MODULE-I

Laboratory screening:

Mesh number

- Mesh number is the number of apertures per linear inch.
- Sieves are designated by mesh number.
- Mesh size is the size of an aperture i.e. the distance between two parallel wires.
- As mesh number increases, mesh size decreases.
- Sieve Scale is the list of successive sieve sizes used in any laboratory, taken in order from coarsest to finest.
- Standard Sieve Scale is the sieve scale adopted for size analyses and general testing work to facilitate the interchange ability of results and data.
- In this standard sieve scale, the sizes of successive sieves in series form a geometric progression.

Test Sieves:

- Test Sieve is a circular shell of brass having an 8 inch diameter and being about 2 inch high as shown in Figure 1.
- Sieve cloth is made of wire, woven to produce nominally uniform cloth apertures (openings).
- The sieve cloth is placed in the bottom of the shell so that material can be held on the sieve.
- Aperture (or Opening) is a distance between two parallel wires.

Fig.1 Test sieve.

- Standard Test Sieves are used in the mineral industry to measure the size of the small and the fine particles, usually down to 74 microns.

For a standard sieve scale, the reference point is 74 microns, which is the aperture of a 200 mesh woven wire sieve. The ratio of the successive sizes of the sieves in the standard sieve scale is 2.

In general, mesh number × mesh size in microns ≈ 15,000.

For closer sizing work the sieve ratio of 2^4 is common.

The different standards in use are:

- American Tyler Series
- American Standards for Testing and Materials, ASTM E-11-01

Table-1 Comparison of test sieves of different standards.

TYLER			U.S.A. ASTM E-11-01		BRITISH B.S 410-2000		INDIAN I.S. 460-1962		FRENCH AFNOR NFX-11-501		GERMAN DIN 3310-1:2000	
Sieve designation mesh no.	Width of aperture mm	Mesh double tyler series	Sieve designation mesh no.	Width of aperture mm	Sieve designation mesh no.	Width of aperture mm	Sieve designation mesh no.	Width of aperture mm	Sieve designation mesh no.	Width of aperture mm	Sieve designation mesh no.	Width of aperture mm
–	–	–	–	–	–	–	–	–	38	5.00		5.00
4	4.75	–	4	4.75	3½	4.75	480	4.75	–	–		4.50
–	4.00	5	5	4.00	4	4.00	400	4.00	37	4.00	2E	4.00
6	3.35	–	6	3.35	5	3.35	340	3.35	–	–		–
–	–	–	–	–	–	3.15	320	3.18	36	3.15		3.15
–	2.80	7	7	2.80	6	2.80	280	2.80	–	–		2.80
8	2.36	–	8	2.36	7	2.36	240	2.39	35	2.50		2.50
–	2.00	9	10	2.00	8	2.00	200	2.00	34	2.00	3E	2.00
10	1.70	–	12	1.70	10	1.70	170	1.70	33	1.60		1.60
–	1.40	12	14	1.40	12	1.40	140	1.40	–	1.40		1.40
–	–	–	–	–	–	1.25	–	–	32	1.25		1.25
14	1.18	–	16	1.18	14	1.18	120	1.20	–	–	5	1.20
–	1.00	16	18	1.00	16	1.00	100	1.00	31	1.00	6	1.00
20	0.85	–	20	0.850	18	0.850	85	0.850	–	–		–
–	–	–	–	–	–	0.800	80	0.79	30	0.800		0.800
–	0.710	24	25	0.710	22	0.710	70	0.710	–	0.710		0.710
–	–	–	–	–	–	0.630	–	–	29	0.630		0.630
28	0.600	–	30	0.600	25	0.600	60	0.600	–	–	10	0.600
–	0.500	32	35	0.500	30	0.500	50	0.500	28	0.500	12	0.500
35	0.425	–	40	0.425	36	0.425	40	0.425	–	–		–
–	–	–	–	–	–	0.400	–	–	27	0.400	16	0.400
–	0.355	42	45	0.355	44	0.355	35	0.355	–	0.355		0.355
–	–	–	–	–	–	0.315	–	–	26	0.315		0.315
48	0.300	–	50	0.300	52	0.300	30	0.300	–	–	20	0.300
–	0.250	60	60	0.250	60	0.250	25	0.250	25	0.250	24	0.250
65	0.212	–	70	0.212	72	0.212	20	0.212	–	–		–

(Continued)

Table-1 Comparison of test sieves of different standards.

TYLER			U.S.A. ASTM E-11-01		BRITISH B.S 410-2000		INDIAN I.S. 460-1962		FRENCH AFNOR NFX-11-501		GERMAN DIN 3310-1:2000	
Sieve designation mesh no.	Width of aperture mm	Mesh double tyler series	Sieve designation mesh no.	Width of aperture mm	Sieve designation mesh no.	Width of aperture mm	Sieve designation mesh no.	Width of aperture mm	Sieve designation mesh no.	Width of aperture mm	Sieve designation mesh no.	Width of aperture mm
–	–	–	–	–	–	0.200	–	–	24	0.200	30	0.200
–	0.180	80	80	0.180	85	0.180	18	0.180	–	0.180		0.180
–	–	–	–	–	–	0.160	–	–	23	0.160		0.160
100	0.150	–	100	0.150	100	0.150	15	0.150	–	–	40	0.150
–	0.125	115	120	0.125	120	0.125	12	0.125	22	0.125	50	0.125
150	0.106	–	140	0.106	150	0.106	10	0.106	–	–		–
–	–	–	–	–	–	0.100	–	–	21	0.100	60	0.100
–	0.90	170	170	0.090	170	0.090	9	0.090	–	0.090	70	0.090
–	–	–	–	–	–	0.080	–	–	20	0.080		0.080
200	0.075	–	200	0.075	200	0.075	8	0.075	–	–	80	0.075
–	–	–	–	–	–	0.071	–	–	–	0.071		0.071
–	0.063	250	230	0.063	240	0.063	6	0.063	19	0.063		0.063
–	–	–	–	–	–	0.056	–	–	–	0.056	110	0.056
270	0.053	–	270	0.053	300	0.053	5	0.053	–	–		–
–	–	–	–	–	–	0.050	–	–	18	0.050	120	0.050
–	0.045	325	325	0.045	350	0.045	4	0.045	–	0.045		0.045
–	–	–	–	–	–	0.040	–	–	17	0.040		0.040
400	0.038	–	400	0.038	400	0.038	3	0.038	–	–	130	–

