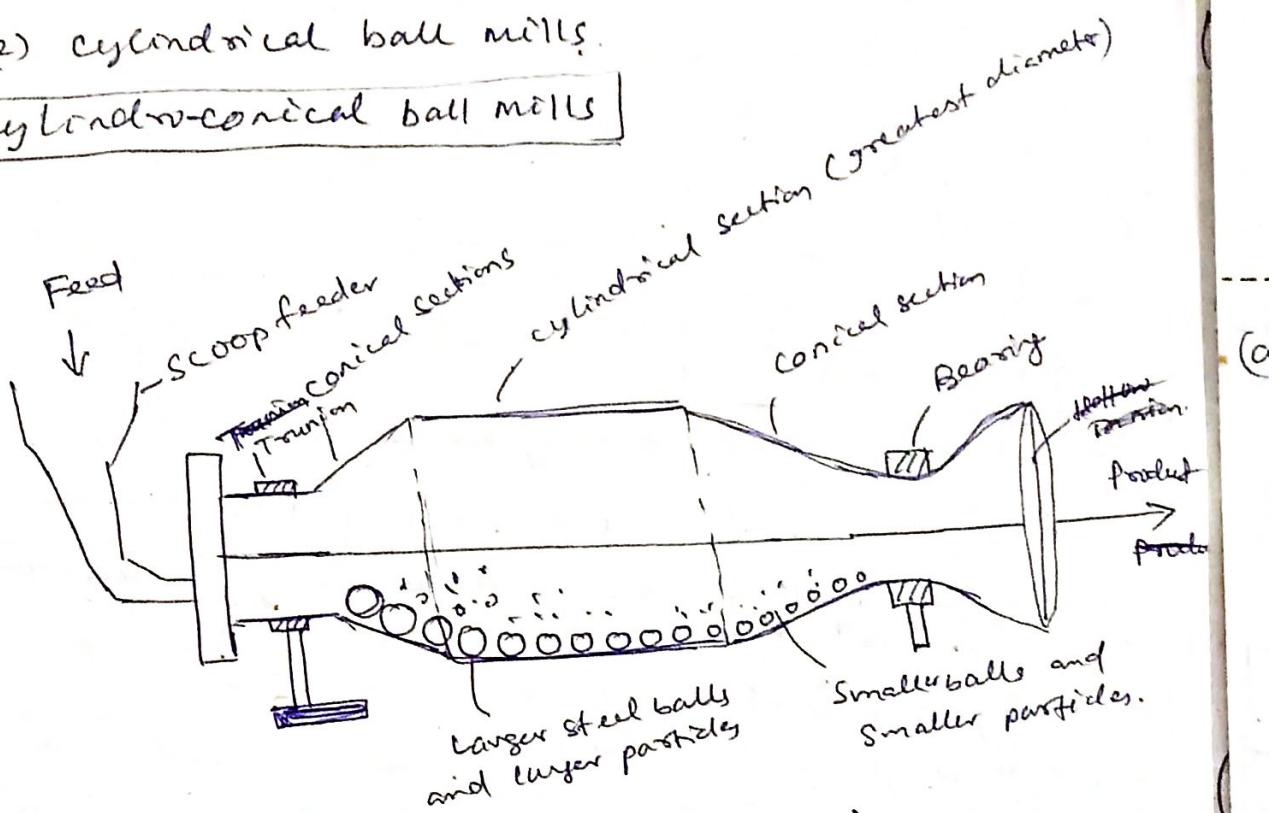
Classification Depending upon the shape of the mill, the method of discharging the ground product, whether grinding is conducted dry or wet, ball mills

are classified into mainly two types:

(1) cylindro-conical ball mills

(2) cylindrical ball mills.

(1) cylindro-conical ball mills



(Hardinge Ball mill).

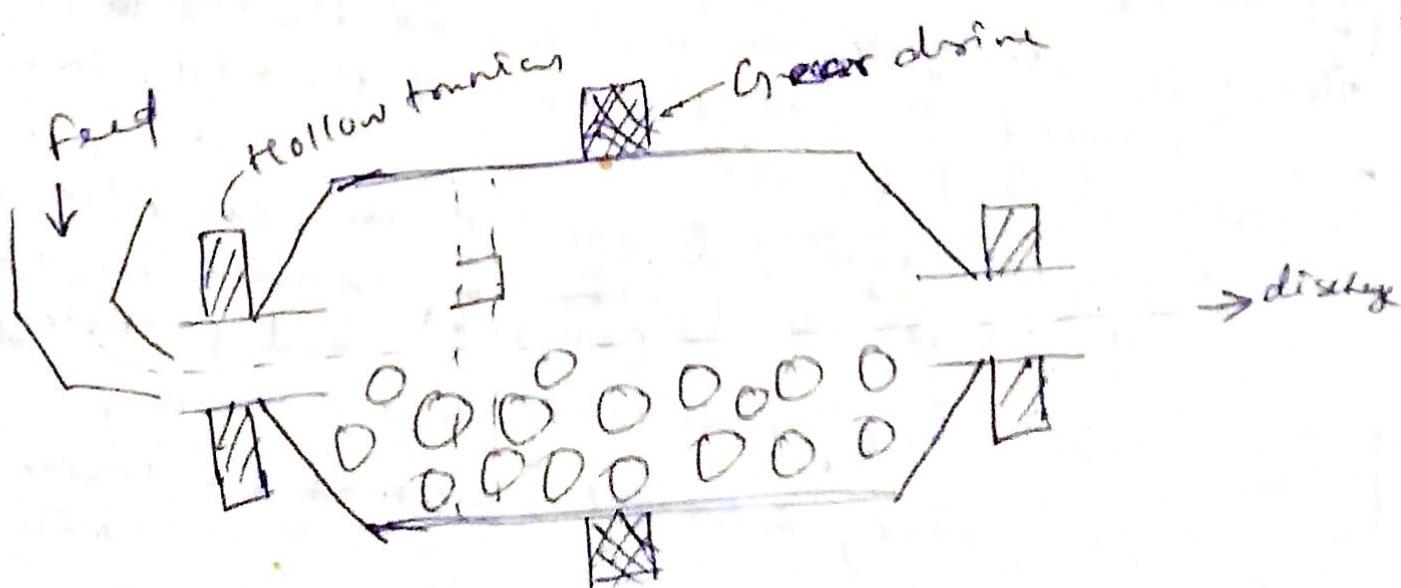
The hardinge mill is typical of cylindroconical ball mill. It consists of two conical sections connected by a short cylindrical section, supported by end bearings on which hollow tournions revolve. Feed is taken in through a feeder located one of the tournions and the ground product is discharged at the other tournion. The mill is gear driven from a counter shaft which may ~~be~~ in turn be driven by a belt. The conical section toward the feed end is obtuse and toward the right discharge end is acute.

Large balls and large particles of feed are supposed to segregate to a certain extent in the cylindrical portion of the mill with the greatest diameter whereas smaller balls and finer particles in the conical section especially near the discharge end of the mill. Thus it is preferable to grind coarse particles by large balls and fine particles by small balls.

Hardinge mills are widely used in the metallurgical field for wet grinding. On dry grinding

WRITING SPACE

- (a) Peripheral discharge mill — Krupp mill is a typical of peripheral discharge mill. Because of the expensive screen wear, they are rarely used for grinding non-abrasive industrial products either wet or dry.
- (b) Overflow mill — Traylor mill is a typical of overflow mill. In this type of mill, the feed enters at one end and the product flows out through the hollow tundish at the other end. These are the simplest of all in design and construction.
- (c) Grate mill — Meray mill is a typical of grate mill. In this type of mill, the product passes out the through the openings in a vertical grate or diaphragm.

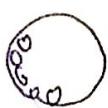


(cylindrical ball mill)

Balls and liners for a Ball mill

The interior of the ball mill is sometimes lined by replaceable liners usually made of alloy steels or of rubber. Least wear takes place on rubber lined interior.

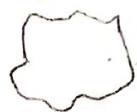
Liners may be of several shapes such as smooth, shiplap or wave liners etc.



Smooth liner



Shiplap liner



Wave liner

Liners other than smooth, are designed to help lift the ball load as the mill is revolved and to minimise gap between layers of balls. Liner wear ranges from 0.1-0.5 pound per ton of ground product. They are expensive than balls because of their complex shapes. In addition their installation involves a shutdown expenses..

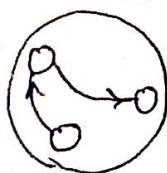
Balls of sizes 1 to 6" are commonly used. They are made of cast iron, cast or forged steel or alloy steel. Larger balls are used for grinding coarser particles and smaller balls for smaller particles.

Ball load — The ball load should be slightly more than half full of the mill even in the ~~absence~~ absence of the ore and water.

Theory of Ball mill operation

Ball mills may be continuous or batch type. In this mill, the grinding media and the ore to be ground are rotated around the axis of the mill. Grinding is accomplished by the

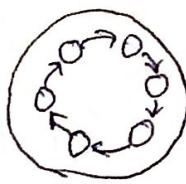
- (a) cataracting (impact of the ball on the particle)
- (b) cascading (attrition between the balls (rolling over) and particles)
- (c) interparticle collision and rubbing
- (d) wear / frictional forces at the lining of the mill.



(Rolling over)
slow speed
cascading



Sudden fall/impact
correct speed
cataracting



wrong with spin
(centrifuging)

Effective grinding depends on the rotational speed of the mill. If the mill rotates at a low speed, balls will be carried up along the inner wall to a certain height, but not large enough to give an impact force. Rather they roll over each other or slip over. This type of condition is known as cascading of the mill. But some grinding is performed due to attrition. (fig-1). If the speed is raised, the balls start moving up further, along the liner wall and suddenly fall from a greater height imparting an impact force on the particles. This impact is largely responsible for most of the grinding (fig-2). This condition is known as cataracting. If the speed of rotation becomes too high, the balls are carried over and over along the liner wall as if they are sticking to the inner wall and there is hardly any grinding. This condition is known as centrifuging.

fig-(3) So mill is to be operated between these two extreme speeds.

Characteristics of Ball mills

- ① Speed of the mill → Speed of the ball mill should be as high as possible without centrifuging.
- ② Capacity — The capacity of the mill depends upon the size of the mill, the hardness of the ore, the reduction ratio and efficiency of the operation. The exact capacity can not be accurately calculated. A reasonably conservative estimate of the capacity of a cylinder-conical ball mill in tons/day is

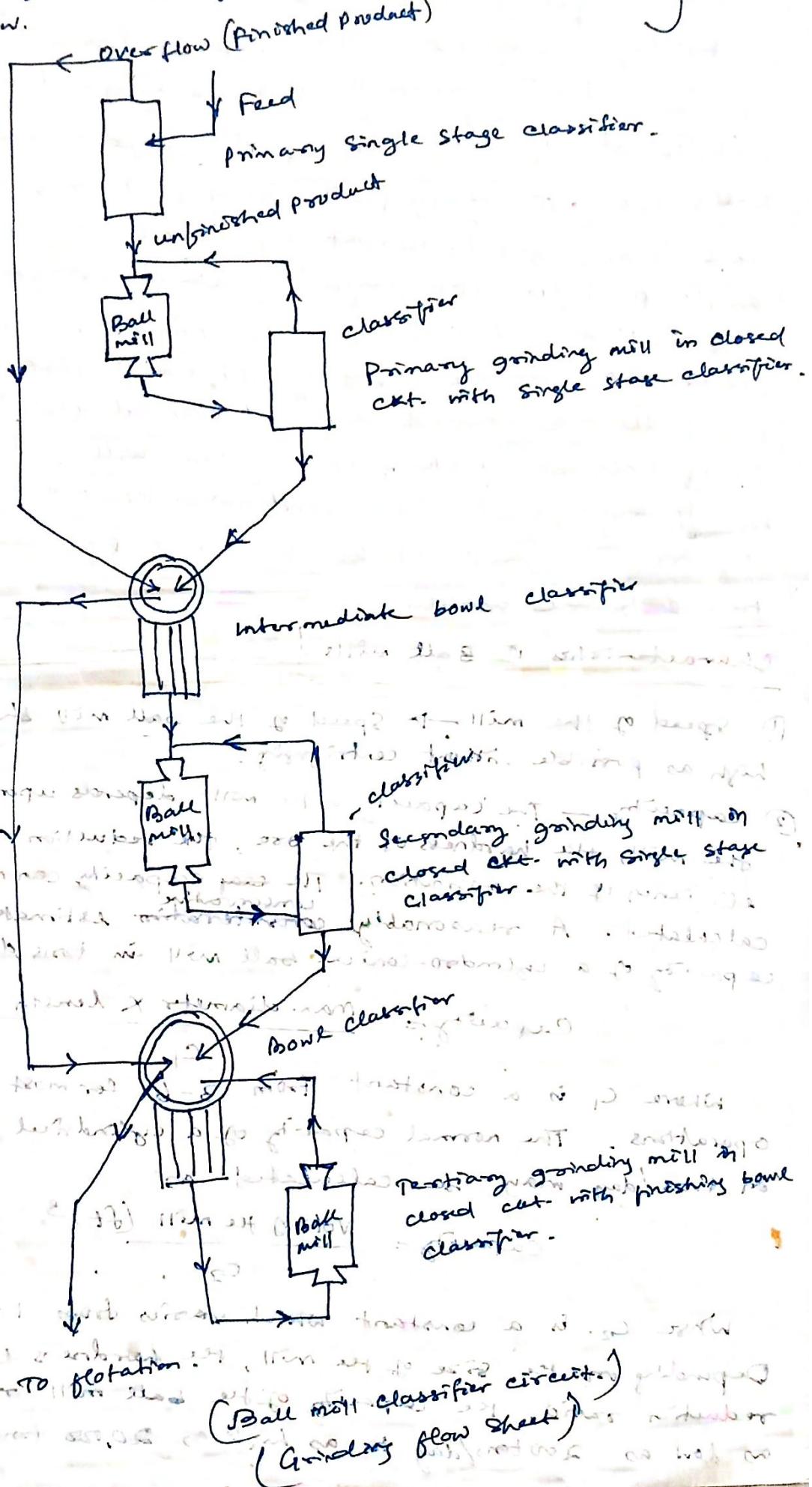
$$\text{Capacity} = \frac{\text{max. diameter} \times \text{length (ft)}}{C_1}$$

Where C_1 is a constant from 3-6 for most normal operations. The normal capacity of a cylindrical ball mill in tons/day may be calculated as

$$\text{Capacity} = \frac{\text{vol. of per mill (ft)}^3}{C_2}$$

Where C_2 is a constant which varies from 1 to 2. Depending on the size of the mill, the hardness of the ore and reduction ratio, the capacity of the ball mill ranges from as low as 200 tons/day to as high as 20,000 tons/day.

③ Reduction ratio → The reduction ratio that can be obtained by ball mills is greater as compared to that obtained by coarse or intermediate crushers. Instead of 5-8 it may range 50-100 for a ball mill classifier circuit, as shown below.



hardinge mills are used for pulvrisation of coal, lime
clay ~~and~~ cement etc.

(2. cylindrical ball mill)

Depending upon the mode of discharge of the ground product, cylindrical mills are classified into three types:

(A) peripheral discharge mill (The discharge is through screen along the cylindrical shell)

(B) overflow mill (The discharge is free overflow from the axis of the mill)

(C) grate mill (The discharge is through a grate across the full section of the mill near the discharge end)

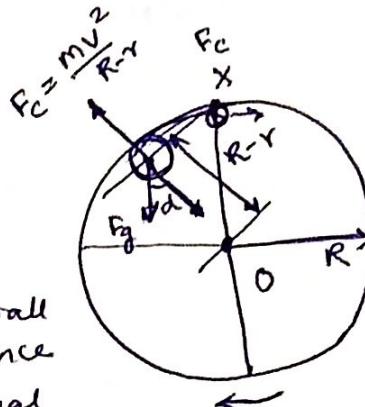
(4) Energy consumption → Average energy input

into the mill is ~~is~~ 16 kWh/ton of ore ground.

