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Mineral Dressing / Benefication

Ques: Operating steps involved in Mineral Dressing.

There are 4 principle types of operation accompanied by no. of auxilary operations -

(1) Comminution (Size Reduction) - It involves reduction of minned ore to a smaller size. It is accompanied either on dry ore or in aqueous pulp. Depending upon the size of the material being comminuted, the operation is regarded as crushing or grinding. Crushing is normally conducted on dry ore and grinding may be wet or dry.

(2) Sizing - Sizing is the separation of a material into products characterized by difference in size. This can be accomplished by screening or classifying. Classification is the sizing method depending upon the relationship between the size of mineral particles and their settling velocity in a fluid medium, generally in air or water.

(3) Concentration - It may be accomplished by washers, sluez boxes, shaking tables, flotation cell, magnetic separator, electrostatic separators or other specific concentrating device. It can also achieved by screens, classifiers or a combination of screens and classifiers.

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(4) Dewatering - It is generally carried out only to the extent of producing a damp cake in 2 steps. First is the thickener to remove most of the water then infilters which receive thickened pulp and yield the damp mineral cake. Further dewatering is desired dryers are used for evaporation of moisture.

Auxilary Operations are quite diverse. They involve storing in bins, conveying, sampling, weighing, reagent feeding, pulp distribution, etc.

Terminologies -

The feed to a concentrating machine is known as Heading. It is a material received for separation. The products of the separation are the concentrate and tailing if only 2 products are made. The concentrate is the valuable part and the tailing is the discarded product. If more than 2 products are made, then the other may be an additional concentrate or a middling.

When a concentrate is not of sufficiently high grade and it is graded up by the re-treatment the primary operation is known as Roughing operation and the re-treatment operation is Cleaning Operation. If several stages of re-treatment

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are used, they may be termed as re-cleaning or re-recleaning operation. The concentrate obtained from primary operation is the rougher concentrate and that obtained from cleaning operation is the cleaner concentrate.

CRUSHERS

Classification of Crushers - Based on application, crushers can be classified as:

1. Crushers for Primary breaking -
   Eg: Jaw Crusher & Gyratory crusher.

2. Crushers for Intermediate or Secondary crushing -
   Eg: cone crusher, disk crusher, spring roll.

3. Crushers for fine crushing -
   Eg: gravity stamp mills.

4. Crushers for special use -
   There are numbers of special machine for soft materials designed to limit over production of fines or to crush selectively the more friable constituents of soft material.
   Eg: Hammer Mills, toothed rolls.

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JAW Crushers

Characteristics of Jaw Crushers -

(1) Jaw Crushers are intended for primary breaking of lumps. Accordingly they have a relatively large gape. The length of the receiving opening is usually greater than the width.

(2) Jaw crushers have an adjustable discharge opening so that they can produce product of size range depending upon the adjustment.

(3) A high reduction ratio ~7 can be obtained although in some cases, the ratio is as small as 4.

(4) The capacity of a Jaw crusher is very large.

$$T = 0.6\,L\,S$$

T → capacity (Tons/hour)

L → Length of receiving opening (inch)

S → width of discharge opening (inch)

(5) The energy consumed by Jaw crusher varies considerably. It depends upon the size of feed, size of product, capacity of machine, properties of mineral and the percentage of idling time. The energy consumption decreases with

increasing size of the feed for constant reduction ratio, with increase in size of the product at constant size of feed and with increasing capacity of the machine.

(6) The attendance is usually one man per machine.

(7) Breakdowns are usually caused by chunks of metal jamming in the crusher and fracturing toggles, pitman or eccentric. Another source of breakdown is the failure of lubricating systems.

(8) Wear loss is a substantial source of expense in jaw plate and cheek plate both of which must be replaced time to time. Wear cost consist of cost of new plate, labour and time lost to operation.

Gyratory Crusher

Gyratory Crusher consists of those substantially vertical, trunketed conical shell, the outer shell having its apex point down and the inner shell having its apex pointing up. The outer shell is stationary and the inner shell is made to gyrate or rotate.

Characteristics:-

→ The capacity of gyratory crusher is much higher than jaw

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crushers for handling same size of feed. Gyratory crushers have a gap suitable for coarsest crushing step with an excessive capacity.

→ The Gyratory crusher has a more regular power draft than jaw crusher. This is because gyratory crusher is crushing continuously whereas the jaw crusher work intermedently. In respect to reduction ratio, Gyratory crusher do as well as Jaw crushers, in respect to power consumption at equal capacity, two types of machines are equivalent but at equivalent gap the gyratory crusher is advantageous as it has higher capacity.

→ If the quantity to be crushed is sufficiently small to be handed by one jaw crusher, the installation of gyratory crusher is economical.

Cone Crusher

→ They are used for intermediate crushing.

→ The principle of operation of cone crusher is analogous to gyratory crusher with two exceptions:

(i) The outside crushing surface flairs out to provide an increased area of discharge for the crushed material. This is necessary if a substantial capacity is to be achieved.

(ii) The outer crushing surface can be lifted away from the lower crushing surface when an uncrushable obstruction enters the machine.

→ For optimum performance cone crushers must be provided with a dry feed of fine particles. If this is not done the crusher may clogged.

→ Lubrication of all moving parts in an enclosed oil bath is used and a special oil cooler is required.

Comparison of rolls crushers with other crushers -

→ Rolls are characterized by production of smaller proportion of fine than other crushers.

→ The reduction ratio is smaller for roll crusher. To obtain a higher reduction ratio, rolls of bigger diameter is required.

$$\Delta h \approx \mu^2 R$$

However, it also increases the weight of the machine and increases difficulties of construction in practice due to the springing of the roll. In loaded condition, actual reduction ratio is much smaller.

→ Because of limited reduction ratio often rolls are not installed.

// With the increasing use of flotation as a concentrating method, the advantages of the roll i.e. production of minimum amount of fine has siezed to be valued. The combination of cone crusher with ball mill is often sufficient to reduce the ore to a fineness suitable for flotation.

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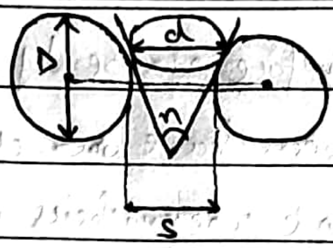
Angle of Nip



n = Angle of nip ; D = diameter of roll ; d = diameter of particle to be nipped ;
N = Normal force ; T = Tangential force ; R = Resultant.

Vertical Component –

$$N_V = N \sin(n/2)$$

$$T_V = T \cos(n/2)$$

$N_V = T_V$

$\Rightarrow \tan(n/2) = \left(\frac{T}{N}\right)$ = coefficient of friction = ϕ (say)

$\tan(n/2) \leq \phi$ (necessary and sufficient condition)

Calculate S

S = separation distance

$$\left(\frac{S}{2}+\frac{D}{2}\right) = \left(\frac{D}{2}+\frac{d}{2}\right) \cos n/2$$

$$\Rightarrow \boxed{\cos(n/2) = \left(\frac{D+S}{D+d}\right)}$$

coefficient of friction

Ques – The CoF is 0.4, what is the minimum diameter of the roll to reduce 1.5 in piece of rock to 0.5 in piece of rock?

Sol – $d_i = 1.5$ inch

$d_f = 0.5$ inch

$D = ?$, $\mu = 0.4$

$\because \tan(n/2) = \phi = 0.4$

$\Rightarrow n/2 = 21.98'$

so, $\cos(n/2) = 0.9285$

$\left(\frac{D+0.5}{d+0.5}\right) = 0.9285$

$D = 12.5$ inch (Ans)

Unit operations in Mineral Processing

1. Comminution

Process	Description	Properties of mineral exploited
Crushing & Grinding	subdivision of mineral lumps & particles into smaller pieces	Brittleness

2. Sizing

Process	Description	Properties of Mineral exploited
Sorting or Hand-picking, Screening.	separation according to the size.	relative difference in size and density among mineral particles.
Hydraulic Classification	settling in fluid	Relative difference in density.

3. Concentration

(A) Gravity Concentration Process	Description	Properties of mineral exploited
Heavy Media Separation	settling in liquid	Relative difference in density among particles
~~(a)~~ Jigging	settling in liquid	Relative difference in density among particles.