- ❖ British Standard Sieves,
- ❖ BSS 410-2000 French Series,
- ❖ AFNOR (Association Francaise de Normalisation)NFX 11-501 German Standard,
- ❖ DIN (Deutsches Institut fur Normung) 3310-1 : 2000
- ❖ The Indian Standard (IS) sieves, the mesh number is equal to its aperture size expressed to the nearest deca-micron (0.01 mm). Thus an IS sieve of mesh number 50 will have an aperture width of approximately 500 microns.

In general, the sieve range should be chosen so that no more than about 5% of the sample material it retained on the coarsest sieve, or passes the finest sieve. These limits may be lowered for more accurate work.

Table 1 shows the comparison of test sieves of different standards.

SIEVE ANALYSIS

- ❖ It is a method of size analysis.
- ❖ It is performed to determine the percentage weight of closely sized fraction by allowing the sample of material to pass through a series of test sieves.
- ❖ Closely sized material is the material in which the difference between maximum and minimum sizes is less.
- ❖ Sieving can be done by hand or by machine.
- ❖ The hand sieving method is considered more effective as it allows the particles to present in all possible orientations on to the sieve surface.
- ❖ The machine sieving is preferred for routine analysis as hand sieving is long and tedious.
- ❖ Table model sieve shaker and Ro-tap sieve shaker (Figures 2 and 3) are the two principal machines used in a laboratory for sieve analysis.
- ❖ Sieving is generally done dry.
- ❖ Wet sieving is used when the material is in the form of slurry.

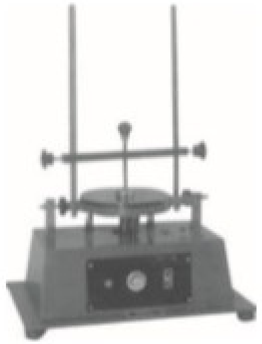


Fig.2 Table model sieve shaker.

Fig.3 Ro-tap sieve shaker.

TESTING METHOD

- The sieves chosen for the test are arranged in a stack, or nest, starting from the coarsest sieve at the top and the finest at the bottom.
- A pan or receiver is placed below the bottom sieve to receive the final undersize, and a lid is placed on top of the coarsest sieve to prevent escape of the sample.
- The material to be tested is placed on the uppermost coarsest sieve and closed with lid.
- The nest is then placed in a Sieve Shaker and sieved for certain time. Figure 4 shows the sieve analysis at the end of the sieving.
- The material collected on each sieve is removed and weighed. The complete set of values is known as Particle Size Distribution data.

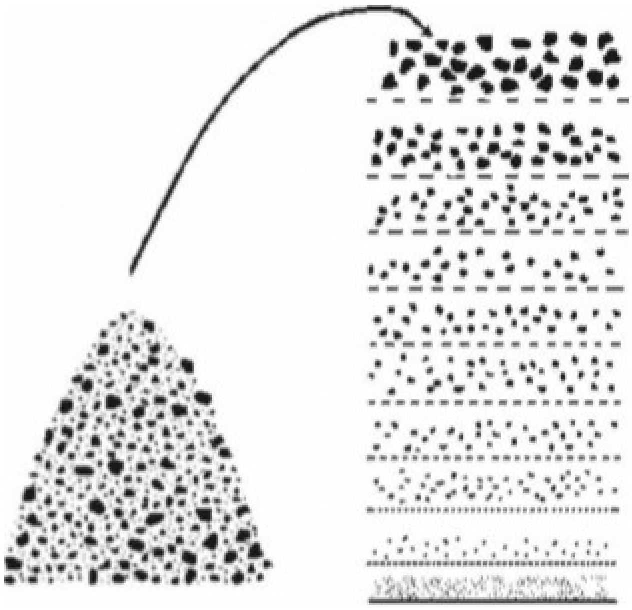


Fig.4 Sieve analysis at the end of sieving.

❖ Particle size distribution refers to the manner in which particles are quantitatively distributed among various sizes.

Particle size distribution data is presented in a tabular form as shown in Table 2.

Table-2 Comparison of test sieves of different standards.

Mesh number	Retained mesh size in microns	Weight of material gm
+14	1200	02.5
−14 + 22	710	18.0
−22 + 30	500	18.5
−30 + 44	355	21.0
−44 + 60	250	27.5
−60 + 72	210	36.0
−72 + 100	150	31.5
−100 + 150	105	26.0
−150 + 200	74	18.5
−200		50.5
		250.0

+ sign designates particles retained on that sieve.
− sign designates particles passed through that sieve.

From the table it observed that:

❖ The weight percentages of the material retained on each sieve are to be calculated to form differential analysis.
❖ Cumulative weight percentage retained is obtained from differential analysis by adding, cumulatively.
❖ The individual differential weight percentages from the top of the table.
❖ Cumulative weight percentage passing is obtained by adding, cumulatively. The individual weight percentages from the bottom of the table.

For example, the size of −14 + 22 mesh fraction is (1200 +710)/2=955 microns.