Derivation of Critical speed of Ball Mill

The minimum speed at which centrifuging occurs in ball mill is known as the critical speed of the ball mill.

At any instant, when the cylinder is rotating, the ball is acted upon by centrifugal force and gravitational force simultaneously. The speed at which the outer most ball loses contact with the inner wall of the mill depends upon the balance between gravitational and centrifugal forces.



forces acting on a ball inside the ball mill is shown in the figure.

Let R = radius of the cylindrical ball mill
 r = radius of the ball (grinding media)

F_c = Centrifugal force

F_g = Gravitational force = mg .

where g = acceleration due to gravity

$$F_c = \frac{mv^2}{R-r}$$

Let V = linear speed of the ball. Expressing linear speed in terms of rotational speed, we have

$$v = 2\pi r N = 2\pi (R-r) N$$

where N = rotational speed, $R-r$ = radius of rotation.

$$\text{And } v^2 = 4\pi^2 N^2 (R-r)^2$$

$$\text{Now } F_c = \frac{m \cdot 4\pi^2 N^2 (R-r)^2}{R-r} = m 4\pi^2 N^2 (R-r)$$

The centripetal force component of gravity force

$$F_g = m \cdot g = m \cdot g \cos \alpha$$

This force opposes the centrifugal force.

As long as the centrifugal force exceeds that of the centripetal force, the ball will not loose contact with the inner wall.

: the angle ' α ' increases, the centripetal force increases. Unless the speed is increased, a point is reached where both of these opposing forces are equal and the particle is ready to fall down. The angle at which this fall occurs is found by equating centripetal and centrifugal forces

$$\text{i.e. } mg \cos\alpha = m 4\pi^2 N^2 (R-r)^2$$

$$\text{or } \cos\alpha = \frac{4\pi^2 N^2 (R-r)}{g}$$

Applying the condition of critical speed, which means that the ball should at least reach the top most point 'x' as shown in the figure.
At this point,

$d = 0$
 $\cos\alpha = 1$ and N becomes critical speed N_c .

(at 'x' position gravitational force = centrifugal force)

(at 'x' position gravitational force = centrifugal force)

$$\text{i.e. } mg = m 4\pi^2 N_c^2 (R-r)$$

$$\text{or } N_c^2 = \frac{g}{4\pi^2 (R-r)}$$

$$\text{or, } N_c = \frac{1}{2\pi} \sqrt{\frac{g}{R-r}}$$

Putting the value of 2π , $g = 980 \text{ cm/sec}^2$, $R, r - \text{in cm}$, feet

$$N_c = \frac{54.2}{\sqrt{R-r}}$$

Balls and liners for Ball mills

The interior of the ball mill is sometimes lined by replaceable liners, usually made of alloy steel or of rubber. Least wear takes place on rubber lined exterior. Liners may be of several types such as smooth, shiplap, wave etc.



smooth liner



shiplap liner



wave liner.

Liners other than smooth, are designed to help lift the ball load as the mill is revolved and to minimize slip between layers of balls. Liners wear ranges from 0.1 to 0.5 pound per ton of ore ground. They are expensive than balls because of their complex shapes. In addition their installation requires a shutdown expenses.

Balls of sizes 1' to 6" are commonly used as grinding medium. They are made of cast iron, cast or forged steel or alloy steel. Larger balls are used for grinding coarse particles and smaller balls for smaller particles. The ball wear ranges 450 gms to 1250 gms per tons of ore ground.

Ball load - Ball load is the volume of the ball mill that is occupied by the grinding media without ore or water in it. The ball load should be slightly more than half full of the mill. Balls of same or various sizes are used as the grinding medium. If single size balls are used, the interstitial pores created by the single sized spheres will work as void space and ores of that particular pore size if caught in the void will not be crushed.

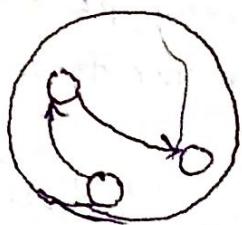
To avoid such problems, balls of various sizes are used in the mill. In fact, the larger balls crush the feed material more effectively ~~while~~ while the smaller ones are responsible for producing fines.

Theory of Ball mill operation

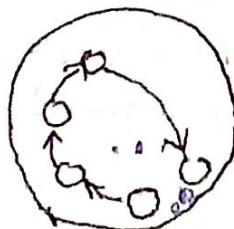
Ball mills may be continuous or batch type. In this mill, the balls and the ore are rotated around the axis of the mill. Due to friction between lining and balls, lining and ore lumps, ~~the~~ both are carried up along the inner wall of the shell nearly to the top, from where the grinding media fall down on the particles below creating a heavy impact.

Effect~~ing~~ grinding depends on the rotational speed of the mill.

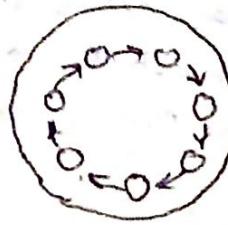
If the mill operates at a low speed, balls will be carried up along the inner shell to a certain height, but not too enough to give an impact force. Rather, they roll over each other or slip over. This type of operational condition is known as cascading of the mill. Even then some grinding is performed ~~due~~ due to attrition (~~sliding~~ rolling over of balls and particles).



tumbling over
slow speed
(cascading)



impact
correct speed
(cataracting)



very high speed
(centrifuging)

If the speed is raised, the balls start moving up further along the inner wall and suddenly fall from a greater height imparting an impact force ~~at~~ at the bottom of the mill.

in impact is largely responsible for most of the grinding. This condition is known as catactacting. If the speed of rotation becomes too high, the balls are carried over and over again all along the inner lining as if they are sticking to the inner wall and there is hardly any grinding. This condition is known as centrifuging of the mill. So mill is to be operated between these two extreme speeds (not very slow or not very high).)

Characteristics of ball mills

(1)

(1) capacity — The capacity of ball mills depends upon the size of the mill, the hardness of the ore, the reduction ratio and efficiency of the operation. The capacity of a cylindroconical ball mill can be expressed as

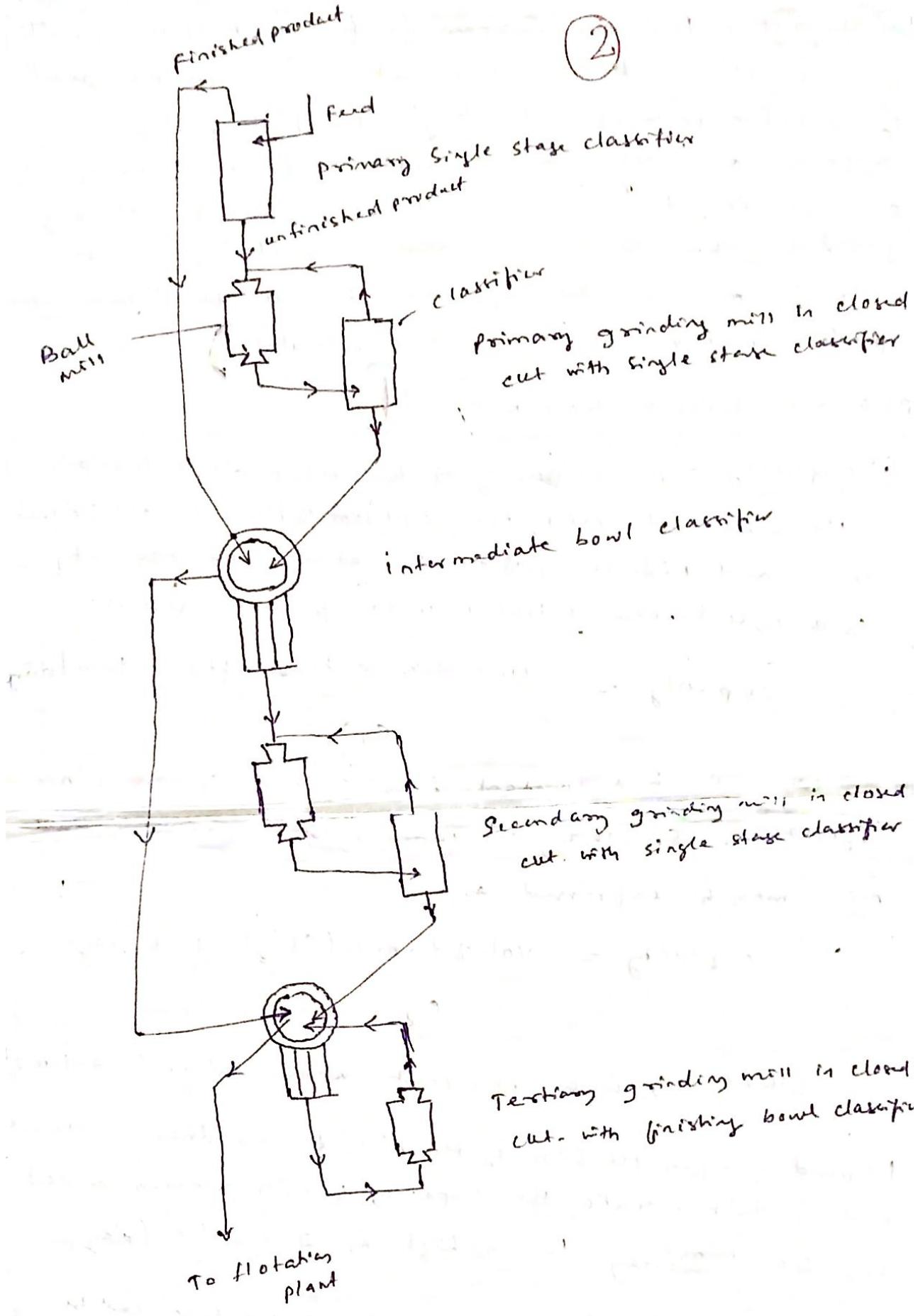
$$\text{capacity} = \frac{\text{max. dia.} \times \text{length (ft)}}{c_1} \text{ tons/day}$$

where c_1 is a constant from 3 to 4 for most normal operations. Similarly, the capacity of a cylindrical ball mill may be expressed as

$$\text{capacity} = \frac{\text{vol. of mill (ft}^3)}{c_2} \text{ tons/day}$$

where c_2 is a constant whose values from 1 to 2 depending upon the size of the mill, the hardness of the ore and reduction ratio, the capacity of mill ranges as low as 200 tons/day. to as high as 20000 tons/day.

(2) Reduction ratio — The reduction ratio that can be obtained by ball mills is greater as compared to that obtained by coarse or intermediate crushing devices. It ranges from 50 to 100 by using ball mill classifier circuits as shown below:



(Ball mill classification circuit)
 (grinding flow sheet)

Froth Flotation

Froth flotation or flotation includes any operation in which one solid is separated from another by floating floating one of them at or on the surface of a fluid. It is one of the ^{most} outstanding mineral beneficiation processes. This process is especially suitable for the concentration of low grade ores or sulphide ores. This process is entirely based on the different wetting characteristics of the ore and the gangue particles with water and oil. The ore is preferentially wetted by oil and gangue particles by water.

The crushed sulphide ore is treated with water to form a pulp or paste of slurry. This is introduced in a tank and water is added. Now a frother or foaming agent such as pure oil together with a little lime or Na_2CO_3 is added to the flotation ~~on~~ tank. Now another ~~substance~~ substance, called collector, such as potassium ethyl xanthate or amyl xanthate is added. The contents of the tank is agitated with a mechanical stirrer and air under pressure is blown in. The ore particles selectively become attached to air bubbles produced in the aqueous pulp as the ground ore and float on the surface, from where they can ~~be~~ be skimmed off. The gangue particles, which are strongly attached to water, do not attach themselves to foam (not affected by the flotation reagents) and hence sink to the bottom of the cell and are separately withdrawn. The froth is removed and suitably treated to get concentrated ore. The ores like copper pyrite, galena and zinc blende are purified by this method. CuFeS_2 - PbS ZnS

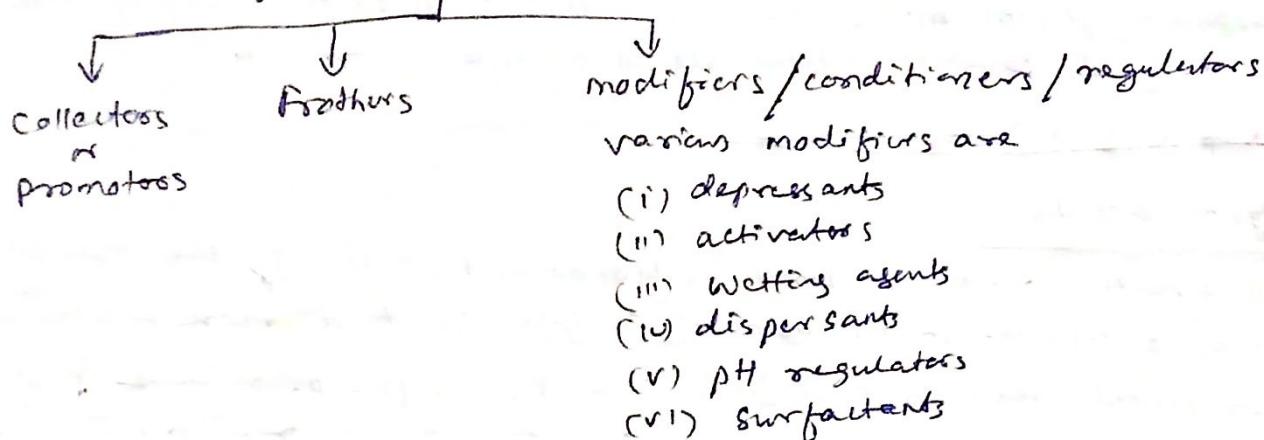
- ✓ Because of the importance of surface conditions and necessity of the air bubbles supporting the solid in the froth, flotation is performed on finely divided materials usually 20-200 mesh size. The material ~~that~~ floated off is called the concentrate as it contains the desired material mineral. The other material which sinks in the water and ~~removed from the~~ removed from the removed from the water and removed from the several valuable minerals, a process of the ore contains consecutive or selective flotation may be used to recover the minerals separately. The feed is treated with proper reagents in ~~at least~~ a flotation cell to float one of the desired elements, leaving

* Flotation Reagents & their functions

(3)

In order to produce optimum conditions for highly selective and efficient flotation process, various flotation reagents are added. In practice, flotation is almost impossible without the use of flotation reagents. Flotation reagents alter the surface properties of minerals over a wide range and make the mineral particles either water-avid or water-repellent. A great variety of flotation reagents is widely used, which differ in composition. Common reagents employed are organic and inorganic compounds, acids and alkalies, various salts, water soluble substances, and materials practically insoluble in water.

Classification of flotation reagents



Collectors

Collectors, sometimes called promoters are organic substances which act selectively on the surfaces of certain mineral particles and form a thin coating by adsorption or adhesion on the mineral surface to render them water ~~repellent~~ repellent or air-adherent. The characteristic features of collectors are

(a) complex molecular composition

(b) Asymmetrical structure

and (c) consisting of two parts i.e. polar and non-polar parts.

The non-polar part is always a hydrocarbon group as a chain and practically does not give any reaction with water dipoles and possesses pronounced water-repellent properties. The polar group possesses the property to react with water. During flotation, the polar part is adsorbed on the mineral surface while the non-polar is oriented outwards and this condition makes the mineral surface water-repellent. → See

Frothers (Frothing agents)

Frothers are the reagents which are added to the pulp to permit the production of a sufficiently stable froth to hold the floating mineral particles until the froth is removed from the flotation cell. These are the surfactants of low solubility and surface tension and thus increase the

life of the bubbles produced. The solid particles of mineral form a network around the pulp and thus a more stable froth is produced.