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Process	Description	Properties of mineral exploited
~~Tabling~~ (A) Tabling	Frictional Movement along weight vibrating ~~wide~~ solid surface.	Density, size, shape & coefficient of friction.
(B) Magnetic Separation	Separation due to Magnetic field in dry or wet condition.	Magnetic susceptibility & Magnetic permeability.
(C) Electrostatic Separation	Charging and charge loss of particles & their deflection in electrostatic field.	Conductivity & charge retention characteristics.
(D) Flotation	(a) attachment of gas bubbles to mineral in aqueous pulp concentrating surfactants & frothers.	→ Surface properties
	(b) Preferential froth flotation for some minerals	→ Affinity for specific surface active reagents.

4. $\boxed{\text{Dewatering}}$

Process	Description	Properties of ME
Sedimentation thickening	Settling of particles	Non-specific
Coagulation	Neutralisation of charge or repulsive force	Adsorption properties of mineral ~~may be~~ ~~have~~ may lead to benefication
Filtration	Solid-liquid separation	Non-specific
Drying	Removal of moisture from moist solid	Non-specific

~~Agglomeration~~

Agglomeration

Process	Description	Properties of M.E
Pelletizing Sintering Nodulizing	Obtaining bigger lumps from small particles ~~to~~ ~~ato~~ through adhesion or incipient fusion	Solid-solid RX at interfaces

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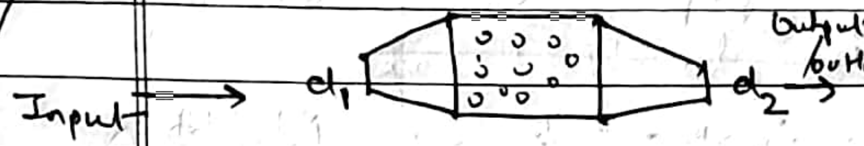
GRINDING

e-N mill

Characteristics of Cylindro-conical mills -



$d_1 > d_2$

Inlet dia.

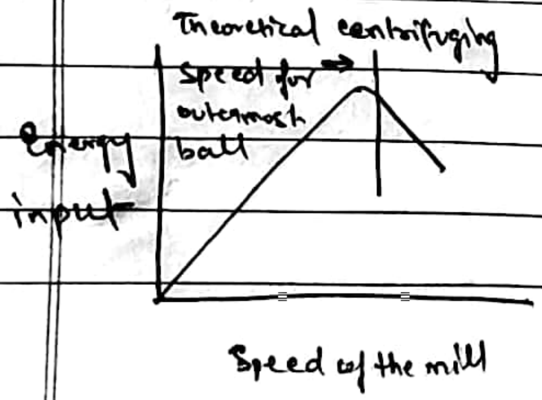
Outlet dia.

(1) Initially with the increase in speed of the mill, work input increases. As sleepage starts, the work input increases more ~~steadily~~ slowly than speed. Beyond the critical speed, power input decreases rapidly. If the solid charge gets ~~cenf~~ centrifused on the mill shell, there is no work done by the mill.

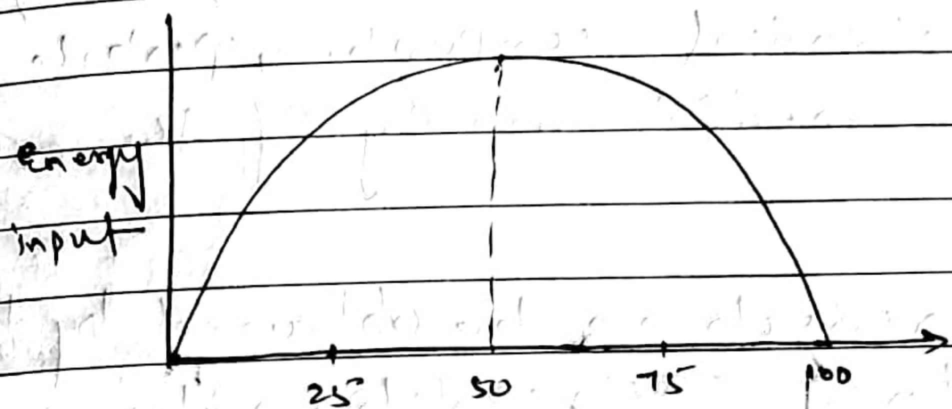
$$\text{Critical Speed }(N) = \frac{54.2}{\sqrt{S-s}}$$

where

S, s are radii of mill and ball (in feet)



(2) The energy consumed by the mill is not only the function of speed of the ball but also of the ball load specific gravity of the ore and the dilution of the pulp.



Ball load, percentage of load filling the mill

If the ball load is increased, the power consumption increases to a ~~maximum~~ maximum beyond which power input decreases gradually. The energy input is proportional to the product of load and ~~dist~~ lever arm. With the increase in ball load, the centre of gravity comes more & more nearer to the axis of rotation of the mill, Hence, the energy input will increase or decrease more rapidly with the change in lever arm.

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(3) Pulp dilution has a considerable effect ~~for~~ on energy input. For a certain critical range in pulp dilution (60-75%), the energy input is maximum. This range depends on chemical composition, particle size, and specific gravity of the ore.

(4) The reduction ratio obtained by the mill is large. The reduction ratio ranges from 50-100 for ball-mill-classifier circuit. To use larger reduction ratio economically, the ball mills should be arranged in series.

(5) The capacity of ball mill depends upon the size of the mill, hardness of the ore, attempted ~~adequate~~ size reduction and the efficiency of the operation.

(6) The cost of grinding is divided into 3 categories: power, supply & labour.

If the tonnage handled is small, the labour cost is less than other two.

(7) Ball mills are usually employed for weight pulp. However, in some cases, specially in chemical industries, ball mills are employed for dry grinding.
Eg: Grinding of coal for the ~~prepart~~ preparation of pulverized fuel.
Dry Grinding are often used to produce extremely fine product.

Rod Mill

(1) Balls mills and Rod Mill are similar in appearance and in general principles.

$$A_{effective}\Big|_{ball} = n \times \pi r^2$$

$$A_{eff}\Big|_{Rod} = 2\pi r \times l$$

(2) Rod Mill can be described as rotating cylindrical shell loaded with rods that

grind the ore by tumbling within the shell. Rod Mills have length greater than diameter to avoid jamming of the rods inside the mill. On the other hand, the dia. of the ball mill is equivalent to the length.

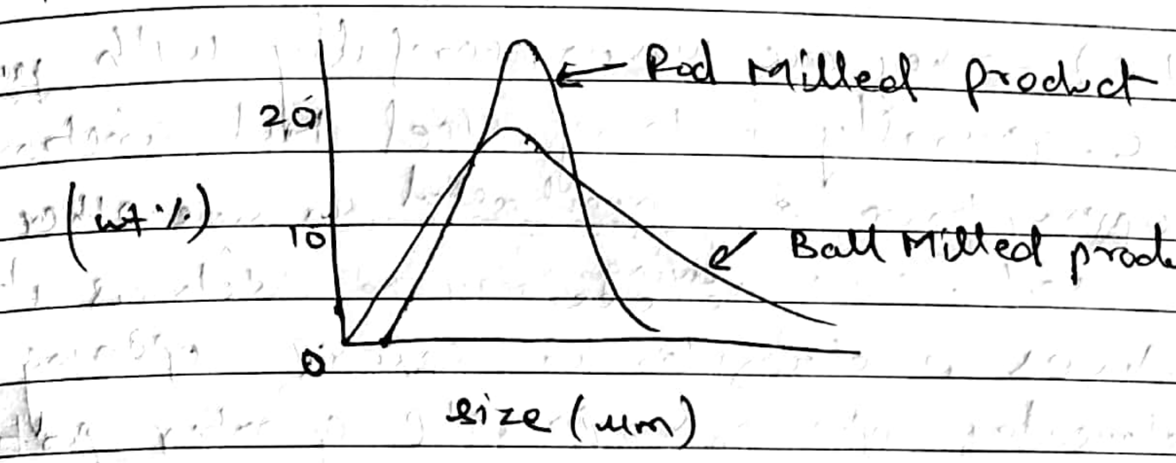
~~Sub~~

Such configuration of the ball mill yields greater capacity for a given weight of the machine.