It means, the particles which pass through 14 mesh and retain on 22 mesh are having the mean size of 955 microns. Similarly the mean sizes of each fraction are to be calculated. Table 3 shows all values.
The average size of the material is determined by using the following simple arithmetic formula

$$\therefore \text{Average size} = \frac{100}{\sum \frac{w_i}{d_i}}$$

Where,
W is the weight percentage of the material retained by the sieve and d is the mean size of the material retained by the same sieve.

Table-3 Calculated values for particle size distribution.

Mesh number	Retained mesh size microns	Mean size d_i microns	Weight gm	wt % retained w_i	Cum wt % retained	Cum wt % passing W
						100.0
+14	1200	1200	02.5	1.0	1.0	99.0
−14 + 22	710	955	18.0	7.2	8.2	91.8
−22 + 30	500	605	18.5	7.4	15.6	84.4
−30 + 44	355	427.5	21.0	8.4	24.0	76.0
−44 + 60	250	302.5	27.5	11.0	35.0	65.0
−60 + 72	210	230	36.0	14.4	49.4	50.6
−72 + 100	150	180	31.5	12.6	62.0	38.0
−100 + 150	105	127.5	26.0	10.4	72.4	27.6
−150 + 200	74	89.5	18.5	7.4	79.8	20.2
−200		37	50.5	20.2	100.0	
			250.0	100.0		

N.B:PRESENTATION OF PARTICLE SIZE DISTRIBUTION DATA(For practical uses)

Particle size distribution data is best presented for use in the form of graphs (Figure 5).

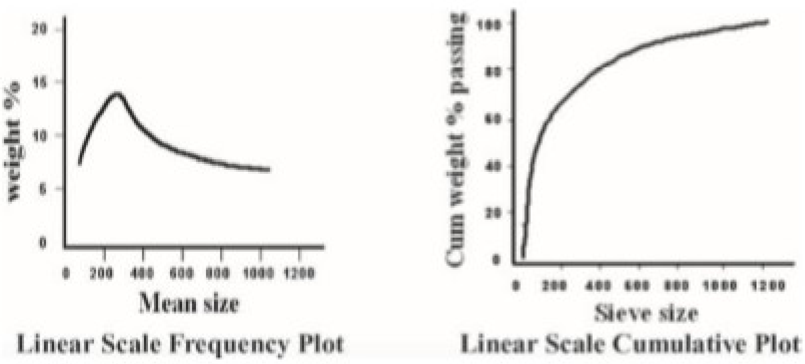


Fig.5 Graphical presentation of particle size distribution data.

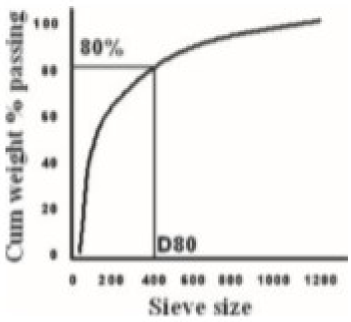


Fig.6 Plot for determination of 80% passing size D80.

80% passing size (D80) is the size of the sieve at which 80% of the particles pass through that sieve. 80% passing size can be determined from the plot of cumulative weight percentage passing versus sieve size as shown in Figure 6.

F80 is the 80% passing size of the feed material.

P80 is the 80% passing size of the product material.

80% passing size is used in all calculations to determine energy requirements for reducing the size of the particles by comminution equipment.

APPLICATIONS OF PARTICLE SIZE DISTRIBUTION DATA

- Comparative efficiencies of comminution units by relating the work done and the product sizes can be studied.
- Particle surface areas can be calculated from size analysis.
- Power required to crush and/or grind an ore from a given feed size to a given product size can be estimated from size analyses of the feed and the products.
- The calculation of the sizing efficiency of a classifier or cyclone can be closely estimated from size analyses of the feed and the products.

Industrial Screening:

- To remove oversize material before it is sent to the next unit operation as in closed circuit crushing operations.
- To remove undersize material before it is sent to the next unit operation which is set to treat material larger than this size.
- To grade materials into a specific series of sized (finished) products.
- To prepare a closely sized (the upper and lower size limits are very close to each other) feed to any other unit operation.

Fundamental of screening

- Screening is an operation used for the separation of particles according to their sizes.
- Sieving and screening are distinguished by the fact that sieving is a batch process used almost exclusively for test purposes, whereas screening is a continuous process and is used mainly on an industrial scale.

- ❖ Sieves are manufactured with definite dimensions and standard aperture sizes. Screens can be manufactured with any dimension and any aperture sizes as per the requirement.
- ❖ In industrial screening, the particles of various sizes are fed to the screen surface.
- ❖ The material passing through the screen aperture is called underflow (undersize or fines) while the material retained on the screen surface is called overflow (oversize or coarse).

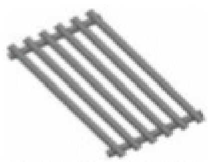
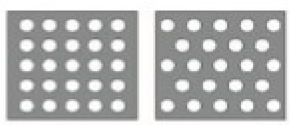
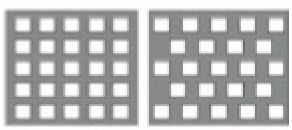
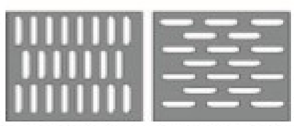
Dry and wet screening