Frothers are hetero-polar surface active substances which are adsorbed at the air-water interface. The functions of frothers are

- (a) it increases bubble resistance to various external forces
- (b) it reduces the speed of bubble movement in the pulp and thus bubble contact with mineral particles is more
- (c) it reduces the force of collision between bubbles and thus a froth stability is achieved -

Various frothing agents are pine oil, Eucalyptus oil, wood tar, cresols, polypropylene glycol methyl esters, methyl aryl alcohol, capryl alcohol, methyl isobutyl carbinal, ethyl alcohol bisulfate ester etc.

Examples of collectors are -

Modifying agents

These are the reagents used in flotation to intensify the specific action of a collector on the mineral surface i.e. to decrease or increase water-repellent effect on specific minerals. In the presence of regulators, few collector activates selectively only specific minerals required to pass in the froth. The function of regulators involves the reactions with minerals, collectors, and ions present in the pulp. The various modifying agents are

(a) Activators → These chemicals are generally inorganic compounds, addition of which leads to change in the chemical composition of mineral surface layer as a result of forming a surface compound or passate of activator ions into the mineral crystal lattice. Examples of activators are - water soluble salts of heavy non ferrous metals ($CuSO_4$)

- " " " of alkali metals

- Na_2S

- atmospheric oxygen

- other water soluble sulphides etc.

(b) Depressors → These are organic and inorganic chemicals, have the opposite effect on a mineral to that of activator. These chemicals render a mineral surface inactive to a collector and thus mineral becomes unfloatable. Various depressors used are

- Na_2S , cyanides, water soluble sulphides, K_2CrO_4 , $K_2Cr_2O_7$

- lime, water gas etc.

Flotation Machines

(7)

Flotation machines or cells are the devices used to carry out the flotation process. The important features of a flotation cell are as the following;

- (a) Aeration of the pulp should be as complete as possible, without letting too large bubbles or bursting of air create.
- (b) Solids should be distributed evenly throughout the pulp without settling.
- (c) The machine should work continuously.
- (d) Removal of mineralised froth (float) and tailings (sink) by separate channels.
- (e) Avoidance of pulp entry to discharge channel without being processed.
- (f) Machine should have a zone where quiet blanket of mineral mineralised froth is formed and gangue particles should drop back from it into the pulp.
- (g) pulp level and height of froth column in the flotation machine should be controllable.
- (h) easy re-start of machine after mechanical failure ~~being~~ should be possible without causing the standing-up of mechanical parts
- (i) power and mill space should be economically utilised.
- (j) machine should not have odd corners to prevent the accumulation of undesired materials such as wood debris, lime scale etc.
- (k) provision for periodic discharge of coarse sand accumulated at the bottom.

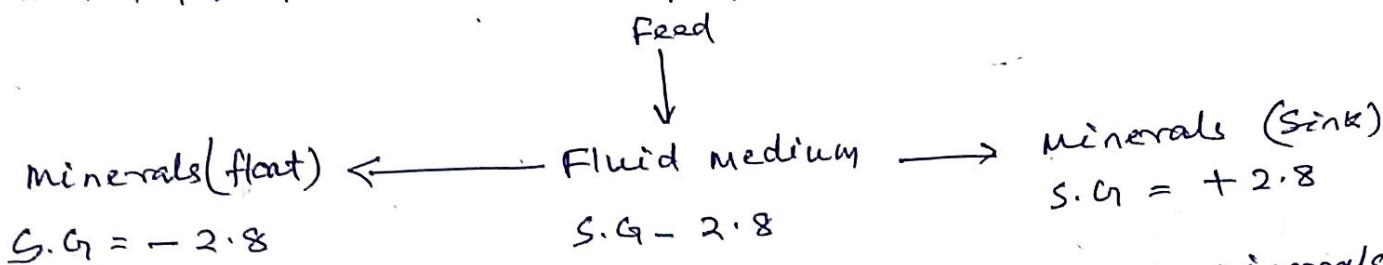
Classification of flotation cells

Basis of classification	Type	Method of pulp aeration	Design features
A. Based on the way of pulp flow	<ol style="list-style-type: none"> 1. Trough type 2. Through type 3. Chamber type 	Same as pneumatic cells Same as mechanical type Same as mechanical type	Single elongated chamber Divided into separate compartments consists of sep separate chambers.
B. Based on method of aeration	<ol style="list-style-type: none"> 1. Mechanical cells 2. pneumatic cells 3. pressure variation cells 4. cascade (air entrained) cells 	By mixing the pulp with air using impellers of different designs.	1. with impellers

Heavy fluid separation / Dense media separation

Page - 1

Heavy fluid separation or float-and-sink method is a process of separation of mineral particles based on the specific gravities of the fluid and that of the minerals. If the specific gravity of the fluid is intermediate between the two solids, then one of the solids will float and the other will sink. The separating products can be collected from the bottom and top of the vessel.



Water is not suitable for fluid medium to separate minerals since they are heavier than the water. Using water as fluid medium, wood chips can be separated from sand, gravel, etc. Some aqueous solutions are available whose specific gravity is sufficient to permit coal to cream, while associated impurities sink, other organic liquids are also available whose specific gravities are well above 2.75. They can be used to separate light minerals particles from quartz and calcite. However they are relatively expensive for laboratory and research purposes. So heavy pseudo liquids can be made by suspending solids in water and these fluids are used almost like true liquids, provided the particles to be separated are coarser in comparison to the size of the medium particles and provided the medium is agitated enough so not to settle. Pseudo liquids are very much cheaper than organic liquids of high specific gravities. On the other hand the use of pseudo liquids is not so simple as that of the high specific gravity liquids.

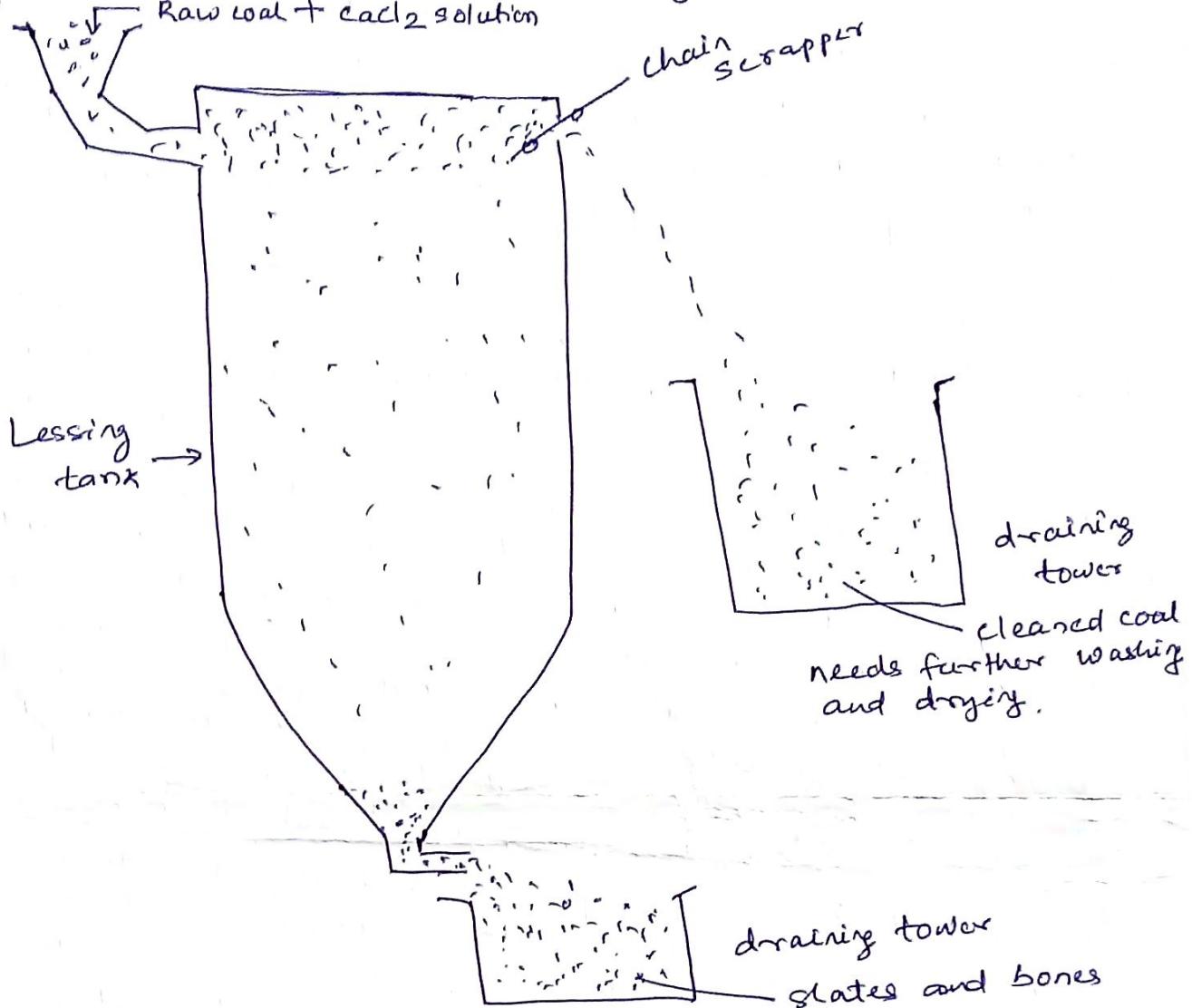
In the laboratory, heavy fluids such as aqueous solutions of zinc chloride and of calcium chloride are used for coal analysis. Another type of heavy fluid is acetylene tetrabromide ($S.G. = 2.96$).

Industrial processes using heavy liquids

There are mainly three industrial processes that use heavy liquids:

- 1) The Lessing process
- 2) Bertrand process
- 3) Du Pont process (Nagelvoort process)

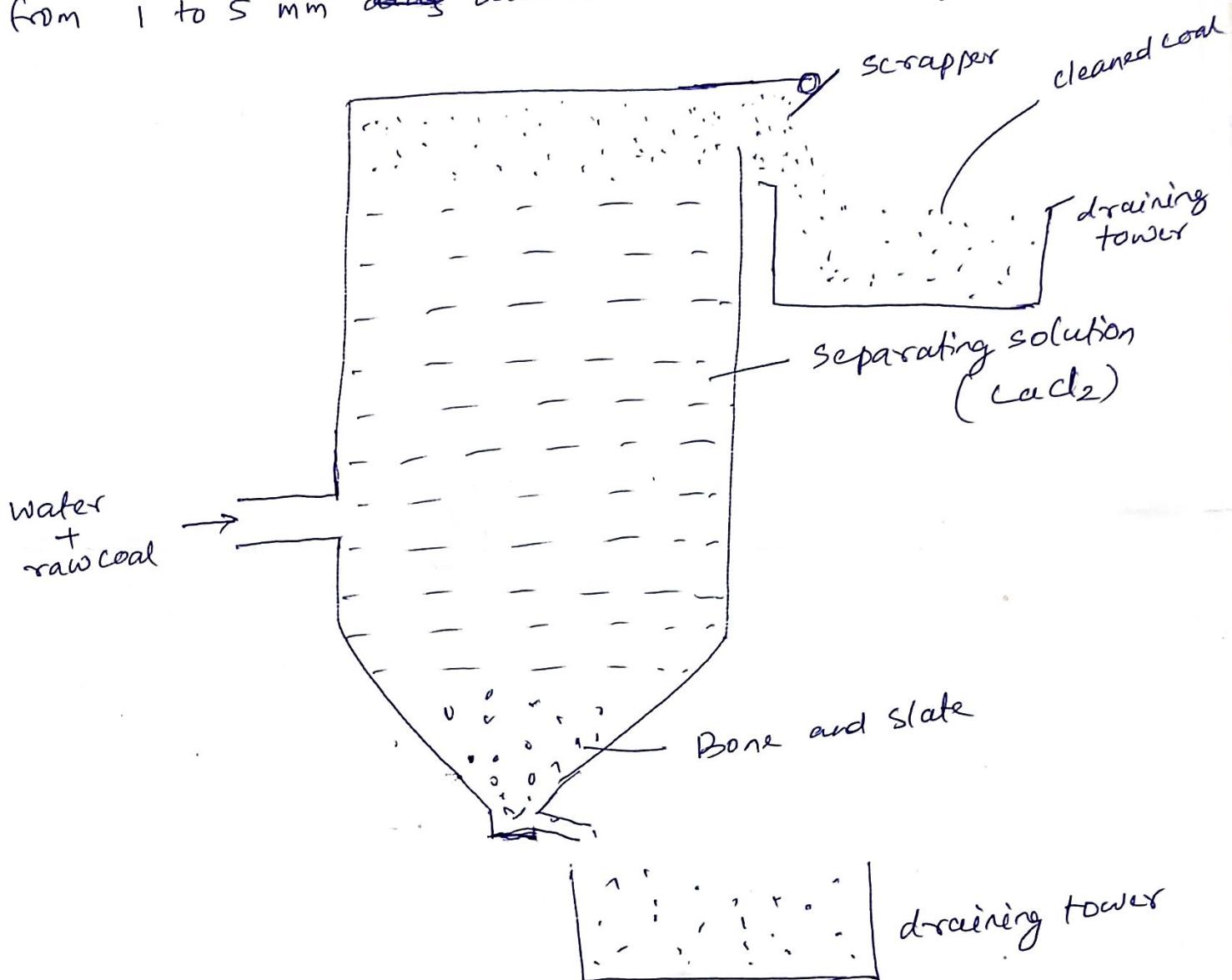
(1) Lessing process — This process is used for the cleaning of coal using heavy liquids calcium chloride of specific gravity of approximately 1.4.



It consists of a cylindrical tank 6 to 10 ft diameter with a conical bottom. The total height being 30 ft. First, the raw coal with fines are mixed in calcium chloride solution. It is then introduced into the centre of the tank. The cleaned coal being lower specific gravity than the separating solution rises to the top where it is removed by a chain scrapper and delivered to the draining tower. The slates and bones being higher specific gravity than the separating solution are sunk to the bottom of the tank and dumped in draining tower. After draining, the coal and slate are washed, the wash liquor is again transferred to the lessing tank to utilize calcium chloride for next operations. The Lessing process is extremely useful to clean coal and is widely used in industrial practice.

(2) Bertrand process:-

In Bertrand process, calcium chloride is also used as a separating solution and the process is only applicable to deslimed feed. Desliming is a process of removing ultra fine coal and clays from heavy media feed circuits. This process is widely practised in Belgium and particles from 1 to 5 mm ~~diameter~~ diameter are treated by this process.



The vessel for cleaning of the coal is similar to that of the Lessing vessel, but here the raw coal with water is feed into the separating solution in counter-current fashion. The purified coal and the waste are withdrawn in a similarly counter-current fashion. Bertrand process gives excellant result, coal of extremely high grade is obtained by this process coal containing less than 1% ash can be obtained.

(3) Du Pont process -

The Du Pont process, an outgrowth of the Nagelvoort process, is a practical ~~adaptation~~ adaptation of the laboratory heavy-liquid separation, in which. In basic principle, it is same as the lessing process, but several requirements have to met for the process. These requirements are

1. Low solubility of "parting" liquid in water and of water in "parting" liquid
2. Low viscosity (high fluidity) of the parting liquid at operating temperatures.
3. Stability, low vapour pressure and non-flammability of the parting liquid.
4. Prior preparation of the ore to remove fine particles.
5. Prior preparation of the ore with suitable chemicals to make the surface of the particles immune to wetting by the parting liquid.
6. Complete sealing of the separating system to prevent loss of parting liquid
7. Use of procedure that completely separate the parting liquid from the separated minerals
8. Use of procedure for ~~purifying~~ purifying the parting liquid.
9. Use of chemicals → active agents such as starch acetate or tannic acid.
10. Parting liquid → a mixture of halogenated hydrocarbons.

Industrial processes using heavy suspensions

These processes include -

- ✓ ① Chance process
 - ✗ ② Frosts process
 - ✗ ③ Wunsch process
- } All the processes are used for washing of coal and separation of ore particles.