(3) The grinding action of the Rod mill is different from the ball mill in that the rods are kept apart by the ~~fine~~ coarser particles. Therefore, rod mills are used for intermediate grinding where concentrating process does not require very fine particles. In contrary to this, whenever floatation is required, ball mills are preferrable.

(4) The main disadvantage of rod mill is the wear of the rod which occasionally wrap ~~~~ and cause entangling of the rod load.

(5) Rod Mill produces more closely sized product than ball Mill.



Industrial Screening

Screening Surfaces

- Parallel Rod Screening Surface (PRSS)
- Punched Plate (PP)
- Woven-wire Screening surface (WWSS)

PRSS- These are usually made of steel bar, steel rail, cast iron or wood.

PP- They are made of steel sheet, punched by dice in various patterns. The openings are circular, square or slot like. If the screening surface is to separate coarse size, circular opening is used, if it has to separate ~~the~~ size, then slotted opening is used.

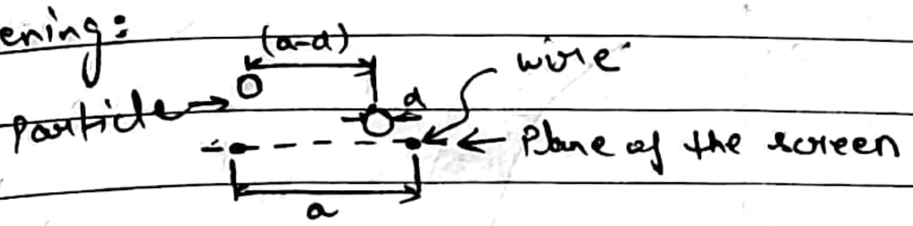
WWSS :- They are woven carefully with gauged wire, generally made of steel but sometimes, copper, bronze, monel metal or some other alloy is used. The waving may be such as it produces rectangular or square opening. Rectangular openings provide greater portion of opening in ratio to the area of the screen than the square opening. Consequently, for coarse screening, a square opening and for intermediate & fine screening, rectangular opening is advantageous.

Factors affecting Screening Process-

(1) The absolute size of the openings — The capacity of a screen is directly proportional to the screen aperture. Therefore, screen capacity is represented as tonnes/ square feet 24h / mm screen opening.

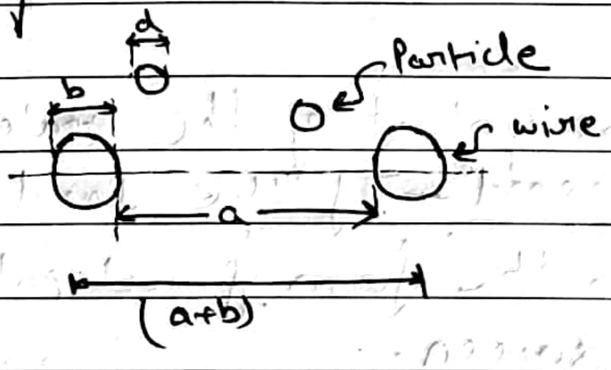
(2) The relative size of the particles to that of the opening —

Case I: For wire of very small section compared to the opening:



$$\text{probability of passage } (p) = \left\{\frac{(a-d)}{a}\right\}^2$$

Case II: For wire of substantial diameter



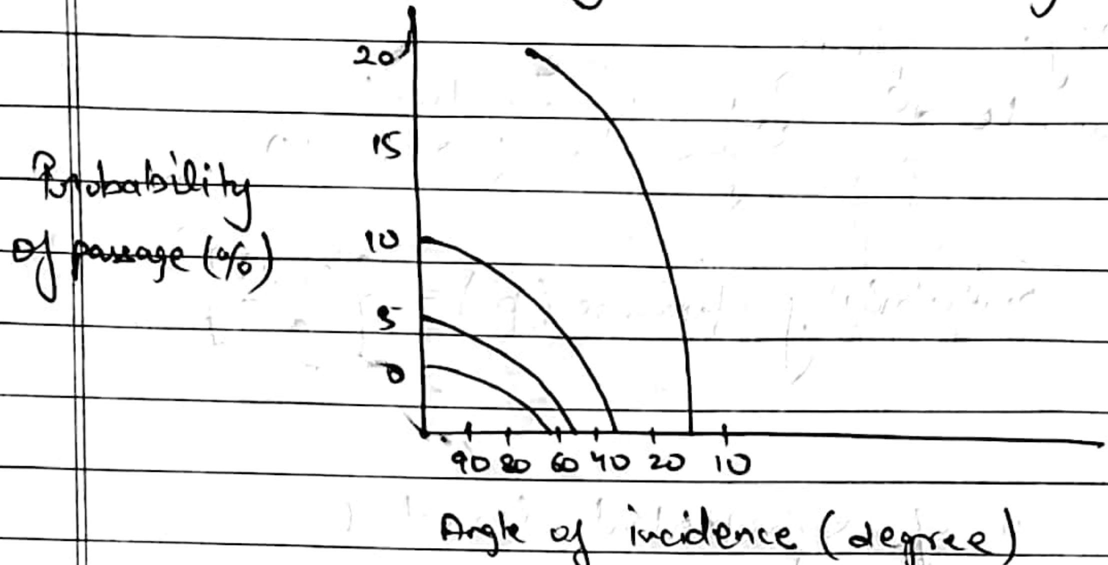
$$p = \left(\frac{a-d}{a+b}\right)^2$$

lower limit of passage

(3) The % of opening to total surface in the screening surface.

(4) The speed with which the particles strikes the screening surface.

(5) The angle at which the particles are striking the screening surface.



(6) The moisture content of the material ~~i.e.~~ that is being screened – If the feed is ~~dry~~ bone dry or in the form of wet pulp, it is relatively easy to screen.
However, small % of water in the dry feed increases difficulty of screening.

Types of screens

- Stationary Screen
- Moving Screen
  - ~~Moving~~ Grizzlies
  - ~~Tommels~~ Trommels
  - Vibrating Screens
  - Shaking Screens

Classification - ~~Crushing~~, ~~Grinding~~, ~~Screening~~
It is a process by which particles of diff. size & specific gravity are sorted out into uniform groups.
Classification differs from sizing in 2 ways-
(1) Classification is normally applicable to a very low range of particle size 65-200mesh

(2) It separates particles on the basis of their densities.

Classification depends on settling rates of individual particles in a fluid, usually water
The difference in the settling rate b/w particles of different sizes & specific gravity is a controlling factor in classification.
There are 2 distinct kinds of settling-
(1) Free settling - It takes place when settling of individual particles is not hindered by other particles, in still water or against a rising current of water.

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(2) Hindered settling — It occurs when particles of different sizes, shape & specific gravity are sorted in a rising current of water. The velocity of the water is less than the settling rate of the particles but sufficiently high to keep them in the turbulent fluid.

Factors affecting settling—

(1) Specific gravity :- A particles that has high SG settles fast.

(2) Shape - A rounded particle settles faster than a narrow grain or a flat grain.

(3) Size - A large particle settles faster than a small one.

(4) Air bubble - A particle that does not adhere to air bubble settles faster than the one that does.

(5) Magnetism - Particles that have a mutual

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magnetic attraction settles faster than those that do not have such attraction.

(6) Density of fluid – The settling rate of particle is higher in a lighter fluid

(7) Viscosity – The settling rate of a particle is higher in a less viscous medium.

Types of Classifiers –
Classifiers ~~fall into~~ can be subdivided into 3 broad categories –

(1) Sorting classifiers using a relatively dense aqueous suspension as fluid medium.
(2) Sizing classifiers using a relatively dilute aqueous suspension as fluid medium.
(3) Sizing classifier using air as a fluid medium.

Sorting Classifier – In sorting classifier, the settling conditions are more or less hindered. The separation achieved in sorting is basically sizing modified by specific gravity & shape. It is usually applied for relatively coarse product.
Eg: Evans classifier, Anaconda classifier, Richards classifier, Hydrotator classifier

Sizing Classifier – This classifier do not require additional water besides that present in the suspension which is being treated. They utilise free-settling condition for sizing as much as possible and remain unaffected by specific gravity & shape.
Sizing Classifier can be further subdivided into –

1. Settling Cone: It does not have any moving part. Eg. Allen cone.
2. Mechanical Classifier: It contains moving part. Eg: Akins Classifier.