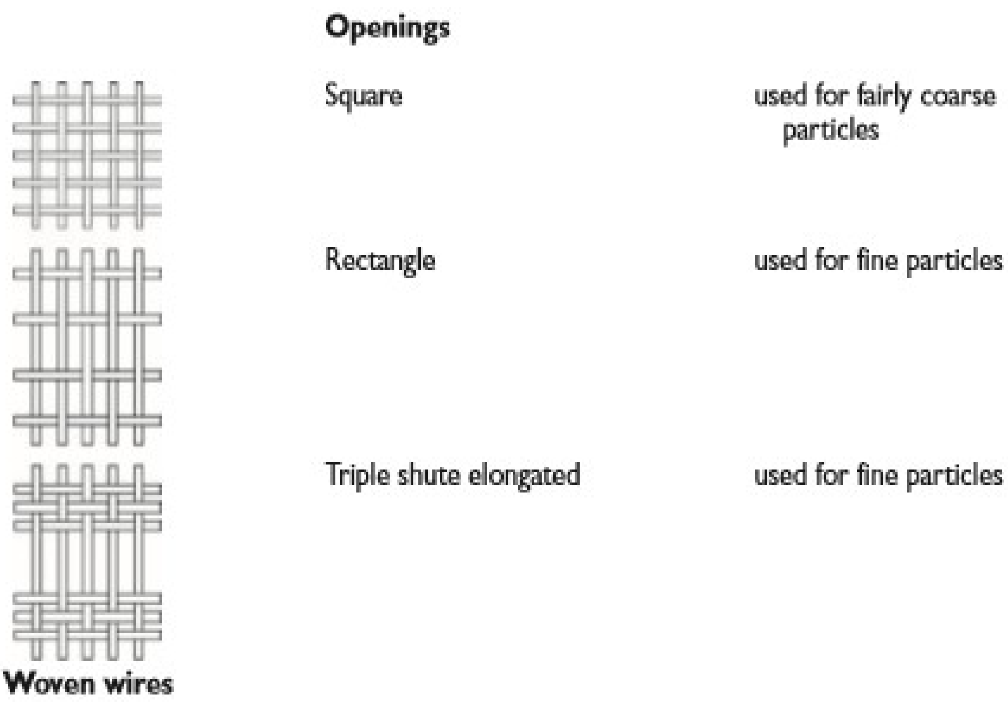
- ❖ Screening is performed either dry or wet. Wet screening is superior, adhering fines are easily washed off, and it avoids the dust problem.
- ❖ But the cost of dewatering and drying the products is high.
- ❖ Screening is generally used for dry treatment of coarse material.
- ❖ Dry screening can be done down to 10 mesh with reasonable efficiency.
- ❖ Wet screening is usually applied to materials from 10 mesh down to 30 mesh (0.5 mm).
- ❖ The recent developments in the Sieve Bend Screen have made the wet screening possible at the 50 micron size.

Classification of screens and their construction

Screen surface is the medium containing the apertures for the passage of the undersize material. Several types of screen surfaces are described in Table 4.

Table-4 Types of screen surfaces.

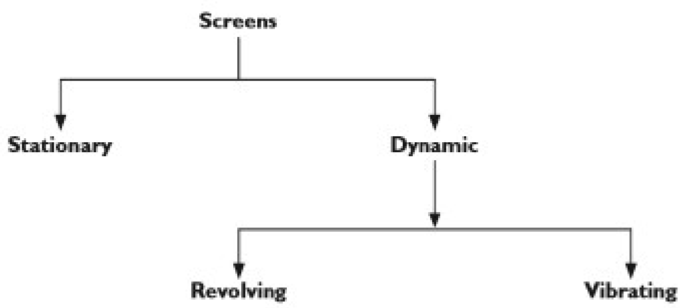
Type of screen surface	*Description*	*Applications*
 **Parallel rods** or **Profile bars**	Rod/bar **Cross sections** Circular, Triangular, Wedge etc.	used for lumpy and coarser size particles
	Openings	
	Circular, In-line and Staggered openings	used for coarser and small sizes
	Square, In-line and Staggered openings	
 **Punched** or **perforated plates**	Slot-like, In-line and Staggered openings	slotted openings are sometimes used for fine particles



Operation and maintenance of different types of industrial screens

- The screens are used for size separations in conjunction with crushing operations.
- In the mineral industry, screens are rarely used for separations below 0.2 mm because they have inadequate capacity.
- The sieve bends are used for separations as low as 50 µm since these devices give sharper separations than wet classifiers.

Screens are classified as stationary and dynamic screens as shown below:

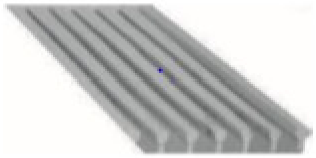
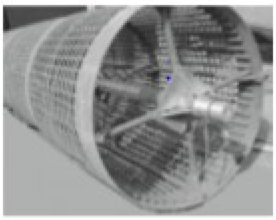


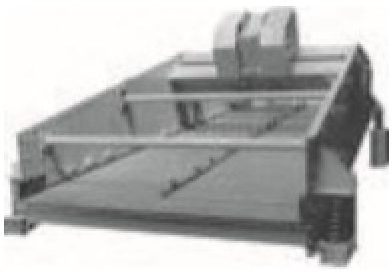
Principal types of Industrial Screens

Principal types of industrial Screens are classified as shown below Table-5:

Table-5 Different Principal types of Industrial Screens

Principal types of Industrial Screens		
Stationary Screens		**Grizzly** ❖ Equally spaced parallel rods or bars running in flow