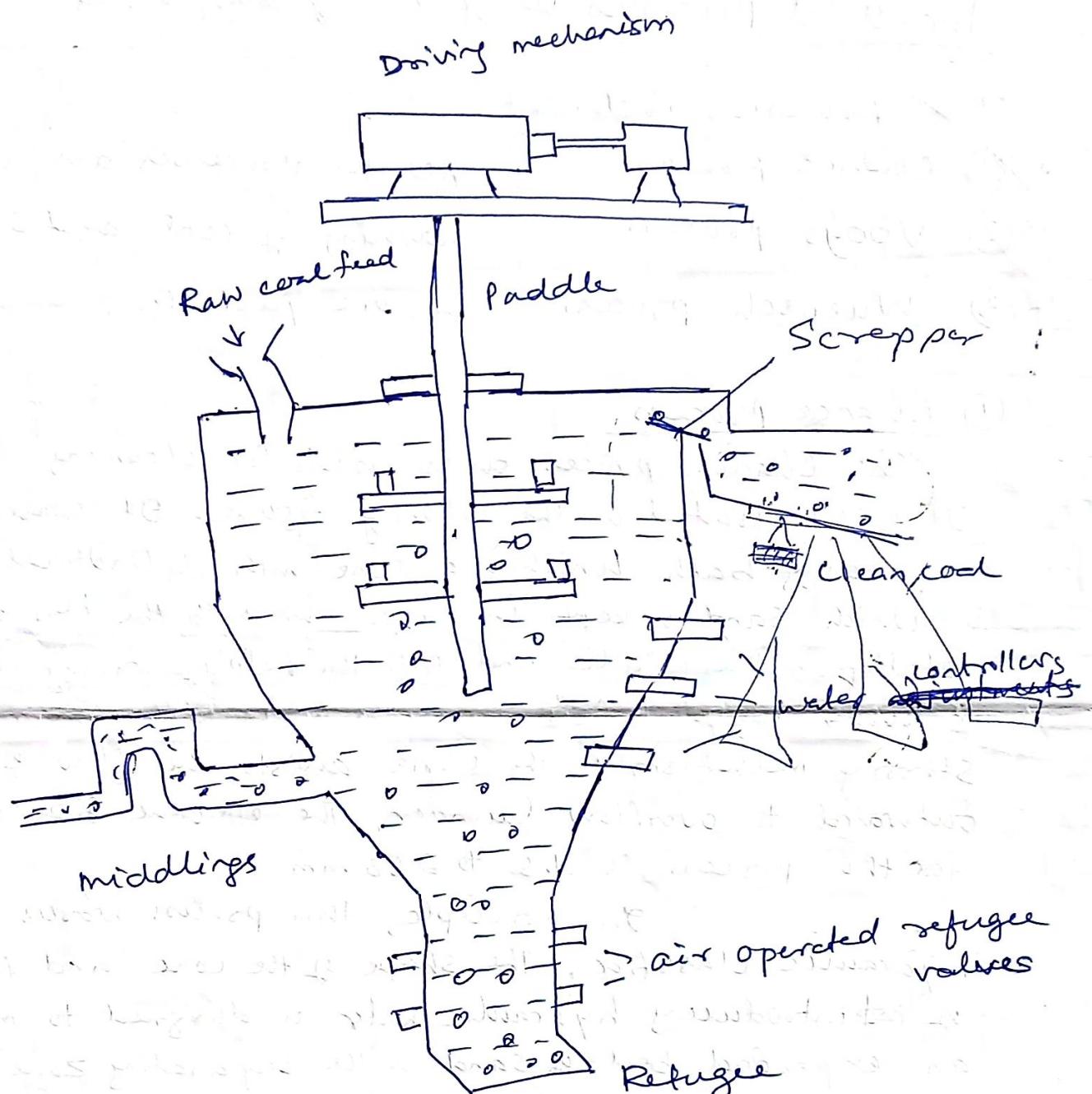
① Chance process

The Chance process is used for cleaning of coal. It is illustrated in the following figure. It consists of a separating bath which is a cone with cylindrical top in which sand is kept in suspension with the help of paddles rotating in the middle and with the help of rising currents of water injected from the sides of the cone. The stirring mechanism in the cone assists the flow of coal outward to overflow launder. The effective size range for this process is 1.5 to 250 mm.

In principle, this process works as hydraulic classifier. The shape of the cone and the method of introducing hydraulic water is designed to maintain an expanded bed of sand in the separating zone. Sand used must be relatively of uniform size. Coarse sand tends to accumulate in the bottom of the zone, while fine sand tends to accumulate in the upper layers of the cone. The specific gravity of the medium is between 1.25 to 1.8, which can be adjusted by varying the proportion of sand and water. Control of gravity is maintained by varying the flow rate in the high gravity and low gravity zones. Cleaning of anthracite coal needs higher specific gravity of medium than required for

bituminous coal.

Page-6



(Fig- Schematic illustration of chance process)

The feed is introduced at the top of the cone at one end. The overflow of clean coal and sand passes from the other end over clean coal screens having water spray.

which ~~sets~~ desand and dewater the coal. The heavy shale sinks to the bottom of the cone and is discarded as underflow through an automatically controlled ~~sieve~~ refuse valve on refuse screens, ~~sets~~ from where the refuse is discarded.

Movement of Solids in fluids

p-1

The movement of solids in fluids plays an important role in various classification processes such as gravity concentration, heavy media separation, jigging, tabling, thickening and filtration. Hence it is extremely important to know how the solid particles behave in fluids.

Fluid resistance and Terminal Velocity →

When a solid particle is immersed in a fluid as shown in the figure, it is acted upon by the following forces under the condition of rest.

1. Gravitational Force

1. Gravity force, $F_g = mg$

2. Buoyant force, $F_b = m'g$
which is equal to the weight of the fluid displaced by the solid body.

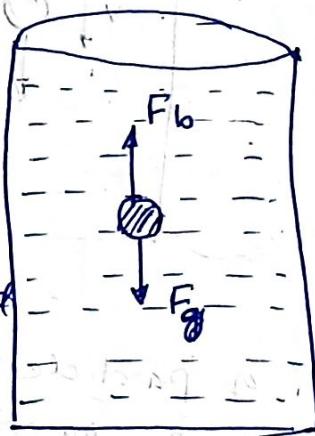


fig- Forces acting on a spherical particle (static condition)

(m = mass of the particle
 m' = mass of the fluid displaced by the particle of mass m)

the gravity force always acts downward while the buoyant force always acts upward as shown in the figure. This is as per the classical Archimede's principle. This is true as long as both the object and the fluid are static or there is no relative motion between the particle and the fluid. Hence the net force acting on the body under the condition of rest is

$$F_n = F_g - F_b = mg - m'g$$

If $F_g > F_b$, the solid particle starts moving down in the fluid column and ultimately to the bottom of the vessel.

Similarly, if $F_g < F_b$, the solid particle floats on the surface of the fluid.

Once there is downward movement of the particle relative to the fluid medium, the situation with regards to the forces acting on the particle changes and a new force, R , starts acting on the particle in addition to F_g and F_b . The new force is termed as the fluid resistance or viscous force on the particle settling in the fluid.

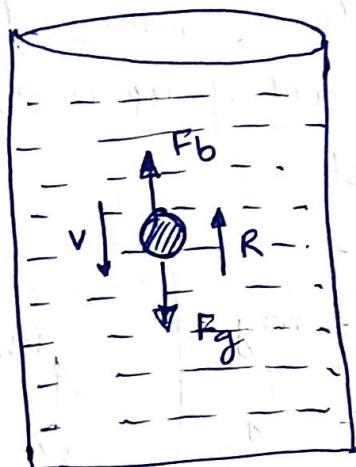


Fig - forces acting on a spherical particle (under motion)

Under the condition of particle settling in the fluid, the net force that works on the particle

$$F_n = F_g - F_b - R = mg - m'g - 6\pi\mu r^2 v$$

$$\text{where } R = 6\pi\mu r^2 v$$

(μ = viscosity of the fluid
 r = radius of spherical particle
 v = velocity of the particle)

Hence, as long as $F_n > 0$, the particle would continue to accelerate down to settle. This suggests that the velocity of the particle will increase steadily starting from zero as it starts to settle. Logically, the settling velocity of the particle can not increase indefinitely. This is due to the fact that, as the velocity of the particle increases, the fluid resistance force, $R = 6\pi\mu r^2 v$ working on it also increases correspondingly.

Hence, a situation would be arrived where the downward gravitational force would be exactly balanced by the fluid resistance force.

and the net force on the particle would be zero. Under this situation the particle would accelerate no more rather it would start settling down at a constant velocity till it reaches the bottom of the fluid column. The constant velocity at which the particle settles in a fluid is termed as terminal velocity (V_t)

Determination of Terminal Velocity \rightarrow

Let us consider the following parameters with regards to the settling of a spherical particle in a fluid (figure-2)

r = ~~mass~~ radius of the spherical particle

ρ_p = ~~sp~~ specific gravity of the spherical particle

ρ_f = ~~sp~~ specific gravity of the fluid.

μ = viscosity of the fluid

g = acceleration due to gravity (980 cm/sec^2)

Applying second law of motion to the falling sphere in a fluid we have

$$F_n = F_g - F_b - R = mg - m'g - 6\pi\mu r^2 v$$

(\therefore mass \times acceleration = Σ forces)

The above equation takes the form

$$m \frac{dv}{dt} = mg - m'g - R$$

$$\text{or, } \frac{4}{3}\pi r^3 \rho_p \frac{dv}{dt} = \frac{4}{3}\pi r^3 (\rho_p - \rho_f) g - 6\pi\mu r^2 v$$

($\because \frac{4}{3}\pi r^3$ is the volume of the sphere)

Dividing both sides of the equation by $\frac{4}{3}\pi r^3 \rho_p$, we have

$$\frac{dv}{dt} = \left(\frac{\rho_p - \rho_f}{\rho_p} \right) g - \frac{9}{2\rho_p r^2} \mu v$$

The terminal velocity is achieved when the net force acting on the particle is zero.

This statement implies

$$m \frac{dv}{dt} = 0$$

Hence $\frac{dv}{dt} = a = 0$, as mass of the particle cannot be zero.

Now $\frac{dv}{dt} = 0 = \left(\frac{\rho_p - \rho_f}{\rho_p} \right) g - \frac{9}{2 \rho_p r^2} \mu v t$

or $\left(\frac{\rho_p - \rho_f}{\rho_p} \right) g = \frac{9}{2 \rho_p r^2} \mu v_t$

or $v_t = \frac{2r^2 (\rho_p - \rho_f) g}{9 \mu}$

This equation is called ~~stokes~~ Stokes's law of settling or terminal velocity.

Free and Hindered settling \rightarrow (Settling of particles)

Movement of solids in fluids is governed by mainly two conditions i.e free settling conditions and hindered settling conditions.

Free settling \rightarrow Free settling refers to the falling of particles freely in still water or against an opposing upward current without the interference of other particles. This condition is observed in settling tanks, thickeners, and classifiers.

Hindered settling \rightarrow Hindered settling refers to falling of particles of mixed sizes, shapes and densities in a crowded mass. The velocity of these particles is much less than the free falling velocity of the particles. Examples of hindered settling are jigs, hydro-turbines, heavy media separation etc.

Factors affecting the settling of particles \rightarrow

The rate of falling particles under the free settling conditions depends upon the following:-

- (i) Specific gravity of the particles: \rightarrow if two particles have the same size but different specific gravities, the particles having higher specific gravities will settle faster.
- (ii) Shape of particles: \rightarrow spherical particles settle faster than narrow, long and flat particles.
- (iii) Size of particles: \rightarrow if the particles have the same specific gravities, larger particles will settle faster.
- (iv) Density of fluid: — Particles will settle faster in lighter fluid.
- (v) Viscosity: \rightarrow with increasing viscosity of the fluid, the rate of settle becomes slower or the resistance to fall increases.

Equal Settling Particles \rightarrow The particles having the same terminal velocities in the same fluid and in the same fluid force, are called equal settling particles. Spheres of one material and of the same size are equal settling. *

Free Settling Ratio (FSR) \Rightarrow

consider two mineral particles of densities ' D_a ' and ' D_b ' and diameters ' d_a ' and ' d_b ' respectively, falling in a fluid of density ' D_f ' at exactly the same settling rate. Their terminal velocities must be the same. Hence from Stokes law,

$$d_a^2 (D_a - D_f) = d_b^2 (D_b - D_f)$$

~~D_a — density or
specific gravity~~

$$\text{or } \frac{d_a}{d_b} = \sqrt{\frac{D_b - D_f}{D_a - D_f}}$$

This expression is known as the free settling ratio of the two minerals, i.e. the ratio of particle size required for the two minerals to fall at equal rates.

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

$$\frac{da}{db} = \frac{D_b - D_f}{D_a - D_f}$$

Expt - consider a mixture of galena (density 7.5) and quartz (density 2.65) particles classifying in water. (density of water = 1)

For small particles, obeying Stokes's law, the free settling ratio

$$\frac{da}{db} = \sqrt{\frac{7.5 - 1.0}{2.65 - 1.0}} = 1.99$$

i.e. a small particle of galena will settle at the same rate as a small particle of quartz which has a diameter 1.99 times as large.

For particles obeying Newton's law, the free settling ratio

$$\frac{da}{db} = \frac{7.5 - 1.0}{2.65 - 1.0} = 3.94$$

The free settling ratio is larger for coarse particles obeying Newton's law than for fine particles obeying Stoke's law.

The general expression for free settling ratio can be deduced from the above equations

$$\frac{da}{db} = \left(\frac{D_b - D_f}{D_a - D_f} \right)^n$$

where $n = 0.5$ for small particles obeying Stokes's law
 $= 1$ for large particles obeying Newton's law

Hindered Settling Ratio — As the proportion of solids in the pulp increases the effect of particle crowding becomes more apparent and falling rate of particles begins to decrease. The system begins to behave as a heavy liquid whose density is that of the pulp \neq rather than that of the carrier liquid. Hindered settling conditions now prevail.

The Hindered Settling Ratio ~~of~~ of two particles is given by

$$\text{HSR} = \frac{d_a}{d_b}$$

$$\frac{d_a}{d_b} = \left(\frac{D_b - D_p}{D_a - D_p} \right)^m$$

(D_p = density / specific gravity
of the fluid)

$m = 0.5$ for Newton's relation
 ≥ 1.0 for Stokes' relation

The hindered settling ratio is always greater than the free settling ratio and denser the pulp, the greater is the ratio of the diameters of equal settling particles.

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. Usually air or water is used as the fluid medium. The coarser, heavier and rounder particles settle faster than finer, lighter and more angular particles. Classification may be regarded as a mineral beneficiation process based primarily on Stoke's law of sedimentation.

* Spheres of different materials may have equal settling, having a proper size ratio. Thus spheres of densities ' D_a ' and ' D_b ' are equal settling if

$$d_a^2(D_a - D_f) = d_b^2(D_b - D_f) \quad (\text{under Stoke's law})$$

$$d_a^2(D_a - D_f) = d_b^2(D_b - D_f) \quad (\text{under Newton's law.})$$

and

D_f = density of the fluid

Factors affecting classification

- 1). Sp. gravity :- For particles of same size but different specific gravities, the particles having higher specific gravity will settle faster than any other particle.
- 2). Size :- For particles of same specific gravity, but different sizes, the larger size particles settle faster than any other particles.
- 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 faster in lighter fluids.
- 5). Air bubbles :- Adherence of air bubbles to the solid particles would decrease the settling speed.

Classification differs sizing by the following two ways

- a) Classification is only applicable to finer size particles.
- b) It separates particles on the basis of their specific gravities.