#new Pneumatic classifier – The medium used in pneumatic classifier is 50–100 times less viscous than water. In addition, the apparent specific gravity of any pneumatic suspension is appreciably less than that of aqueous suspension of equivalent volume. The settling velocity in pneumatic classifier is roughly 100 times better than water classifier. Consequently, higher fluid

aqueous

velocity prevails & the suspensions are volumetrically more dilute.

Pneumatic Sorting classifier have not been designed & the sizing classifiers are applied to fine particles only. Pneumatic sizing classifiers are used in conjunction with dust collector. Eg: Gayco air separator.

Flowing film concentration & Tabling -

Principle/Operational method - Liquid film in laminar flow have a mechanical property that is easily adoptable for the separation of minerals according to their specific gravity. The velocity of the fluid varies with depth of the film. The velocity is almost nil at the bottom and maxima at or very near to the top. This property also depends on the viscosity of the fluid. The simplest device for ~~sh...~~ flowing film concentration consists of an inclined surface or table on which particles are subjected to flowing water. The lighter particles are washed off while the heavier particles accumulated.

on a perfectly smooth deck or table, the critical angle below which motion of a particle does not occur increases with size of the particle & specific gravity. ~~Under~~

Under sliding condition, heavier particles moves slower than light particles. When other conditions are equal, the speed of particles is directly proportional to the square of film thickness & inversely proportional to the viscosity of the fluid. Increasing the slope increases the velocity but not in direct proportion.

Factors affecting FFC & T

1. The slope of the deck
2. The thickness of the fluid film or the rate of flow of the fluid.
3. Viscosity of the fluid.
4. The coefficient of friction b/w the particles & the deck.
5. Specific gravity of the particles.

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6. Shape of the particles.
7. Roughness of the deck.

Operational Modes of Shaking Table -

In shaking table, adjustments are provided for amount of wash water, the cross tilt, the speed & length of the stroke. The speed of the table usually ranges from 180 - 270 strokes/min. with stroke length of 0.5 - 1.5 inch. The main adjustments are -

(i) For Roughing operation - More water, more ore, more tilt and longer stroke.

(ii) For cleaning operation - Less water, less ore, less tilt and shorter stroke.

(iii) For Fine feed - Less water, Less feed, faster reciprocation, shorter stroke.

(iv) For coarse feed - More water, more feed, shorter reciprocation, longer stroke.

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Application of Flowing Film concentration

1. For the concentration of ~~Case~~ ~~Casse~~ cassiterite.
2. " " " " some ~~ore~~ free-milled gold ore.
3. For the benefication of many non-metallics. eg- glass sand, chromite.
4. For the recovery of relatively coarse ~~pellet~~ pellet-like by product metal in metallurgical work.
5. For the recovery of part of Galena and sphalerite in coarsely aggregated lead and zinc ore.
6. For the benefication of some iron ore.
7. For the cleaning of fine coal.
8. As an adjust- concentrating device for the recovery of free gold in ~~potassium~~ flotation plant and some cyanidation plant.

Heavy-Media Separation (HMS)

It is a special concentration process which depends exclusively on the specific gravity of particles. The particle size does not come into the picture in this process. The comminuted ore after the removal of finer size is put into a fluid having specific gravity in b/w the specific gravities of 2 minerals that are to be separated from each other. If there are more than 2 minerals in an ore, then the heavy mineral is generally recovered as "sink" and the waste as "float". For eg:- densities of most metallic oxides ranges from 3.5 — 4.5 g/cc. silica - the main constituent of gangue having density around 2.65 g/cc ∴ during HMS, the liquid should have density of around 3 g/cc. The metallic oxides sinks and the silica floats.

~~It is difficult to find~~

It is difficult to find an inexpensive liquid with sufficiently high density that lies b/w the densities of mineral & gangue. Such liquid can be obtained by suspending fine dense particles in water. For this, heavy minerals or alloys grounded upto -100 mesh. Eg: Galena with effective specific gravity of the medium 4.3, ferro-silicon with effective specific gravity 2.5 — 3.5, etc.

Suspensions normally used in HMS contains 70-85% solid by weight.

Heavy Media Separation

- Process using true heavy liquid
  - Lessing Process
  - Bertrand Process
  - Du-Pont Process
- Processing using heavy suspension.
  - Chance Process
  - Vooys process
  - Wuensch Process

Lessing Process -

(1) Calcium Chloride soln. of specific gravity around 1.4 is used for suspension.

(2) Separation is carried out in a cylindrical tank with conical bottom.

(2) Raw coal free from dust and fine is introduced near the centre of the tank after mixing with separating soln. in a mixture.

(4) The cleaned coal rises to the top and removed and delivered to the draining tower.

(5) After draining, the coal and slate are washed and the washed liquor returned to the supply of $CaCl_2$.

(6) Further washing ~~is done~~ of the coal is required for complete removal of chloride.

(7) After mixing ~~the~~ of recirculated solution it is concentrated by evaporation to the original volume. The cost of thermal concentration of the separating liquid restricts its wide spread application.

Betrand Process -

(1) It utilises $CaCl_2$ soln. as a separating medium and it is applicable only to de-slimed feed.

(2) Particles varying from 1-5 mm dia can be treated by this process.

(3) It differs from the Lessing Process in that the raw coal is introduced into the system counter current fashion & the purified coal and waste is also withdrawn in similar fashion.

There are 5 ~~different~~ circulating liquors viz. hot water, ~~mixed solution~~ weak solution, med. soln, strong soln. & separating solution.

(4) This process avoids costly thermal concentration of dilute liquor but introduces a relatively complex hydrometallurgical flow sheet.

(5) Coal of extremely high grade, less than 1% ash can be obtained with near theoretical yield. Coal of such purity is used for manufacturing of electro-coke, preparation of colloidal-coke, and as fuel of gas producer

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Du-Pont Process

It is practical adaptation of laboratory scale heavy media separation. However, several requirements that had to be made to commercialise the process.

1. Low solubility of parting liquid in water and of water in the parting liquid.
2. Low viscosity of parting liquid in operating temp.
3. Stability, low vapour pressure and non-flammability of the parting liquid.

(4) Prior preparation of the ore to remove fine particles.

(5) Prior treatment of the ore with suitable chemicals to make the surface of the ore immune to wetting ~~weighting~~ by the parting liquid.

(6) Complete sealing of the separating system to prevent loss of parting liquid by evaporation and to eliminate health hazards due to the noxious vapours of the parting liquid.

(7) Use of procedure ~~so~~ that completely separates parting liquid from the separated minerals for complete re-generation of the parting liquid.

(8) Constant purification of the parting liquid.

The active agents have been devised ~~devised~~ to keep the minerals wetted by water in case of coal active agents such as starch acetate ~~starch acetate~~ or tannic acid is used. The conc. of active agent in the water is in order of about 0.01%.

The main expense of the Du-Pont process is for the parting liquid which is a mixture of several halogenated hydrocarbons. The consumption of medium is also very low. The process is not-applicable for fine particles, ∴ it is limited to the treatment of minerals in coarse state. Such treatment is successful when the ore is closely aggregated.

Industrial Processes using Heavy suspension -

(1) Chance Process : It is used for coal cleaning. The medium consists of suspension of sand in water. The sand size must be uniform (-40 to +80 mesh). Coarse sand tends to accumulate in the bottom of the separating vessel and fine sand is difficult to re-trive and tend to accoomulate in the uppor portion of the separator.

The Chance cleaner consists of a separating vessel in which sand suspension moves gently upwards. An agitator for stirring the suspension. The overflow of clean coal and sand passes over to clean coal - screen which de-sand it and de-water the coal. The underflow of the separator is discarded by ~~very few~~ refused valves to the refused screen. It screens out the coal and de-sand it. The dilute sand including the coal sludge is purified in a cone-thickner. The sludge coal is wasted. The re-generated medium is returned to the system with new feed. The specific gravity of the fluid is adjusted by varying the proportion of sand and water.