	 Grizzly	direction. ❖ Sloped to allow gravity transport. **Applications** ❖ Lumpy or coarse separations. ❖ Scalping before crushing. ❖ Dry separation.
Stationary Screens	 Divergator	**Divergator** ❖ Parallel rods running in flow direction. ❖ Fixed at one end. ❖ Gap increases from fixed to free end. ❖ Alternate rods diverge at 5º–6º. **Applications** ❖ Separations in the range 400 to 25 mm size. ❖ Self-cleaning and blockage free. ❖ Dry separation.
Stationary Screens	 **Sieve Bend**	**Sieve Bend** ❖ Stationary curved screen with horizontal wedge bars at right angles to slurry flow. ❖ Feed slurry enters tangentially. ❖ Imparts centrifugal action. **Applications** ❖ Separations in the range of 2 mm to 45 µm. ❖ Wet separation.
Revolving Screens	 **Trommel**	**Trommel** ❖ Rotating, punched or woven wire. ❖ Slightly inclined cylindrical shell. **Applications** ❖ Separations in the range of 10 to 60 mm. ❖ Dry if coarse, wet if

		fine. ❖ Also used for scrubbing lumpy or coarse.
Vibrating Screens	 **Vibrating Grizzly**	**Vibrating Grizzly** ❖ Similar to stationary grizzly. ❖ Mechanical or Electrical vibrations. **Applications** ❖ Coarse and Dry separations. ❖ Also used as feeders.
Vibrating Screens	 Vibrating Screen	**Vibrating Screen** ❖ High speed motion to lift particles. ❖ Mechanical or Electrical vibrations. ❖ Both horizontal and inclined types. **Applications** ❖ Separations from 200 mm to 250 µm. ❖ Dry if coarse, wet if fine.

- The shaking screen, mounted either horizontally or with a gentle slope, has a slow linear motion essentially in the plane of the screen.
- Particles slide jerkily and remain in contact with screen surface during screening.
- Shaking screens may have different aperture surfaces in series so as to prepare a number of different grades.
- Shaking screens are used for coarser particles down to 12 mm size. These are widely used for coarse coal sizing.
- The Reciprocating screen, Gyratory screen, Rotating probability screen, Resonance screen, and Mogensen sizer are some of the other dynamic screens. They are similar to vibrating screens but differ in the type of motion given to the screen deck.
- The industrial screens are arranged as single-deck and multi-deck screens.
- The screen having one screening surface is called a single-deck screen and if a screen has two or more screen surfaces, it is called a multi-deck screen.

- Screening is performed either dry or wet.

- Wet screening is superior, adhering fines are easily washed off, and it avoids the dust problem. But the cost of dewatering and drying the products is high.

The following are some terms used for screens in the mineral industry according to the purpose:
1. Feed screen: used to prepare the feed to any unit operation.
2. Trash Screen: used to remove the trash material.
3. Scalping screen: used to remove small amounts of either oversizes or undersizes.
4. Dewatering screen: used to remove water from mixture of solids and water.
5. Desliming screen: used to remove slimes from the coarse material.
6. Medium recovery screen: used to remove medium solids from coarse material.

Screen efficiency

- Screen efficiency (often called the effectiveness of a screen) is a measure of the success of a screen in closely separating oversize and undersize materials.
- There is no standard method for defining the screen efficiency.
- Screen efficiency can be calculated based on the amount of material recovered at a given size.
- In an industrial screening operation, it is to be specified whether the required material is oversize or undersize or both.

For the oversize material,

Screen fficiency = η = $\dfrac{Weight\ of\ \dfrac{actual}{¿\ presents} \in the\ feed}{Weight\ of overflow\ material\ obtained\ ¿}\ the\ screen\ ¿$

For the undersize material,

Screen fficiency = η = $\dfrac{Weight\ of\ actual\ under\ ¿\ presents \in the\ feed}{Weight\ of underflow\ material\ obtained\ ¿}\ the\ screen\ ¿$

Pre-scrubbing and other processes to improve screening efficiency

- The screen efficiency is the recovery of oversize material into the screen overflow and the recovery of undersize material into the screen underflow.
- The overall efficiency is defined as the product of the recovery of oversize material into the screen overflow and the recovery of undersize material into the screen underflow.

  The following is the expression used for determining the efficiency of an industrial screen:

Screen fficiency = η = $\dfrac{c(f-u)(1-u)(c-f)}{f(c-u)2(1-f)}$

Where

f = fraction of oversize material in the feed

c = fraction of oversize material in the overflow obtained from the screen

u = fraction of oversize material in the underflow obtained from the screen

Another expression for efficiency of an industrial screen is given by

$$\text{Screen efficiency} = \eta = \frac{u(u-f)(1-c)(f-c)}{f(u-c)2(1-f)}$$

Where

f = fraction of undersize material in the feed

c = fraction of undersize material in the overflow obtained from the screen

u = fraction of undersize material in the underflow obtained from the screen

- The capacity of an industrial screen is defined as the quantity of material screened per unit time per unit surface area of the screen and is expressed as tons/hr/m^2.

The capacity of screens depends upon

(1) The area of the screen surface

(2) The size of the screen aperture

(3) Characteristics of an ore

(4) The type of screening mechanism used.

- Efficiency and capacity are opposite to each other in the sense that capacity can be increased at the expense of efficiency and vice versa. It means that as the capacity increases, efficiency decreases and as the capacity decreases, efficiency increases.

Comminution:

- ❖ The operation of applying a force on the particle to break it is called size reduction.
- ❖ The comminution is a general term for size reduction that may be applied without regard to the actual breakage mechanism involved.
- ❖ In any industrial comminution operation, the breakage of any individual particle is occurring simultaneously with that of many other particles.
- ❖ The breakage product of any particle is intimately mixed with those of other particles.
- ❖ The industrial comminution operation can be analysed only in terms of a distribution of feed particles and product particles.
- ❖ The each individual particle breaks as a result of the stresses applied to it and it alone.

Principles and theories

- ❖ Fracture in the particle occurs as a result of application of a force.
- ❖ When a force is applied on a particle, stress will develop within the particle.
- ❖ When this stress exceeds ultimate stress, the particle will break.
- ❖ Let us consider a particle subjected to two opposing forces by a concentrated load as shown in Figure 7

  From the figure it observed that:
- ❖ The principal stress in the z-direction is a compressive stress throughout the particle.
- ❖ The principal stress in the x- and y-directions is a compressive stress adjacent to the load points but a tensile stress within the particle.
- ❖ The tensile stress is lower than compressive stress.
- ❖ The tensile strength is as little as 1/10 of compressive strength, fracture occurs primarily because of the tensile stress which results in breakage into a small number of large pieces.
- ❖ Due to the compression adjacent to the loading points, it results a large number of small pieces.