Classifiers

The machine or equipment used for classification is called as classifiers. Classifiers are broadly divided into the following types:

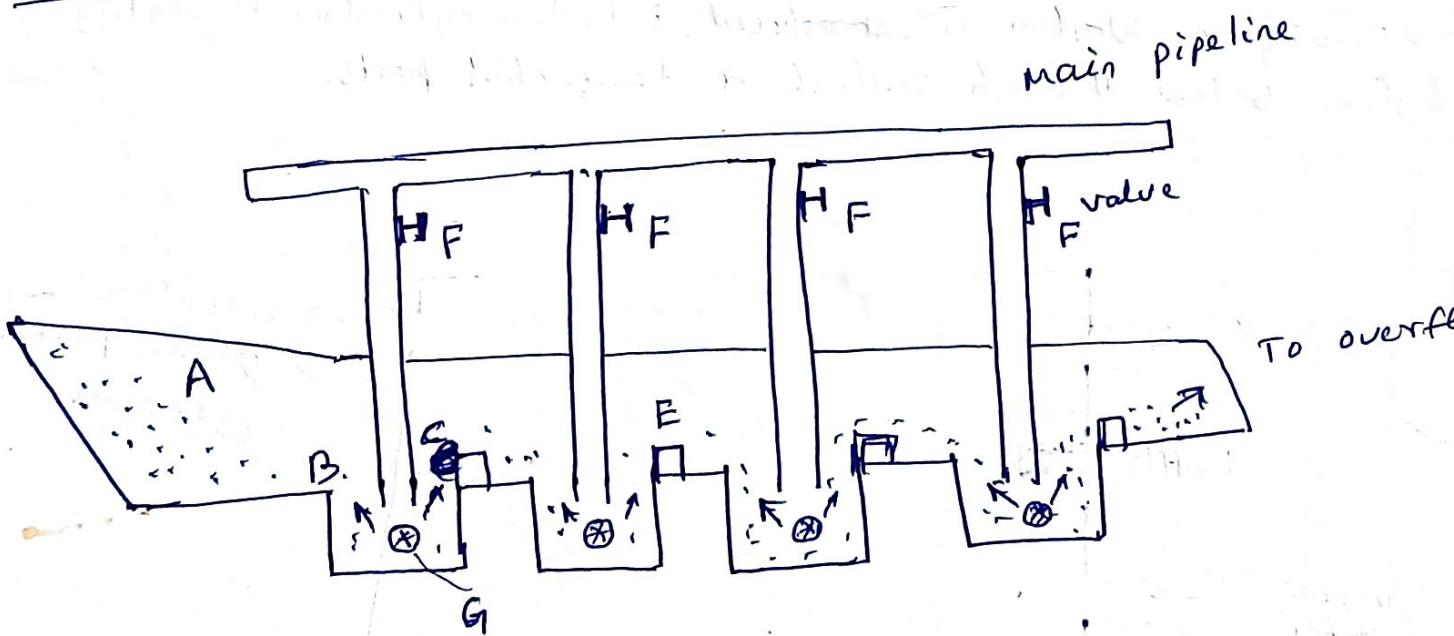
1. Sorting classifier :- It uses a relatively dense aqueous suspension as the fluid medium for classification.

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

f. Sorting classifiers

In sorting classifiers, more or less hindered settling conditions are used. In this, sizing is modified by specific gravity and shape of the particle. It is usually employed for relatively coarse products. A dense suspension of 40-70% of solids by weight is used depending on sp. gravity, size of the particles to be sorted. The ~~usual~~ usual types of sorting classifiers are:

- (A) Launder classifier (Evans classifier)
 - (B) Richard's hindered settling classifier
 - (C) Richard's pulsator classifier
 - (D) Hydrotator classifier
- (A) Launder, or Evans, classifier:-



(Fig: Evans classifier)

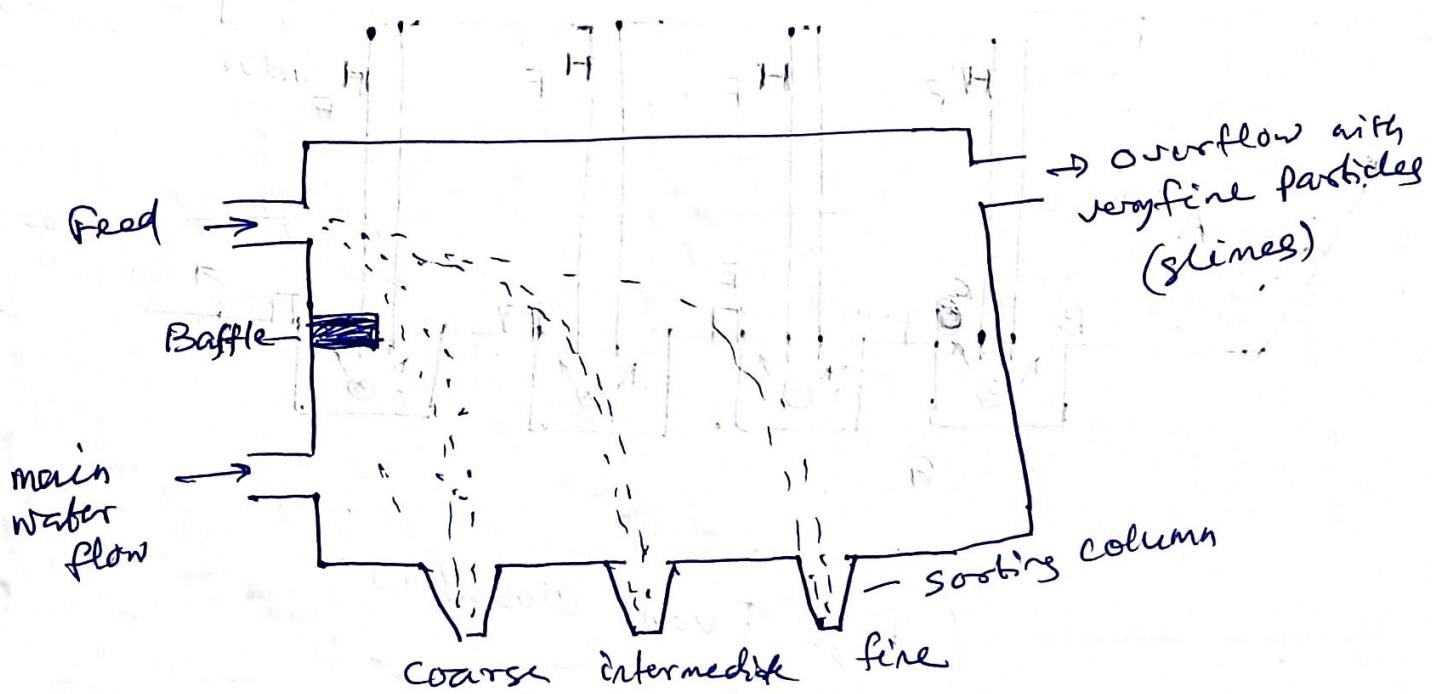
P-10

Evans classifier consists of a sloping launder A, opening to this launder several rectangular boxes BC are attached. To the rectangular boxes spigot, G, 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.

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 the particles to the same box ~~where~~ from where they have been taken away as overflow. Depending upon the number of rectangular boxes and spigots attached to the launder, several products are obtained.

(B). Richards Hindered Settling Classifier →

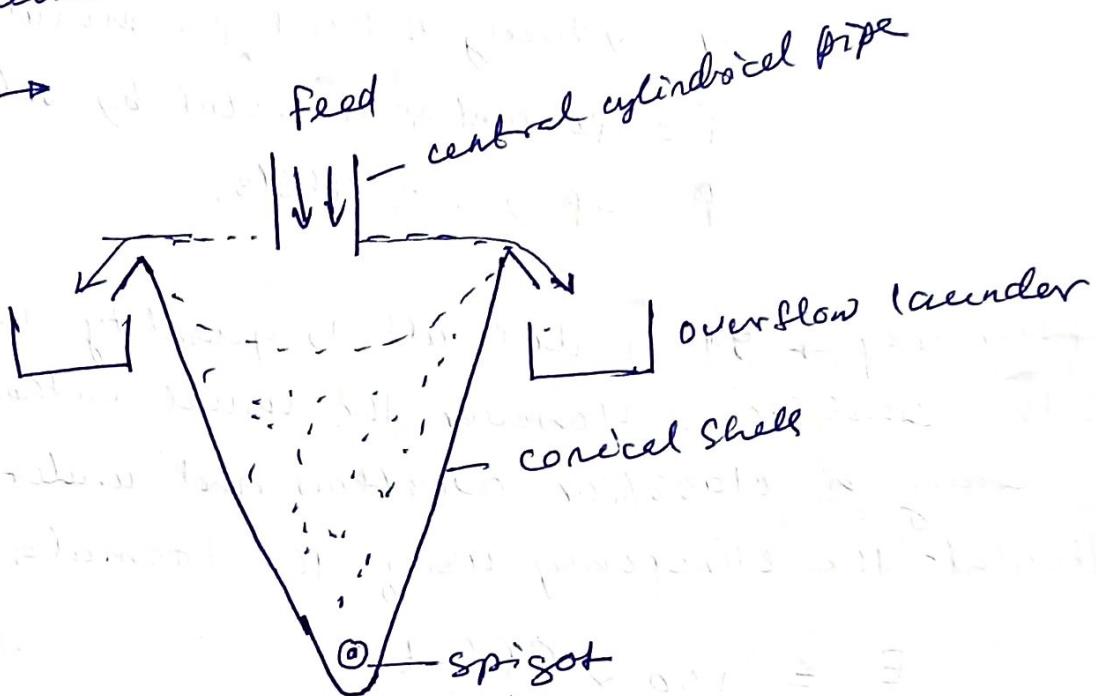
It is a modified version of Evans classifier. In this classifier cylindrical sorting columns replace the boxes of the Evans classifier. Water is introduced into the cylindrical sorting columns from below through radial or tangential ports.



Sizing classifiers -

Sizing classifiers utilize free settling conditions to effect sizing as much as possible unaffected by specific gravity and shape. These classifiers do not require any additional water besides that is present in the suspension which is to be classified. Sizing classifiers may be sub-divided into - 1) settling cones having no moving parts and - 2) mechanical classifiers having moving parts.

1. Settling cones:



Settling cones are conical sheet metal shells apex at the bottom and a peripheral overflow launder at the top. Feed is charged at the top centre, ~~inside a small cylindrical~~ spigot discharge through the bottom.

Performance of classifiers:-

1. Capacity: - The capacity of a classifier is directly proportional to following variables

- (a) cross sectional area of the sorting column, A .
- (b) The rising velocity of the fluid in the sorting columns, V
- (c) solid content in the feed, R .
- (d) specific gravity of the solid P .

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

$$C = a A \sqrt{f_P}$$

where $a = a$ constant ($= 1.875$) to obtain

'C' in tons per hour.

A = Cross sectional area in square feet.

A = cross section
 V = velocity of fluid per minute

V = velocity
 r = percentage of solid by volume.

r = percent of solids.
 ρ = sp. gr. of solids.

$\rho = \text{sp. gr. of solids}$

2. Efficiency: → It is difficult to quantify the efficiency of the classifiers. However the usual methods consists of screening of classifier overflow and underflow and then calculate the efficiency using the formula;

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

where E = efficiency expressed in percentage

C = content of -x-methyl material in the ^{overflow} ~~overflow~~

$f = \dots$ method of drawing the feed

$t = \dots$ underflow

* being any size such that neither 'i' nor 't' or 'f' is zero

Many metallurgists do not agree to this efficiency calculation since if some feed is bypassed to the overflow, the efficiency increases theoretically, but practically there is no increase in the efficiency of the classifier.

Hence it has been proposed to use

$$E = \frac{10000 (c-f)(f-t)}{f(100-f)(c-t)}$$

c, f, t have the same meaning as above.

The efficiency of the classifier ranges from 50-80%.

3. Cost of Operation

The cost of classification is strictly less except for fine sized material. In large plants the total cost of classification is around Rs 15 per ton.

Magnetic separation

It is a known fact that many minerals exhibits magnetic properties. Minerals that are strongly attracted by magnets are called as ferro-magnetic. Those only weakly attracted are called paramagnetic and those are hardly attracted are called diamagnetic minerals. The following list shows the relative attractability of some minerals.

Classification	Minerals	Relative attractability
Strongly Magnetic	Fe (standard) Magnetite Ilmenite	100.00 40.2 24.7
Weakly Magnetic	Pyrrhotite Siderite Hematite Pyrolusite Quartz Pyrite	6.7 1.8 1.3 0.7 0.4 0.2
Non magnetic or hardly magnetic	Magnesite Chalcocite Cuprite Calcite	0.15 0.09 0.08 0.03

It should be noted that, magnetic concentration entails the separation of a valuable mineral from the gangue whereas magnetic separation is the separation of one mineral from another essentially based on the difference in the values of magnetic attractability of the minerals. In operation, a continuous stream of ore is simultaneously subjected to magnetic field, more magnetic and non-magnetic are separated.

Magnetic Separators

Depending upon the separating medium, mode of feed presentation, mode of discharge of products and whether the magnets are stationary or moving,

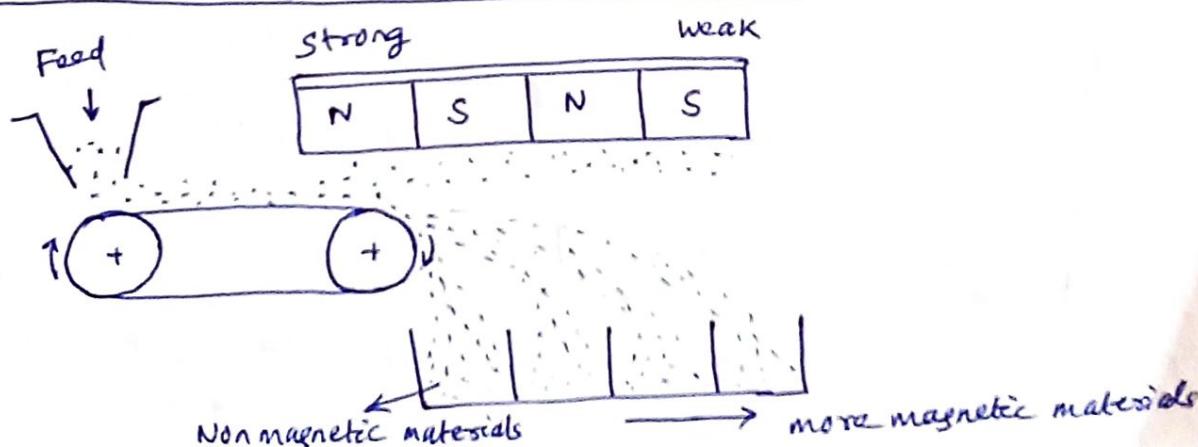
Magnetic separators are classified into the following types:

Medium	Presentation of feed	Disposal of magnetic products	Magnets	Name
Air	1. Gravity fall	Gravity fall	stationary	Edison
	2. Flow around revolving roll	Gravity fall	Moving	Pulley
	3. Horizontal belt	Gravity fall	stationary	Humboldt
	4. Horizontal belt	Longitudinal belt	stationary	Wetherill
	5. Horizontal belt	Cross belt	stationary	Ball-Norton or Dings
	1. Agitated pulp	scrapping Conveyors	stationary	Wetherill Rowand
	2. Vertically flowing pulp	gravity	stationary	Davis magnetic Log washer
				Heberle separator

Of the above magnetic separators, the typicals are

1. Edison Gravity fall magnetic separator
2. Ball Norton drum magnetic separator
3. Dings - induced-roll magnetic separator
4. Wetherill Rowand cross-belt magnetic separator
5. Davis magnetic log washer etc.

1. Edison Gravity Fall Magnetic separator : →



As shown in the figure, it consists of a bar magnet. The ore in the form of thin stream fall in front of the poles, susceptible particles being deflected inward and non-susceptible particles continuing to fall undeflected. This separator was not wholly successful because of inability to control flow of solids in a thin stream and lack of control over the speed of the falling particles.