For cleaning of Anthracite coal, the fluid of higher specific gravity is required than that necessary for cleaning the bituminous coal.

(2) Vooys Process:

(i) The suspension used in this process consists of clay and finely ground barite (−150 or −200 mesh) in water.

(ii) The specific gravity of the medium is adjusted at 1.47 and raw coal finer than −100 mesh are excluded as far as possible.

(iii) Since the solids in the separating media are much finer than the chance Process, much finer ~~~~ coal can be treated by this process.

(iv) Coal containing 3.3 − 3.4% ash can be ~~usually~~ easily produced with near theoretical yield.

(v) Re-generation of the medium requires the use of thickner, the loss of barite is in order of ~~~~ 2 lb/tonne of raw coal.

(vi) The cost of operation is lower than corresponding Jig Plant.

(3) Wuensch Process:

This process has been designed for concentration of ores ~~or minerals~~ where the gangue mineral has specific gravity of 2.7 or higher. A mineral having specific gravity more than 5.25 must be used since a suspension containing more than 40% solid by volume is too plastic to be utilised. It would be preferable if the suspension were to contain not more than 30% solid by weight. Thereby requires specific gravity of 6.7 or higher.

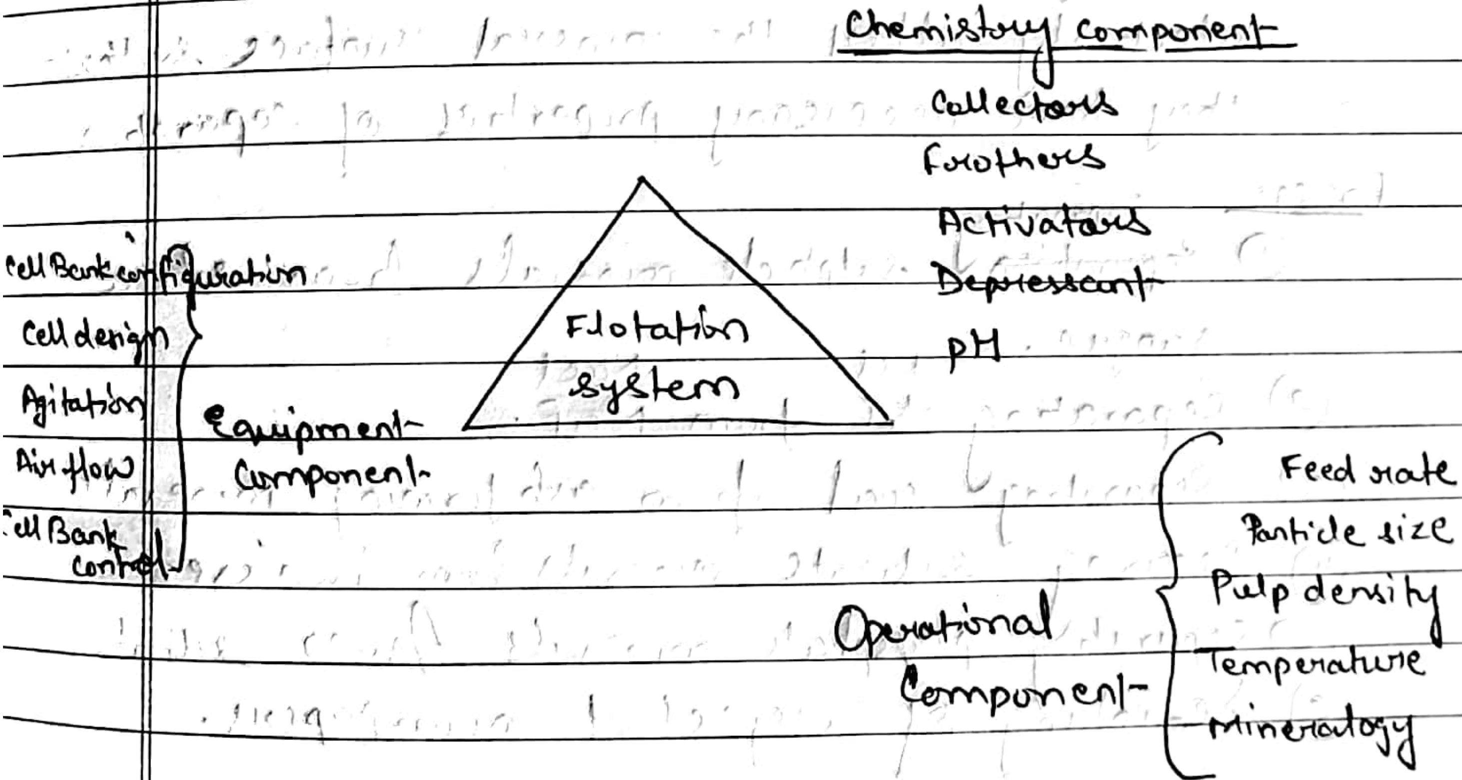
Haematite, ~~a~~ magnetite and pyrite are too light to be used but Galena is suitable. Since Galena is relatively valuable, loss of the medium must be minimum. It is also important to keep the medium clean of degraded ore particles. Therefore periodic flotation purification of the medium is necessary.

In the Butler Bros. experimental benefication plant of iron ore ground ferro-silicon is used as medium.

Ferro-silicon is chosen for its magnetic property, oxidation resistance and brittleness. It has specific gravity ranging from 6.7 to 7.0 and the SG of the suspension of 3.2 was made by this material. The magnetic susceptibility of ferro-silicon makes it suitable for magnetic jog washer and resolve the difficulty of keeping the medium clean.

Flotation -

Froth flotation : Fundamental principles



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Froth flotation is a highly versatile method for physical separation of particles based on differences in the ~~abilities~~ ability of air bubble to selectively adhere to specific mineral surfaces in a mineral-water slurry. The particles attached with air bubble are then carried to the surface and removed while the particles that remain completely wetted stay in the liquid phase.

Froth flotation can be adapted for a broad range of mineral separation as it possible to selectively alter the mineral surface so that they have necessary properties of separation.

For eg:

1. ~~Separation~~ Separating sulphide minerals from silica gangue.
2. Separating ~~KF~~ KCl from ~~NaF~~ NaCl.
3. Separating coal from ash-forming minerals
4. Removing silicate minerals from iron ore.
5. Separating phosphate minerals from silicates.
6. De-inking of rejected newspapers.

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It is particularly useful for processing of fine-grade ores that are not suitable for conventional gravity concentration.

Performance Calculation-

(a) Ratio of concentration $= \frac{F}{C}$

F = total weight of the feed

C = total weight of the concentrate

$F = (C+T)$ — (1)

C – Concentrate

T – Tailing

$F \cdot f = C \cdot c + T \cdot t$ — (2)

f, c and t metal grade in feed, concentrate and tailing (fraction of metal)

Now,

(1) × t, $F \cdot t = (C \cdot t + T \cdot t)$ — (3)

(2) − (3), $F(f-t) = C(c-t)$

$$\frac{F}{C} = \left[\frac{c-t}{f-t}\right]$$

Metal recovery

$\frac{C}{F} \frac{c}{f} \times 100$

Ques. A copper ore initially contains 2.09% Cu. After concentration, the concentrate contains 20% Cu and the Tailing contains 0.1% Cu.