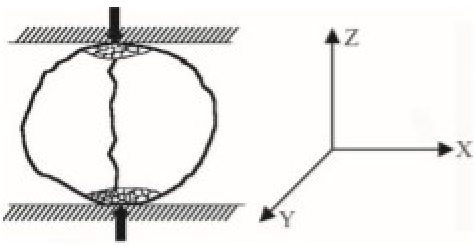


Fig.7 Compressive force.

Forces in comminution

(a) Compressive force

- ❖ Compressive force can be applied at either a fast or a slow rate.
- ❖ Under the conditions of slow compression, energy applied is just sufficient to load comparatively few regions of the particle to the fracture point and only a few particles result.

- The size is comparatively close to the original particle size.
- Under the conditions of rapid loading such as in high velocity impact, applied energy is well in excess of that required for fracture.
- Many areas in the particle are overloaded and the result is a comparatively large number of particles with a wide size distribution.
- Impact causes immediate fracture with no residual stresses.

(b) Attrition or abrasion fracture

- Attrition or abrasion fracture occurs when a force (shear force) acts parallel to the surface of the particle.
- Due to insufficient energy applied on the particle, localized stress occurs and a small area is fractured to give very fine particles.

(c) **Chipping fracture**

- In chipping fracture, the edges or corners of a particle will break due to the application of oblique forces, generally impact forces, on the particle.

In practice, these events do not occur in isolation. All these types of forces and fractures, and sizes of the particles after fracture, are shown in Figure 8.

From the figure it observed that:

- It can be summarized that all types of forces exist in any size reduction operation even though individual size reduction units are predominantly designed for application of one type of force.

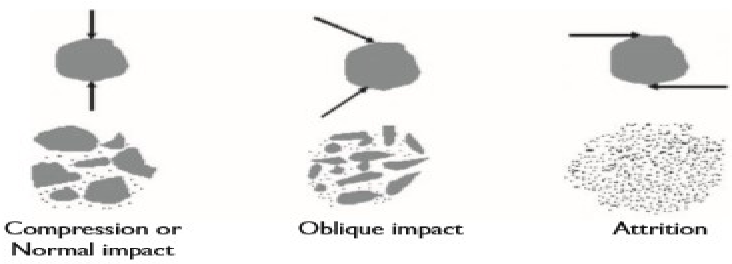


Fig.8 Mechanism of fracture.

Empirical evalution of size reduction

- Laws of comminution are concerned with the relationship between energy input and the size of feed and product particles.
- Three laws of comminution energy requirements have been put forward by Rittinger, Kick and Bond respectively.
- None of these three laws is applicable over a wide range of sizes.
- The Rittinger and Kick laws while tenable in some cases, were never of much use as practical tools.
- The third law proposed by F.C. Bond (1952) is based on a detailed compilation and study of numerous laboratory and plant comminution data and provides the technician with a reasonably accurate measure of power requirements.

Bond's Law

- Bond states that the total work useful in breakage that has been applied to a given weight of homogeneous broken material is inversely proportional to the square root of the average size of the product particles.
- The directly proportional to the length of the crack tips formed and directly proportional to the square root of the new surface created.

Mathematically, Bond's law is expressed as:

$$W=Kb\left[\frac{1}{\sqrt{P}}-\frac{1}{\sqrt{F}}\right]\text{--(1)}$$

Where

W = gross energy required, kWhr/short ton

P = 80% passing size of the product, microns

F = 80% passing size of the feed, microns

Kb = Bond's constant

Application of Bond's law:

- To apply Bond's law, Bond's constant has to be evaluated.
- Bond's constant is evaluated by defining what is called work index, Wi.
- It is defined as the gross energy in kWhr/short ton of feed necessary to reduce a very large feed to such a size that 80% of product particles passes 100 microns screen.

Based on this definition, it can be written that:

If F = ∝, and P = 100 microns, W = Wi kWhr/short ton

On substitution in equation (1), this gives

$$Wi=\frac{Kb}{10}\text{ , }Kb=10\,W\text{--(2)}$$

Thus, Bond's equation becomes:

$$W¿10\,Wi\left[\frac{1}{\sqrt{P}}-\frac{1}{\sqrt{F}}\right]\text{------------------(3)}$$

The work index includes the friction in the crusher and the power W is gross power. Bond's law is applicable reasonably in the range of conventional rod mill and ball mill grinding.

Objectives of comminution

The following are some of the objectives of comminution:

1. Reduction of large lumps into small pieces.

2. Production of solids of desired size range.

3. Liberation of valuable minerals from gangue minerals.

4. Preparation of feed material for different beneficiation operations.

5. Increasing the surface area for chemical reaction.

6. Convenience in handling and transportation.

Particle disintegration

- ❖ To break a particle the application of one force or several forces is needed.
- ❖ When the force is week, the result is particle deformation leading to stress, which is proportional to the load force and inversely proportional to cross section of the material.
- ❖ The stress causes stretching the atoms forming particles which, in turn, causes the tensile forces in the material (Fig. 9).

From the figure it observed that:

- ❖ The increase in the load force transfers higher amount of energy to particles until the stress exceeds the adhesion forces within the material.
- ❖ It is leads to breaking particle bonds and particle disintegration.