2. Ball-Norton Drum Magnetic Separator:

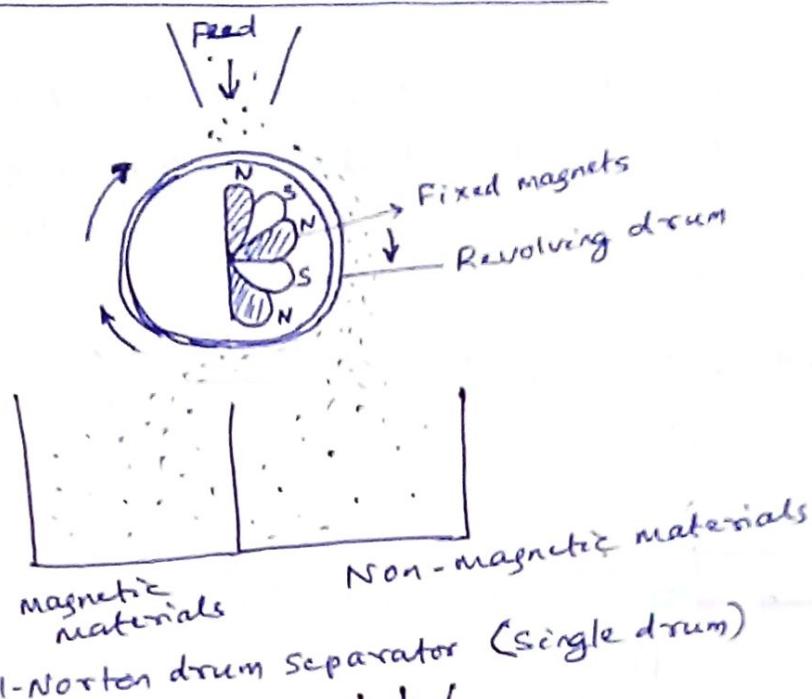


Fig. Ball-Norton drum separator (single drum)

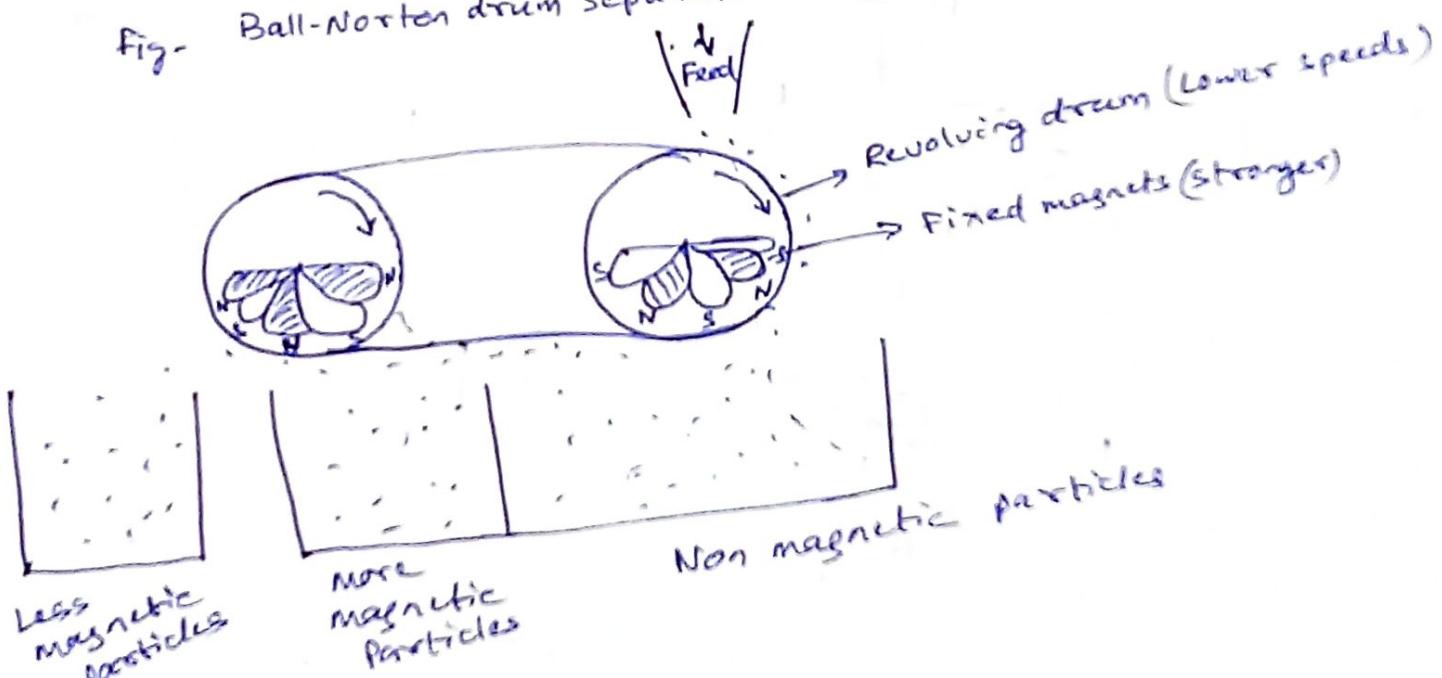


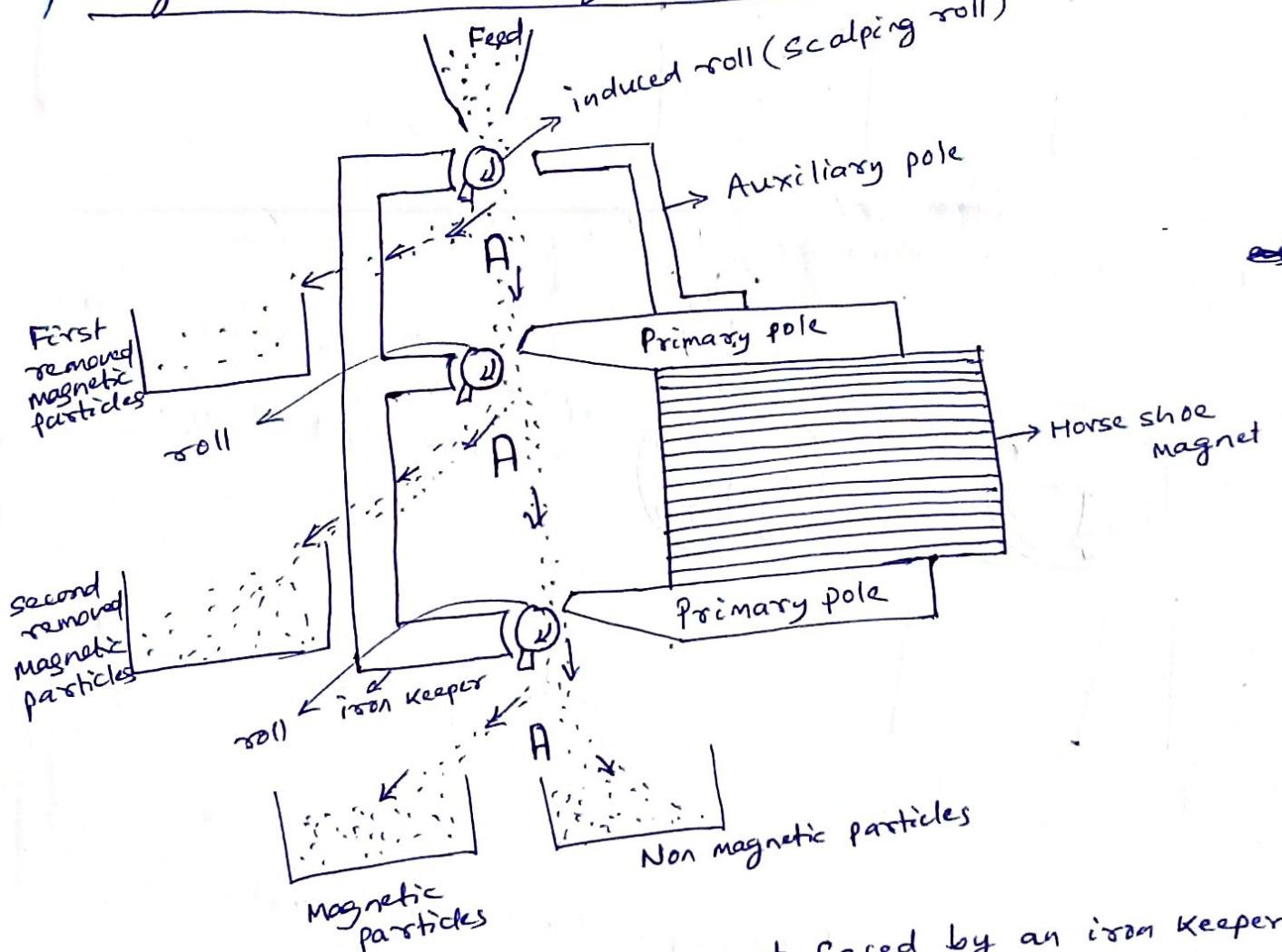
Fig. Ball Norton drum separator (two drums)

The Ball-Norton drum separator consists of one or two rotating drums of non-magnetic metals. In drums, a number of fixed magnets are arranged in such a fashion that consecutive poles are opposite nature.

Much of the magnetic field passes directly from one pole to the other inside the drum, and, thereby is washed. But enough flux lines come out of the drum to attract and hold the magnetic particles strongly. The particles which are magnetic stick to the surface of the drum and travel along the periphery. They are finally scrapped off from the surface of the drum by the help of a scrapper. The non-magnetic particles just fall off at the edge of the drum during rotation.

In a two drum Ball Norton separator, the 2nd drum revolves at a higher speed and has weaker magnets inside. This magnetic separator is used for concentration of low grade magnetic ore.

Ding's induced roll magnetic separator:



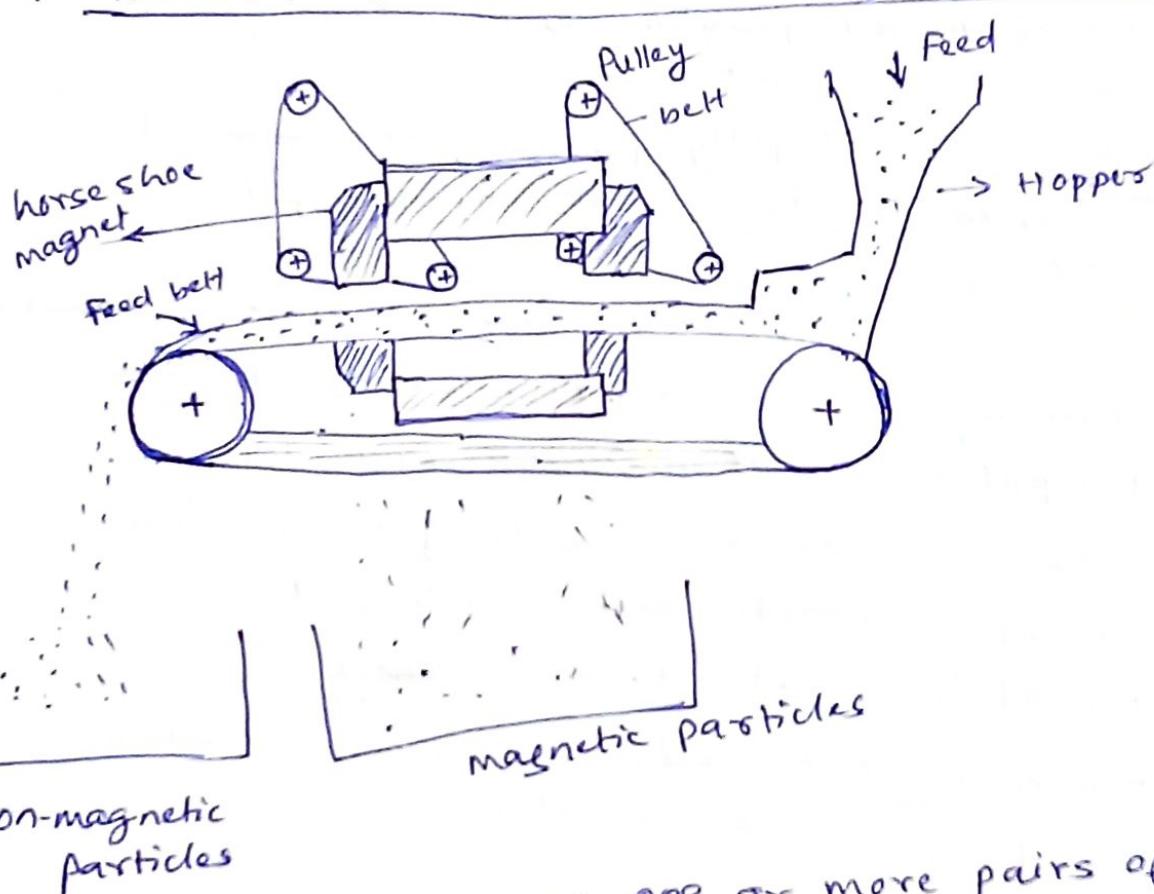
It consists of a horse-shoe magnet faced by an iron keeper and consists of two rolls, one opposite each ~~the~~ pole.

The rolls are laminated so that the magnetic field is strongly convergent toward the roll at the place where the roll is closest proximity to the primary pole.

The rolls act as the secondary pole. The strength of the secondary pole varies with time, as the roll revolves ~~is~~ being ~~nil~~ nil twice per revolution.

As the ore passes over a roll, the susceptible particles are drawn to the laminated roll from which they fall only while the non-susceptible particles fall earlier than those. If the separator is used to separate freely magnetic from non magnetic material, a scalping roll is used. This is made by extending the first primary pole so as to have a branch or auxiliary primary pole. It permits primary removal of most strongly magnetic particles.

Wetherill Rowand Cross belt magnetic Separator: →



This machine consists of one or more pairs of powerful horseshoe electro magnets, one below and other above the feed belt. The magnets are arranged in such a way that there is very small air gap. The upper magnet is convergent by rounding or pointing while the lower one being flat above which the feed belt passes.

In operation, the ore is fed over a feed belt at one end which is provided a hopper for feeding. Cross belts prevent the susceptible particles from sticking to the upper poles as jump from the lower belt to the region of denser magnetic field.

The Separation depends on various parameters such as field intensity, shape of pole pieces, distance apart of pole pieces, specific gravity of the ore and speed of the feed belts.