	% wt.	% Cu
Feed	100%	2.09
Concentrate	10%	20.0
Tailing	90%	0.1

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Calculate:-

(1) Ratio of concentration 10

(2) % Metal Recovery 95.7

(3) % Weight Recovery 10

(4) % Metal Loss 4.3

(5) Enrichment Ratio c/f 9.57

Sol- (1) Ratio of concentration $= \frac{F}{C} = \frac{100}{10} = 10$

(2) % Metal Recovery $= \frac{C \cdot c}{F \cdot f} \times 100$

(3)

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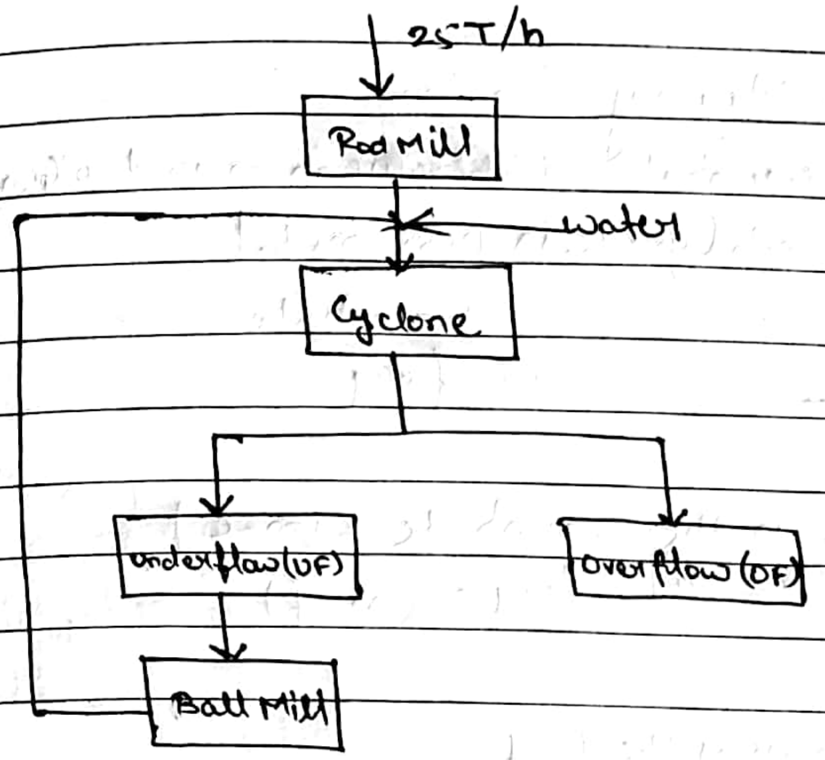
Ques



1 t = 1000 kg

- Density of dry solid 3000 kg/m³ and feed rate 25 T/h
- Feed to the cyclone contains 36% solid by weight.
- 250 µm sized particle in rod mill discharge, ball mill discharge and in cyclone feed is 27%, 5% and 14% respectively.

Calculate the volumetric flow rate of feed (solid + water) to the cyclone.

~~VfR~~
~~VfR~~
~~100 × 0.6~~
(dilution Ratio)

Sol.

$$C_F = C_B + \boxed{C_R} \quad (25\ T/h) \qquad \text{—— (1)}$$

$$\cancel{27}: (C_F \times 14) = (C_B \times 5) + (25 \times 27) \qquad \text{—— (2)}$$

$C_F = 61.1\ T/h$

108.6 m³/h

12.8.97

VMR of solid = C_F ≈
VMR of water = C

feed = Groundore + water

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Separation Efficiency

Assume, concentrate = Metal value in mineral + Gangue

m = metal grade in pure metal

c = " " " concentrate

f = " " " feed

∵ Gangue in the concentrate $= (m-c)$

" " " feed $= (m-f)$

if m_F = mass of the feed

m_C = " " " concentrate

Then

Recovery of gangue in concentrate $R_g = \frac{m_c}{m_F} \frac{(m-c)}{(m-f)} \times 100$ — ①

" " metal " " $R_m = \frac{m_c \times c}{m_F \times f} \times 100$ — ②

and Separation Efficiency $= (R_m - R_g)$

$$(R_m - R_g) = 100 \times \frac{m_c}{m_F} \times \left[\frac{c}{f} - \frac{(m-c)}{(m-f)} \right]$$

$$(R_m - R_g) = 100 \times \frac{m_c}{m_F} \times \left\{ \frac{m}{f} \frac{(c-f)}{(m-f)} \right\} \quad — ③$$

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from (2) $\Rightarrow$ $\dfrac{m_c}{m_F} = \left[\dfrac{R_m \times f}{100 \times c}\right]$ — (4)

$$\boxed{SE = \text{Separation Efficient} = (R_m - R_g) = R_m \times \frac{f}{c}\left\{\frac{m(c-f)}{f(m-f)}\right\}}$$ — (5)

Q. ~~Recycling~~ Recirculation

Feed (100 t/h)

↓

Hydrocyclone

Underflow (70% of original feed)

Overflow (30% of original feed)

feed stream contains 35% solid by volume and 40% water is recycled. Calculate the concentration of hydrocyclone product. (Given $\rho_{solid} = 3.215\ t/m^3$)

Sol.

Total feed = Overflow (OF) + Underflow (UF)

~~100 = OF + UF~~

Basis → 1000 t of feed

Fresh feed = 1000 × 0.3 = 300 t/h

Recycled " = 1000 × 0.7 = 700 t/h

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circulating load ratio $= \frac{700}{300} = 2.33$

$$\underset{F}{\frac{1000}{3.215}} = \underset{UF}{\frac{700}{3.215}} + \underset{OF}{\frac{300}{3.215}}$$

$311 m^3 = 217.7 m^3 + 93.3 m^3$

Volume of water in feed $= \frac{311 \times 65}{35} = 578\, m^3$

" " " in UF $= \cancel{217.7}\ 578 \times 0.4 = 231 m^3$

Solid concentrate in UF $= \frac{217.7}{(217.7 + 231)} \times 100 = 48.5\%$

~~" " " OF = 347/347~~

vol of solid concentrate in OF $= \frac{93.3}{93.3 + 347} \times 100 = 21.19\%$

Mass Balance in Hydrocyclone separator / Classifier -

Case I: slurry have f_s% solid by weight

underflow → u% solid

over flow → v% solid

weight of solid per unit time in feed $= M_F$

" " " " " " " overflow $= M_o$

" " " " " " " underflow $= M_u$

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Under equilibrium, $M_F = M_O + M_u$ —— (1)

Dilution ratio = $\frac{\% \text{ of water}}{\% \text{ of solid}} = \left[\frac{100 - \% \text{ solid}}{\% \text{ solid}}\right]$

$\therefore$ Dilution ratio of feed $f_s' = \left[\frac{100 - f_s}{f_s}\right]$

" " " overflow $u' = \left[\frac{100 - u}{u}\right]$

" " " underflow $v' = \left[\frac{100 - v}{v}\right]$

Water balance on cyclone = Weight of water entering the cyclone

= Weight of water leaving the cyclone.

$[M_F \times f_s'] = [M_O \times u'] + [M_u \times v']$ —— (2)

Calculate $\frac{M_u}{M_F}$ using (1) & (2)

Separation efficiency $\frac{M_u}{M_F} = \left[\frac{f_s' - v'}{u' - v'}\right]$

Case II: % of solid unknown

Mass Balance on slurry

$$\frac{M_F}{\% f_s} = \frac{M_u}{\% u} + \frac{M_O}{\% v}$$

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$$\% \text{ solid in slurry} = \frac{100 \rho_s (\rho_m - 1000)}{\rho_m (\rho_s - 1000)}$$

density of solid

density of slurry

Q. A hydrocyclone produces 2 products from the feed, underflow & overflow. The OF is treated further for concentration of valuable minerals whereas the UF is recirculated. The slurry density of 1140 kg/m³ is fed for separation. Determine the mass flow rate of feed to the cyclone when 3 lt. sample of UF takes 4 seconds.
The UF slurry density is 1290 kg/m³ and OF slurry density is 1030 kg/m³ & the density of dry feed is 3000 kg/m³

Sol.

$$\% \text{ solid in slurry} = \frac{100 \times 3000 (1140 - 1000)}{1140 (3000 - 1000)}$$

$= 18.42\%$

$$\% \text{ solid in feed} = \frac{100 \times 3000 (1140 - 1000)}{1140 (3000 - 1000)}$$

$= 18.42\%$

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$$\%\ \text{solid in OF} = \frac{100 \times 3000\,(1030 - 1000)}{1030\,(3000 - 1000)}$$

$$= 4.37\ \%$$

$$\%\ \text{solid in UF} = \frac{100 \times 3000\,(1290 - 1000)}{1290\,(3000 - 1000)}$$

$$= 33.72\ \%.$$

Dilution Ratio of feed $f_s' = \frac{100 - 18.42}{18.42} = 4.42$

" " " of $u' = \frac{100 - 4.37}{4.37} = 21.88$

" " " UF $v' = \frac{100 - 33.72}{33.72} = 1.97$

$$\frac{M_u}{M_F} = \left[\frac{f_s' - v'}{u - v}\right] = \frac{4.42 - 1.97}{21.88 - 1.97} = 0.12$$