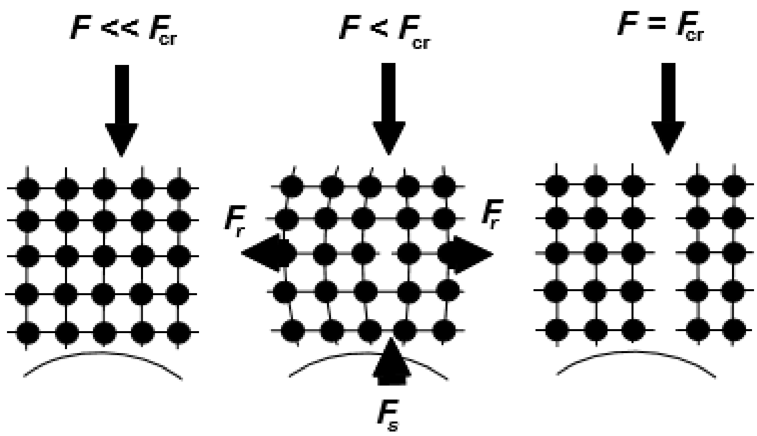


Fig.9 Compressive Fs and tensile forces Fr leading to disintegration of brittle particles.

- ❖ The simplest delineation of breaking can be based on the Hook law relating the force applied to the sample material and the change of its lengths without changing its cross section area:

$F = E\ S\ \Delta\ l/lo$

Where,

F – applied force, N

E – constant also known as Young's modulus, modulus of elasticity, elastic modulus or tensile modulus, N/m2

S – cross section area of the sample , m2

Δ l – increase or reduction of lengths of the tested material, m

lo – original length of the sample, m.

The force needed to break the tested material is:

$F_{cr} = E\, S\, \Delta l_{cr} / l_o$

Where,

Fcr – critical force needed to rupture the sample, N

Δ lcr – increase or reduction of lengths of the tested material needed for breaking, m.

- The at least two parameters are needed to characterize breaking of materials having identical l and S, that is the Young modulus E and characteristic critical lengths increase Δ lcr.
- The additional parameters are needed for odd shape objects, and for the samples which do not obey well the Hook law.

Kinetics of crushing and grinding

Kinetics of grinding

Different functions can be used for delineation of kinetics of comminution. The most useful are simple kinetic equations of the first order (kelly and spottiswood, 1982; lynch 1977; manlapig et al., 1979)

$DW(D)/DT = - K(D)\ W(D)$

Where,

W(d)/dt – mass of particles of size d

k(d) – constant for particles of size d.

They are also,, matrix” equivalents of Eq. (Lynch, 1977, Horst and Freeh, 1970). A precise description of the size reduction kinetics, taking into consideration particle size distribution in the feed and its products is quite complicated. This problem was discussed in details in the monograph by Brożek et al. (1995).

MODULE-III

Crushing:

- As defined by A.M. Gaudin (1939), crushing is that operation or group of operations in a Mineral Beneficiation plant whose object is to reduce large lumps to fragments.
- The coarsest particles in the crushed product being 1/20 inch or more in size.
- The size of coarsest particles is 1/2 inch in many cases.
- The crushing action in all crushing machines (crushers) results from forces applied to the particles by some moving part working against a stationary or some other moving part.
- It is the first stage of size reduction. It has to crush run-of-mine ore which contains large size particles.
- It requires greater force to be applied on the particles. Crushing is generally a dry operation and is usually performed in two or three stages.
- Crushers are designed in such a way that they reduce rock in such a manner that all pieces are less than a stated size.
- But no crusher has been devised which produces only fragments greater than a specified size.
- A crusher always produces various sizes of particles with substantial amount of fines. As investigated by Gaudin and Hukki (1944), when the products of crushing are separated into a series of closely sized fractions, the total surface of each fraction will be more or less equal.
- Broadly it is defined as the ratio of the maximum size of the particle in the feed to the maximum size of the particle in the product.

  Two definitions commonly used are termed as average reduction ratio and 80% passing reduction ratio which are defined as follows:

$$\text{Average reduction ratio} = \frac{\text{Average size of the feed particles}}{\text{Average size of the product particles}}$$

$$80\% \text{ passing reduction ratio} = \frac{80\% \text{ passing size of the feed}}{80\% \text{ passing size of the product}}$$

- Reduction ratio is a convenient measure for comparing the performance of different crushers.
- As the crushing is performed in stages, crushing may be divided into primary, secondary, tertiary and quaternary stages based on the particle size.

The crushers can be classified into five groups according to the size of the product they produce such as:

1. Primary Crushers: Jaw crusher, Gyratory crusher.

2. Secondary Crushers: Reduction gyratory, Cone crusher, Rolls crusher.

3. Tertiary Crushers: Short-head cone crusher.

4. Fine Crushers: Impact crushers.

5. Special Crushers: Bradford Breaker, Toothed Roll crusher.

Lumps of run-of-mine

- ❖ Lumps of run-of-mine ore usually of 1 m size is reduced to 100–200 mm size in heavy duty primary crushers.
- ❖ The usual size of feed to secondary crushers is 600 mm and the product is usually 10–100 mm size.
- ❖ In tertiary crushers, particles of 250 mm size are reduced to 3–25 mm size.

Fine crushers

- ❖ Fine crushers reduce the coarse particle to fine, even to 200 mesh in some cases.
- ❖ Special crushers are designed for specific ores, for example, rotary breaker and toothed rolls crusher for coal and gravity stamps for gold ore milling.

Construction

Operation and maintenance of crushers such as

jaw crusher

- ❖ Jaw crushers consist of two jaw plates set at an acute angle, called angle of nip, to each other which forms a crushing chamber.
- ❖ One jaw is fixed and kept vertical, the other jaw is a movable or swing jaw and is moved to approach and recede alternately from the fixed jaw.
- ❖ Motion to the swing jaw is transmitted by pitman working on an eccentric and toggles.