Applications of Magnetic Separation

Magnetic separators are used

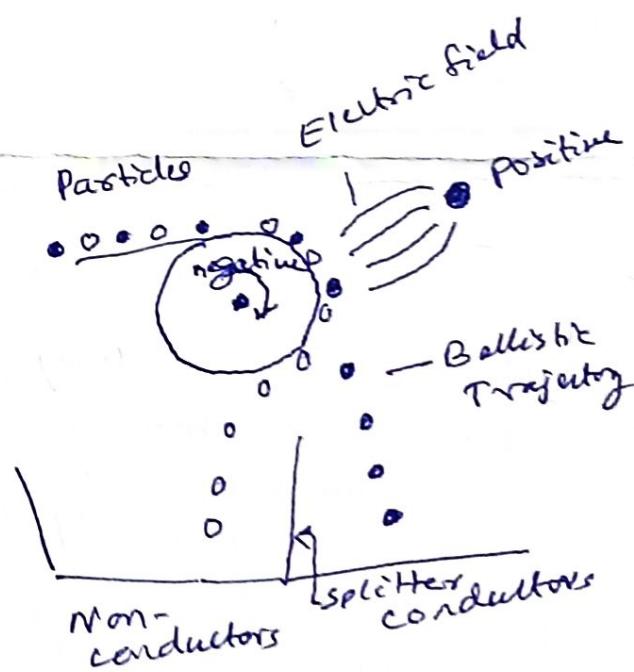
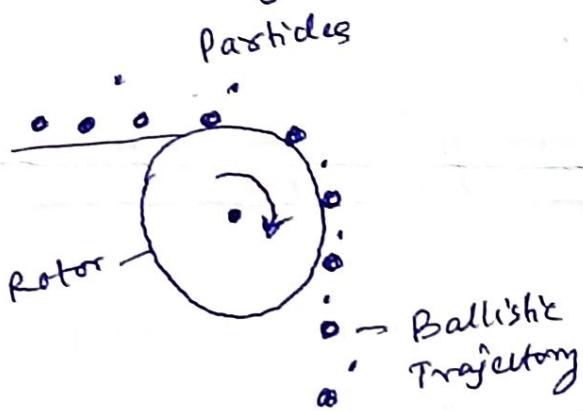
- ① For the removal of the tramp iron ore in coarse and intermediate crushing circuits, as a protection to the crushing machinery.
- ② For the separation of iron ores rendered ferromagnetic such as haematite, limonite, siderite, pyrrhotite, Marmatite, monazite, chromite, garnet, rutile and manganese minerals.
- ③ For the separation of minor quantities of iron ferruginous minerals from ceramic raw materials.
- ④ For the concentration of slightly paramagnetic minerals such as Mn, W, Cr, Sn, Zn, Ti, Ce, etc by using high intensity separators.
- ⑤ By the use of wet magnetic separators, much of phosphorus and Sulphur can be removed from iron bearing minerals.
- ⑥ Others typical applications of magnetic separators are
 - (a) Separation of cassiterite from tungsten minerals.
 - (b) separation of monazite from rutile and garnets.
 - (c) Separation of chromite from silicates
 - and (d) separation of magnetic minerals from corundum, barite and other concentrates.

Electrostatic Separation

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Separation of minerals utilising differences in their electrical properties may be carried out using an electrostatic separator. It will separate electrical conductors (minerals such as cassiterite and rutile) from those that are electrical non-conductors (minerals such as zircon and siderite).

The principle of separation is that as the particles to be treated are passed through an intense electric field, each particle acquires a charge. The conductors pass on their charge when emerging from the field while the non-conductor retains their momentarily. Separation is effected by passing the particles on to a rotating metal cylinder (roll), with any external forces, all the particles will follow a ~~normal~~ ballistic trajectory when leaving the roll surface.



In the presence of an electric field, the rotor becomes negatively charged, while the particles are positively charged. The non-conducting particles loss their charges to the roll and follow the normal trajectory. Separation is affected by splitter plates

Types of Electrostatic Separators: →

They are of mainly two types:

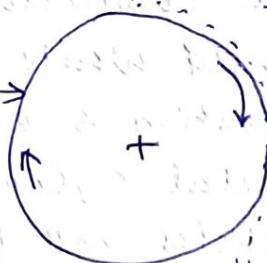
(1)

Blake-Morscher Electrostatic Separator.

(2) Huff Electrostatic separator.

(1) Blake-Morscher Electrostatic Separator →

Electrified
roll



poorer
conducting
particles

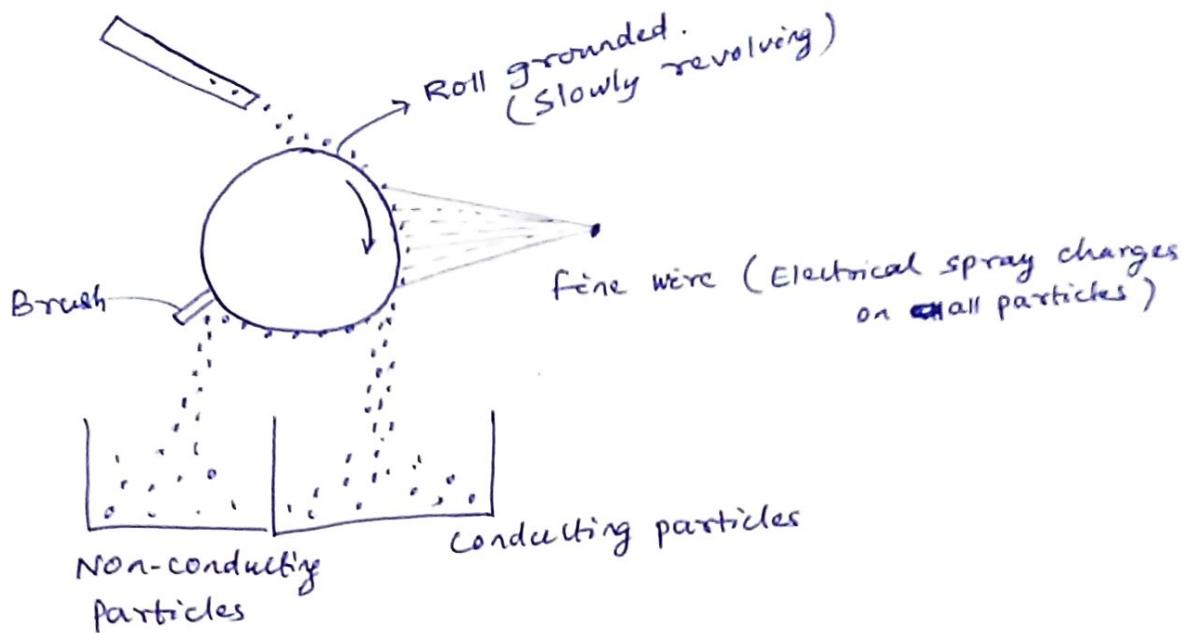
Better conducting particles

It consists of a slowly revolving electrified roll which draws feed from the bin, the conducting particles are thrown clear of the path of free fall while non-conducting particles fall under the influence of gravity.

Principle: → When different types of minerals are given an electrostatic charge, and then brought into contact with a good electrical conductor, the charge leaks away from a good conductor more rapidly than from a bad conductor. This process of ~~charging~~ discharging is combined with a falling of particles in air so as to separate a mineral which is a good conductor of electricity from one which is not. That means, when conducting particles are brought into a conducting surface, the particles become charged by induction. The total charge on each particle becomes nil, but the distribution is such that the total charge on the particle will be opposite in sign to that of the conducting surface, as a result repel each other. Non conducting or poorer conducting particles are unaffected and fall under the influence of gravity.

2. Huff Electrostatic Separator:

In Huff electrostatic separator, the principle is somewhat same to that of Blake Morscher type Separator, but in this case, the roll is charged with a charged fine wires situated at one side of the roll.



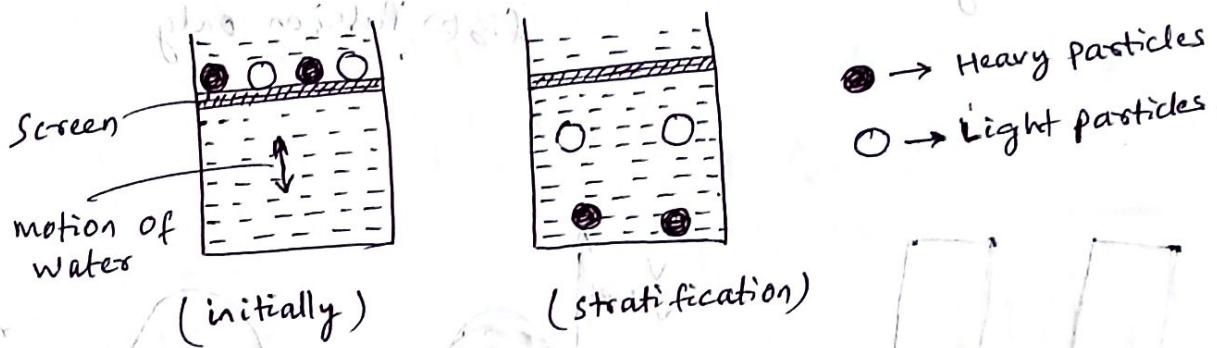
In the principle, the conducting particles lose the charge quickly by passing them to the grounded roll and they fall down unaffected and the non-conducting particles acquire a charge by induction and this induces in the ground roll a charge of opposite sign and are dropped off or scrapped off because of leakage of the charge.

Applications:-

- (i) To separate conducting ore/minerals from non-conducting materials in ceramic industries.
- (ii) This is applied for beneficiating beach sands to separate conducting minerals from non-conducting ones in rare earth plants.
- (iii) Beneficiation of coal
- (iv) It is used for separating monazite, spinel, sillimanite, garnet, zircon, rutile and ilmenite from heavy beach or stream placer sand.

Jigging

Jigging is one of the oldest methods of gravity concentration of ore. It is a special form of hindered settling, resulting in stratification of particles into layers of different densities. The stratification is caused by repeated upward and downward current of fluid to a very thick suspension of the mixed particles to settle or fall for short periods of time. A pulsator forces the water up through the screen with adequate velocity. This upward movement is called pulsion, and the minerals of two or more specific gravities arrange themselves. Then the water is allowed to drain back through the screen and this ~~downward~~ downward movement is called suction. During this action, small grains move downward through the interstices between the large grains. The cycle of pulsion and suction is repeated continuously. Finally the stratified layer is discharged into concentrate, tailing and middlings.



Factors affecting stratification in Jigging →

As a result of repeated cycles of pulsion and suction, the individual particles find its position in its most stable horizon in the mass and becomes stratified with other particles. The stratification taking place in Jigging is influenced by the following factors:

- The size range of the total load in the Jig box.
- Size, shape and specific gravity of different particles.
- The apparent density of the bed.
- The average particle shape in the bed.
- The density of surrounding particles.
- The pulsion and suction rates of fluid and height of rise.

(g) volume of voids and their distribution, layer by layer

Jigging cycles

A complete cycle of one suction and one pulsion is known as Jigging cycle. In pulsion, the fluid moves upward and in suction, it moves downward with reference to a stationary point or screen. Most Jigs use both pulsion and suction but in some Jigs the suction is avoided. The plot of fluid velocity with respect to time to describe a full cycle of pulsion and suction is known as Jigging cycle. The following figure shows various Jigging cycles.

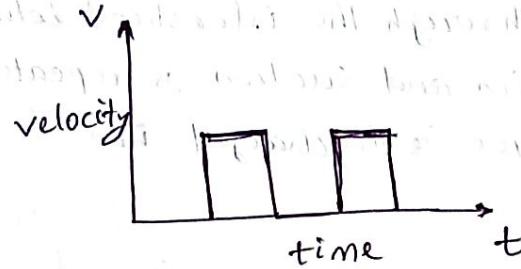


fig.(1) Pulsion only



fig.(2) Pulsion only

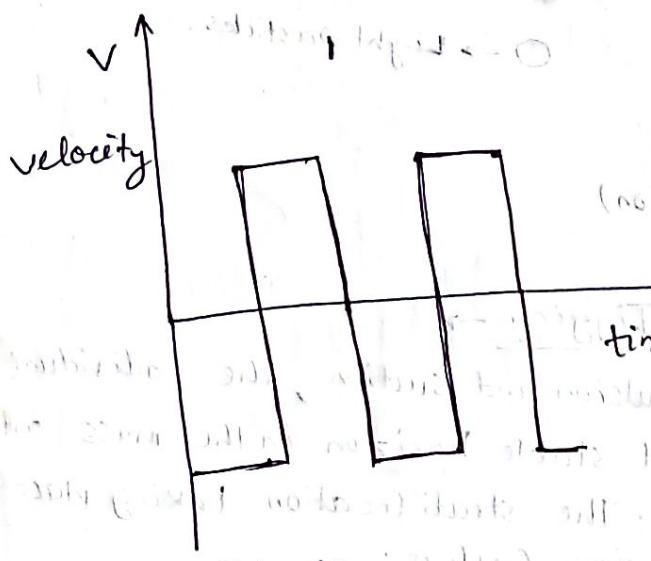


Fig-(3)

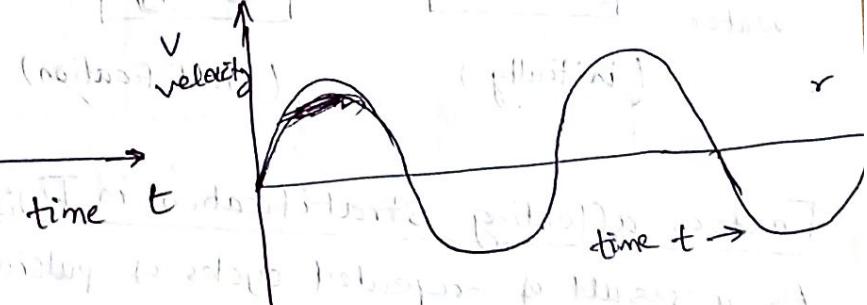


fig-(4) Pulsion and Suction

Fig (3) and (4) use pulsion and suction which are fully symmetrical

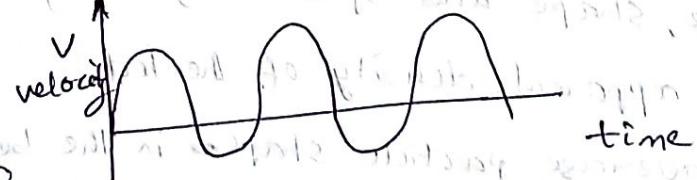


fig-(5)

Fig-(5) Pulsion is more and Suction is less.

If two particles settle to equal distance during a fixed time period of fall, they are said to be equally jiggging or equal-jigging particles.

Jigging characteristics : →

1. Jigging Ratio: → gt is the ratio of diameters of equal-jigging particles. This varies enormously with the duration of fall.

Clearly, if jigging is practised on unsized feed to poorly sized feed, a very short settling time must be used if stratification is to result. If jigging is practised on feed closely sized by screening, stratification may result even if a long settling time is used.

Methods of Jigging →

Jigging methods are mainly classified into two classes based on arrangements of withdrawing the products: They are

- (1) Jigging on screen
- (2) Jigging through screen

1. Jigging on screen: → This method employs the supporting screen with smaller apertures than the feed size. Concentrate as well as tailings after their desired stratification are removed from jig bed via side ports. The rate of withdrawal is so adjusted that a bed of desired thickness is maintained. The travel of bottom layer may be facilitated by the use of a sloping screen. The top layer may be removed through crowding of bed by new feed. Jigging on screen should preferably be conducted with a slight deficiency in suction.

2. Jigging through screen: → This method employs the screen of larger apertures than that of the feed size. An oversized bed of selected material (broken ore, steel shot, metal discs etc) called the bedding or ragging is required on the sieve to prevent the passage of the light product into the hutch and permitting the passage of heavy product in the hutch. The bed is maintained in a suitable thick layer.

Types of Jigs

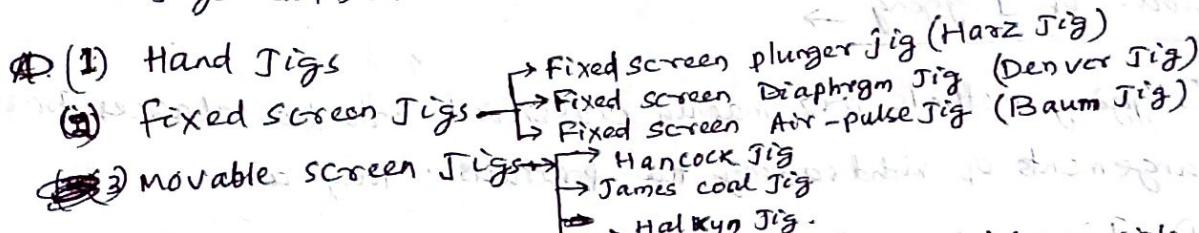
In general, the jigs are tanks of rectangular cross section with a screen fitted below the rim or overflow at a short distance in a horizontal or slightly sloping position. The screen or water is given a pulsating or zigging motion which causes an upward and downward motion of fluid through the screen. The feed is introduced over the screen at one side and subjected to a series of short settling periods as it moves across the screen to overflow.

The Jigs can be classified based on the fluid used, i.e.