Now ~~$M_F = M_o + M_u$~~

Mass flow rate at UF $= F \times \rho_s \times [\%\ S]_{UF}$

Volumetric flow rate (m^3/h)

Density of solid $\rho_s = \rho_u \bar{\epsilon} \rho_o$

% of solid in UF

$\frac{m^3}{h} \times \frac{kg}{m^3}$ %

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$\frac{kg}{h}$

$$\text{Volumetric flow rate} = \left(\frac{3}{1000} \times \frac{3600}{4}\right) m^3/h$$

$$= 2.7\ m^3/h$$

$$\text{Mass flow rate at UF} = 2.7 \times \cancel{3}1290 \times \frac{33.72}{100}$$

$$= \cancel{2781.32\ kg/h}$$

$$= 1172\ kg/h$$

Water Balance in cyclone -

$$4.42 \times M_F = (1.97 \times 1172) + (21.88 \times M_o)$$

$M_o = M_F - 1172$

$$\boxed{M_F = 1336\ kg/h}$$

Hydrophobicity / Hydrophilicity

The basis of froth flotation is a difference in wettability ~~weighability~~ of different minerals. The particles that are easily wettable by H_2O - hydrophilic and those that are water-repellant - hydrophobic. If a mixture of hydrophilic & hydrophobic particles are suspended in H_2O and the air is bubbled through the suspension then the

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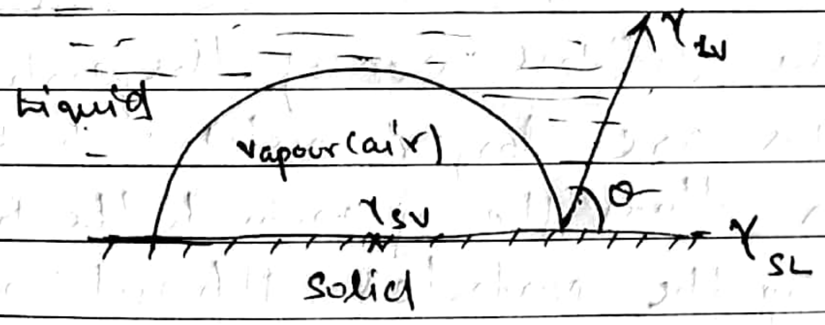
hydrophobic particles will ~~take~~ tend to attach to the air bubbles and float to the surface. The froth layer that forms on the surface of the suspension will be heavily loaded with the hydrophobic minerals. It can be removed as a separated product. The hydrophilic particles will remain in the suspension and can be flushed away.

Particles can either be naturally hydrophobic or the hydrophobicity can be induced by chemical treatment. Naturally hydrophobic materials include hydrocarbon and non-polar solid such as elemental sulphur. Coal is naturally hydrophobic becoz it is ~~naturally~~ mostly composed of Hydrocarbons. Chemical treatment that render a surface hydrophobic is selective coating of particle surface with monolayer of non-polar oil.



$\theta \sim 90^\circ$ preferable for froth flotation

θ — contact angle

$$\gamma_{LV} \cos\theta + \gamma_{SL} = \gamma_{SV}$$

$$\cos\theta = \left[\frac{\gamma_{SV} - \gamma_{SL}}{\gamma_{LV}}\right]$$

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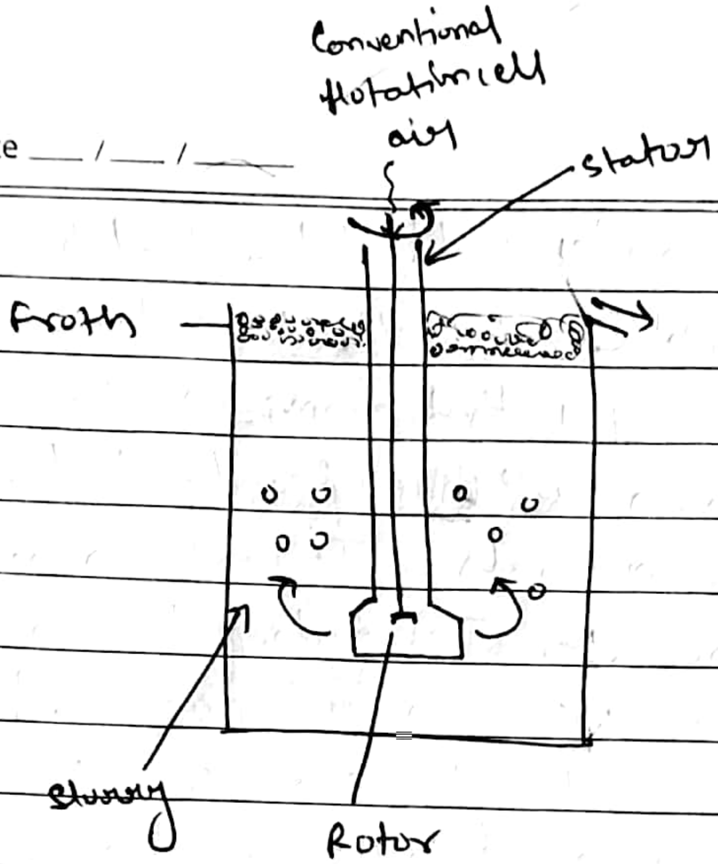

- The rotor draws slurry through the stator and then expels it to the side. It creates a suction that draws air down the shaft of the stator.
- The air is then disposed as bubbles through the slurry and comes in contact with the particles in the slurry.
- Particle bubble collision ~~coalition~~ is affected by the relative size of the particles. If the bubbles are larger relative to the particles, then fluid flowing around the bubble can swap the particles without any contact.
∴ it is best if the bubble diameter is comparable with the diameter of the particle to ensure good particle-bubble contact.

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Frothers - Frothers are compounds that stabilizes air bubble so that they will remain well-dispersed in the slurry and will form a suitable froth layer that can be removed before the bubble burst.
The most commonly used frothers are alcohol particularly MIBC (Methyl Isobutyl carbinol or 4-methyl-2-pentanol) or any water soluble polymer based on PO (propylene oxide) such as polypropylene glycol. The polypropylene glycols are very versatile and can be tailored to give a wide range of froth properties. Many other frothers are available such as pine oil but most of them are considered obsolete. Some work has also been done by using salt-water particularly the sea water as a frothing agent and the process has been used industrially in Russia.

Function of Frothers - Frothers mainly affect the flotation rate (K) and recovery index (R) of any " process. The main ~~purposes~~ functions are :-

1. When frother ~~contains~~ content remains constant

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& amt of collector increased, the flotation rate increases to a maxima & then decrease. It has ~~can~~ been ~~ben~~ observed for all types of frothers and all particle size fraction.

(2) For all types of frothers, the finest at coarsest particles tends to float more slowly than the intermediate sized particles.

(3) Change in flotation rate where due to both change in particle size & frother/collector content. The contribution of particle size was more significant.

(4) With aliphatic alcohol frothers, the flotation rate maxima (K_{max}) is much higher than the propylene oxide and combined propylene oxide alcohol frothers.

(5) Regardless of frother type, increase in the frother content leads to less selective flotation.

(6) The PO and PO alcohol frother are more powerful recovery agent than alcohol frother

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∴ should be used in lower quantity.

(7) Overdozing with alcohol frother leads to slower flotation because excess frother tend to de-stabilize the froth. Such phenomenon does not occur with PO and PO alcohol frother and so overdozing with this frother leads to higher recovery.

(8) PO frothers with molecular weight higher than 300 to 500 are optimum for coal recovery.

(9) Alcohol frothers are more effective for fine particle recovery. To recover coarse particles, the alcohol frother & hydro-carbon collector doze should be high.

(10) The high molecular wt PO based frothers are more effective for coarse particle flotation than the alcohol or low molecular wt. PO frothers but also have a lower selectivity. For ~~good~~ both good coarse particle recovery and good selectivity, the PO frothers should be used at low dozes with lower collector content.