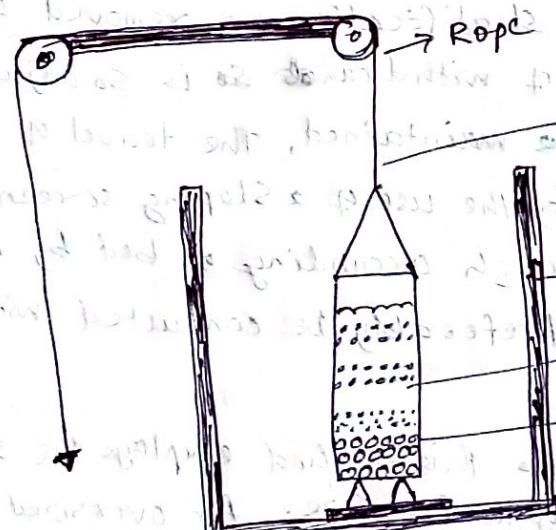
1. Hydraulic Jigs (using water)

2. Pneumatic Jigs (using air)

Hydraulic Jigs can be further classified into the following types



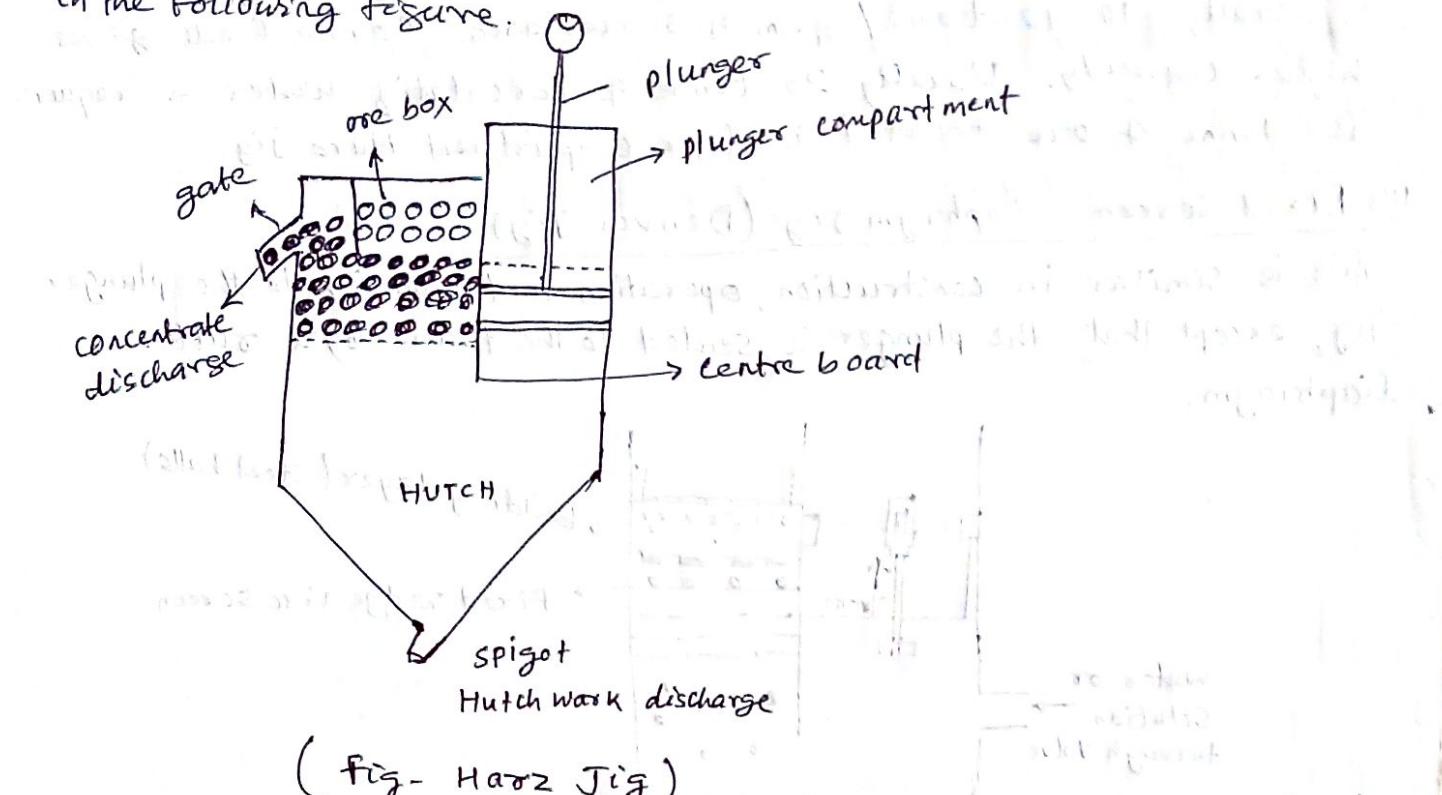
(1) Hand Jigs → This is the simplest of all jigs which consists of a framed sieve held by hands and is actuated by the operator with a reciprocating vertical motion.



In general, a perforated cylindrical shape container is used. After filling up the minerals into the vessel upto the desired level, it is closed tightly. With a rope and pulley arrangement, it is made to up and down in a water tank or hutch to attain the condition of pulsion and suction of water in the mineral bed and stratification takes place.

Fixed screen plunger Jigs (Harz Jig) :

This is the oldest type of Jig in use. This was developed in the Harz Mountains in Germany to treat lead-zinc ores. It is shown in the following figure.



The Harz Jig is usually made of steel or concrete. It has a fixed screen consisting of an ore box which occupies about half the plan area of the hutch (compartment in a water-filled tank). The other half of this compartment consists of a loosely fitting plunger which moves vertically to pulse the water upward and downward. Additional hydraulic water is used to aid in controlling the tightness of the closed bed. Several successive compartments, usually four, are placed in series in the hutch. The sized feed is charged gently at the head of the first compartment without upsetting the stratifying work. The controls are so manipulated (maximum amplitude of Jig in the first compartment and minimum in the last) as to produce high grade concentrate in the bottom of the first compartment. The lighter fraction stratifies upward and passes over to the second compartment and further to the next compartment till it is finally discharged as tailing from the last box. The control over the pulsion and suction amplitudes can be obtained by controlling the opening of the hutch discharge and by varying the amount of rising water. The tailings (upper layer) can be discharged over a weir at the side opposite the feed. The concentrate (lower layer) can be discharged either through the gate when feed is coarser than aperture of screen) or as hutch product

through a valve (when feed is finer than aperture of screen). The length of stroke depends upon the size of the feed and may range from 0.5 to 8 cm (coarse feed requires long strokes). Jigging cycles may range 100 to 300 strokes per minute. The capacity of jigs is usually 10-40 tonne/sq. m. of screen area. Coarse feeds gives higher capacity. Usually 20 tonne of circulating water is required per tonne of ore treated in four compartment Harz jig.

(ii) Fixed Screen Diaphragm Jig (Denver Jig)

This is similar in construction, operation and capacity to the plunger jig, except that the plunger is sealed to the frame by a rubber diaphragm.

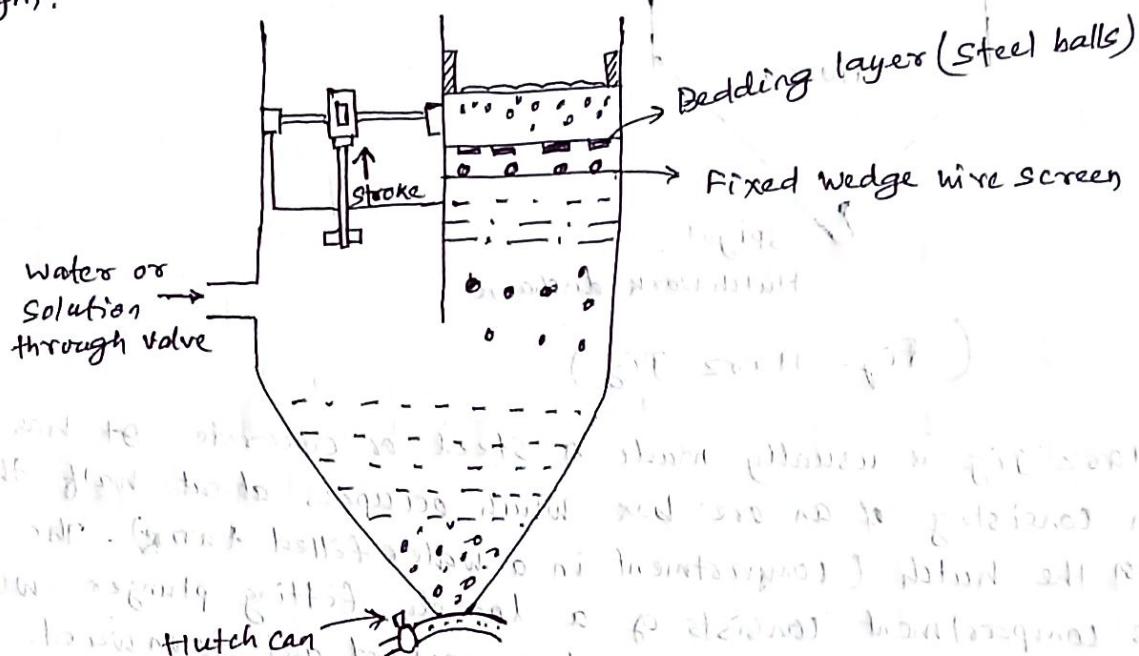


Fig: Fixed screen diaphragm jig. (Denver Jig)

This gives more positive pulsion and suction due to the prevention of leakage around the plunger. The most commonly employed jig in this category is, Denver Jig as shown in the figure. The movement of diaphragm head is vertical and a long stroke is possible. The action of diaphragm results into positive pressure and the bed is lifted with less pulsion. If desired, more suction can be had.

Water can be admitted below the screen through check valves either with suction (upward stroke) or the pulsion (downward stroke) of diaphragm.

(iii) Fixed Sieve Air-pulse Jig (Baum Jig)

The most important of fixed sieve air-pulse jigs is Baum Jig. The distinct feature of this jig is that the water is pulsed by means of compressed air and no suction stroke is used. The bed is ~~reclosed~~ reclosed by unassisted gravitation. The Jig box has a U-shaped cross section. Two compartments of such a section forms a complete jig.

The Sieve of the first compartment slopes backward towards the feed end.

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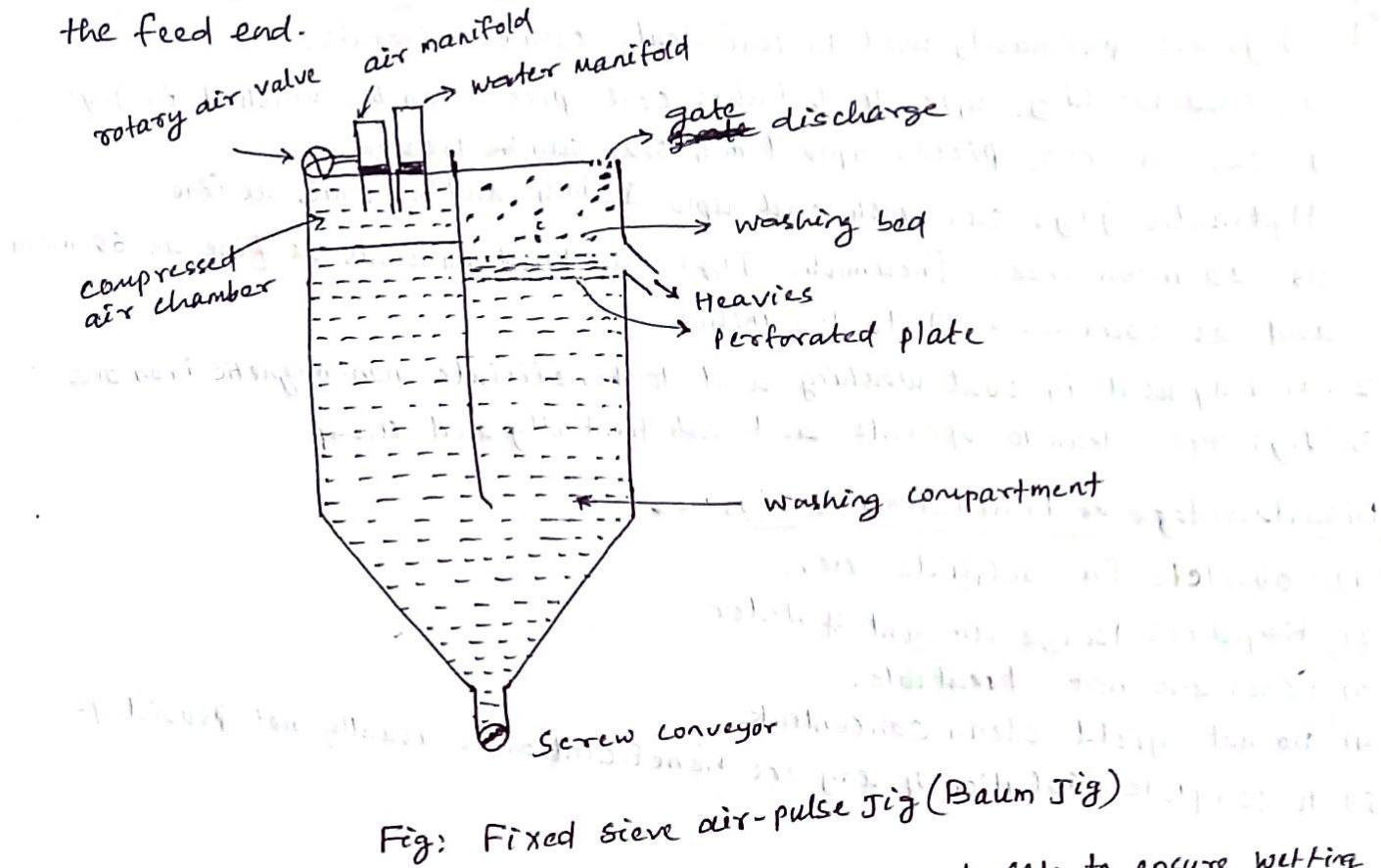


Fig: Fixed sieve air-pulse Jig (Baum Jig)

The feed is admitted gently below a very shallow baffle to ensure wetting and prevent excessive disturbance to upset the stratification. The air pressure used is approximately 0.1 to 0.15 kg/cm². Most of the dirt falls in the first compartment and a part of it falls through the screen to a spiral conveyor, which takes it out.

(3) Movable screen Jigs.

In this type of jigs, the screen box is moved upward and downward with fore and aft motion in a tank of water either by hand or power. Acceleration at one end is more than at the other to cause the bed to move forward. The compound motion can be obtained from a cam through a set of levers, links and rocker arms. The Jigging is carried out through the screen. The concentrate accumulates in the hutch of the first compartment whereas the middlings are collected in the hutch of the last compartment. The other compartments make concentrate or tailing, depending upon the characteristics of the ore and requirements. The important Jigs of this class are Hancock Jig, James coal Jig and Halkyn Jig.

Advantages of jigs →

1. Jigs are primarily used to concentrate coarse minerals.
In coal washing, upto 4-5 inches coal pieces can be washed in jigs
In case of ores, pieces upto 1 inch size can be treated.
Hydraulic jigs can wash coal upto $\frac{1}{8}$ inch and minerals as fine as 20 mesh size. Pneumatic Jigs can treat minerals as fine as 65 mesh and as coarse as 1 to 1.5 inches.
 2. Mainly used in coal washing and to beneficiate non-magnetic iron ores.
 3. Jigs, are clean to operate and save costatty and cheap.

Disadvantages or Limitations of Ticks: →

- (1) Obsolete for sulphide ores.
 - (2) Requires large amount of water
 - (3) Fines are not treatable.
 - (4) Do not yield clean concentrate
 - (5) A complete solution of any ore beneficiation is usually not provided