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The PO alcohol frothers are more effective for coarse particle recovery & should be used at very lower dozes.

(11) The optimum frother for high recovery ~~for~~ with good selectivity will often a blend of various frothers. Such frother blending will give superior result & low cost.

(12) For medium and coarse sized particles, the total gangue recovery is linearly related to the total recovery. It is only for the finest particle for which rate of gangue recovery is ~~not a lin~~ non-linear with the total recovery.

(13) For flotation of coal with wide particle size range, the majority of the gangue reaching the froth is from the fine particle size fraction.

(14) As the rate of ~~coal~~ ~~speed~~ ~~flo~~ coal flotation, the rate of gangue flotation also increases proportionally. This yields typical characteristics of froth enfringement process acting on the gangue

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Synthetic & Natural Frothers

The original frothers were natural product such as pine oil. They are rich in surface active agents that stabilize froth bubbles. As natural products, they are not pure chemicals, contains a broad range of chemicals that are effective frothers. Some of these compounds can act as collectors by attaching to the mineral surfaces. As a result, these frothers are also weak collectors. This can have the advantage of reducing the amt of collector that needs to be added separately. However, it introduces some problems with process control. If the natural frother is a collector then it becomes impossible to alter the frothing characteristics and collecting characteristics of the flotation operation independently.

Synthetic frothers such as alcohol type and polypropylene glycol type frother have the advantage that their effectiveness as a collector is negligible. ∴ It is possible to increase the frother content without altering the quantity of collector. This in turn

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makes the flotation process much easier to control

Modifiers - are chemicals that influence the weight the collector attach to the mineral surface. They may either increase the absorption of collector onto a given mineral ie. activators or prevent collector from absorbing onto a mineral surface ie. depressant. It is important to note that a reagent which is a depressant for a particular mineral - collector ~~comm~~ combination may not be a depressant for other combination, for eg - sodium sulphide is a powerful depressant for sulphide minerals, ~~could~~ flotated with Xanthate but does not affect flotation when the sulphide minerals are flotated with hexadecyl trimethyl ammonium bromide

Factors affecting collection in the froth layer -

1) once a suspended ore particle and bubbles comes as and contact, the bubble must be large enough for its buoyancy to lift

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the particle to the surface. This is easier if the particle is having a low density than the high density such as PbS.

eg of low density — coal particle

eg of high density — PbS.

(2) The particle & bubble must remain attached while they move up into the froth layer on top of the flotation cell.

(3) The froth layer must be persistant for either flow over the discharge lip of the cell are to be removed mechanically by scrapper. If the froth is not stable, the bubble will burst & drop the hydrophobic particles back into the slurry however, the froth should not be so stable to become persistant foam as foam is difficult to convey and pump through the plant.

(4) The total surface area of the bubbles in the froth is also important since particles are carried into the froth by attachment to the bubble surfaces.

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Increase in ~~amt~~ amt. of bubble surfaces allow a rapid flotation of particles. At the same time, increased surface area also carries more H_2O into the froth in form of a film b/w the bubbles. Since fine particles that are not attached to the air bubbles will be unselectively carried into the froth along with the H_2O. Consequently, excessive amt of H_2O in the froth can result in significant contamination of the product with gangue minerals

Collectors- are reagents that are used to selectively absorb onto the surfaces of the particle. They form a monolayer on the particle surface that essentially makes a thin film of non-polar hydrophobic hydrocarbons. The collectors greatly increase the contact angle so that bubbles will adhere to the surface. ~~S~~ Selection of correct collector is critical for effective separation.

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Collectors can be generally classified. Depending on their ionic charge, they can be non-ionic, cationic or anionic. The non-ionic collectors are simple hydrocarbon oil while cationic & anionic collectors consist of a polar part that selectively attach to the mineral surface & a non-polar part that projects out into the soln. and makes the surface hydrophobic. Collectors can either chemically bond to the mineral surface i.e. chemisorption or can held on the surface by physical forces i.e. physical absorption.

In chemisorption, ions or molecules from the solution phase undergo a chemical R^x with the surface becoming irreversibly bonded. This permanently changes the nature of the surface. Chemisorption of the collector is highly selective as the chemical bonds are specific to particular atom.

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In physical absorbtion, ions or molecules from soln. phase becomes reversibly associated with the surface due to the electrostatic attraction or vander waal's bonding. The physiabsorb substances can be de-absorb from the surface if the condition like pH or composition of the soln. changes. It is much less selective than chemisorption as collectors will absorb on any surface that has the correct electrical charge or degree of natural hydrophobicity.

Collectors

- Non-ionizing (Non-polar hydrocarbons that do not dissociate in water)
- Ionizing
  - Anionic
    - Oxyhydryl
      - Carboxylic: R–C(=O)–O; sodium oleates, fatty acid with polar group of vegetable oils
      - Sulfates: R–O–S(=O)(=O)–O
      - Sulfonates: R–S(=O)(=O)–O
    - Sulfhydryl ('S' atom chemically bond with the surface of sulfide elements)
      - Xanthates: R–O–C(=S)–S
      - Dithiophosphates: (R–O)(R–O)P(=S)–S
  - Cationic (Based on pentavalent-nitrogen cation)

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Eg for Carboxylic – used as collectors for Haematite & other oxide minerals.
It is a strong collector but has low selectivity.

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Sulfates – Less collecting power, higher selectivity

~~Non Ionic~~ Non-ionizing / Non-ionic collector

H/c oils and similar compounds have an affinity for surfaces that are partially hydrophobic. They selectively absorb on these surfaces and increases their hydrophobicity. The most commonly flotated ~~..~~ naturally hydrophobic material is coal. Addition of collectors such as kerosene & fuel oil significantly enhance the hydrophobicity of coal particles without affecting the surfaces of the associated ash-forming minerals. This improves recovery of coal & increases the selectivity b/w coal particles & mineral matter. Fuel oil & kerosene have certain advantages over specialized collectors —

1. They have low viscosity to disperse into the slurry & spreads over the coal particles very easily
2. Their cost is much lower as compared to other compounds which can be used as coal collector.

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Except coal, it is also possible to float naturally hydrophobic minerals such as molybdenite, elemental sulphur and talc with non-ionic collector. Non-ionic collectors can also be used as extenders for other collector. For eg: if a more expensive collector makes a surface partially hydrophobic, addition of non-polar oil often increases the hydrophobicity at low cost.

Anionic collectors are weak acid or acid-salt that ionize in water and produces a collector that has one negatively charged end and a hydrocarbon chain. The negatively charged end will attach to the mineral surface and hydrocarbon chain extends out into the liquid. ~~Absorption of Anion collectors~~ The anionic portion is responsible for attachment of collector to the surface while the hydrophobic part alters the surface hydrophobicity.

Anionic collectors for sulfide mineral → The most common collector for sulfide mineral are sulfhydryl collectors such as various

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Xanthates and Dithiophosphates. Xanthates are high selective collectors for sulfide minerals as they chemically react with the sulfide surfaces and do not have any affinity for non-sulfide gangue minerals.

Other highly selective collectors for sulfide minerals such as Dithiophosphates ~~of~~ have different absorption behaviour & ∴ can be used for separations that are difficult by using Xanthates.

Anionic collector for oxide minerals → The collectors available for flotation of oxide minerals are not as selective as the collector used for sulfides because they attach to the surfaces by electrostatic attraction rather than the chemical bonding. As a result, there is some collector adsorption onto the minerals that are not intended to float.

Since particles that are immersed in water develop a net charge due to exchanging ions with the liquid. It is often possible to manipulate the chemistry

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of the soln. so that one mineral has a strong positive charge while other minerals have a charge that is either weakly positive or negative. Under this condition, the anionic collectors will preferentially adsorb ~~onto~~ onto the surface with the strongest positive charge and renders them hydrophobic.

(cc) Cationic Collectors – have a positively charged amine group to attach to the mineral surface. Hence the CC have an opposite effect than Anionic Collectors which attach to the positively charged surface. CC are mainly used for flotation of silicates & certain rare earth metal oxides and for separation of ~~potassium~~ ~~potassium~~ KCl ~~fluoride~~ from ~~Sodium~~ ~~fluoride~~ NaCl.