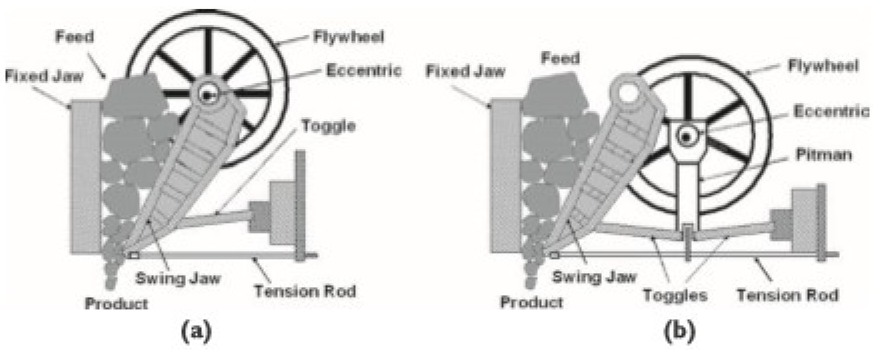


Fig.10 (a) Single toggle jaw crusher; (b) Double toggle jaw crusher.

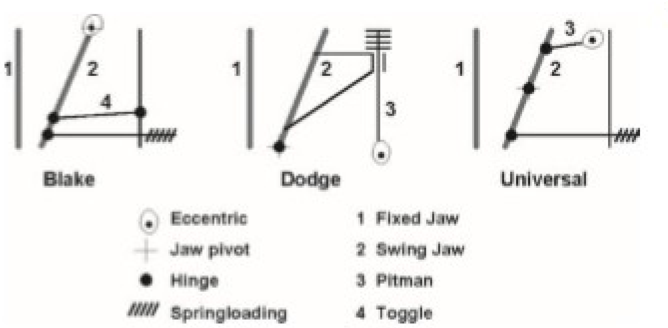


Fig.11 Types of jaw crushers.

- ❖ The material is fed between the jaws and is alternately nipped and crushed.
- ❖ Single and Double Toggle Jaw crushers are shown in Figure 10.

Jaw crushers are classified by the method of pivoting the swing jaw (Figure 11) such as

(a) Blake crusher

The swing jaw is pivoted at the top, it has a fixed receiving area and variable discharge area and is known as a Blake crusher.

(b) Dodge crusher

The swing jaw is pivoted at the bottom, it has a fixed discharge area and variable receiving area and is known as a Dodge crusher.

(c) Universal crusher

The swing jaw is pivoted at an intermediate position, it has both variable receiving and discharge areas and is known as a Universal crusher.

- ❖ In a Blake crusher, the distance between the two jaw plates at the feed opening is known as gape.
- ❖ The distance between the two jaw plates at the discharge opening is known as set.
- ❖ The minimum distance is called closed set and maximum distance is called open set.
- ❖ The maximum amplitude of swing of the jaw is known as throw.
- ❖ In the mining industry, Jaw crushers are used to crush the run-of-mine ore to a size suitable for transportation.
- ❖ The reduction ratio of jaw crushers varies from 4 to 7.

Gyratory crusher

- ❖ Gyratory and Cone crushers are of similar in construction and working.
- ❖ They consist of two vertical truncated conical shells of which the outer hallow conical shell is stationary and the inner solid conical shell is made to gyrate.
- ❖ In a gyratory crusher the inner conical shell is pointing up and outer conical shell is pointing down.
- ❖ The reduction ratio varies from 3 to 10. Figure 12 shows the cut section of a gyratory crusher.

- Reduction gyratory crusher is the modification of gyratory which has straight or curved heads and concaves and used for secondary crushing.
- The fine reduction gyratory crusher can also be used for tertiary crushing.

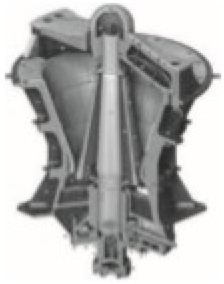
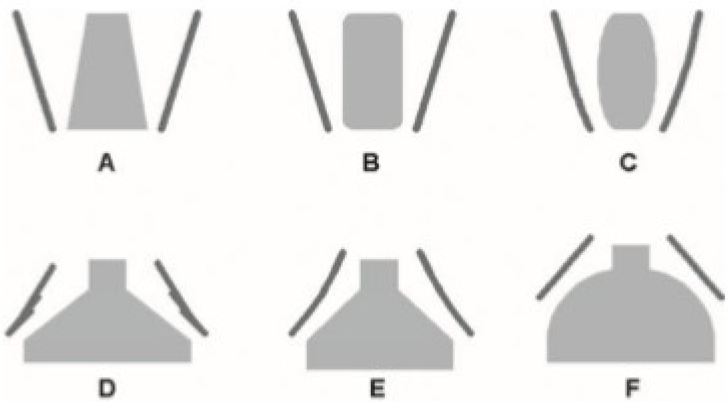


Fig.12 Cut section of Fuller-Traylor gyratory crusher (Courtesy FLSmidth Minerals).

Cone crusher

- The cone crusher is a modified gyratory.
- Both the outer and inner conical shells are pointing up.
- Simons cone crusher is the most widely used type of cone crusher.
- It has two forms: Standard cone crusher and Short-head cone crusher.
- The outside surface of the standard cone crusher has stepped liners to allow a coarser feed.
- It yields the product at reduction ratio of 6 to 8.
- The Short-head cone crusher has a steeper head angle to prevent choking of finer material.
- The reduction ratio is about 4 to 6.



(A) Gyratory; (B) Straight head and concave reduction gyratory; (C) Curved head and concave reduction gyratory; (D) Standard cone; (E) Short-head cone; (F) Gyrasphere

Fig.13 Types of crushing chambers.

The Telsmith gyrasphere is another type having a spherical steel head and used for tertiary crushing. Figure 13 shows crushing chambers of all types of gyratory and cone crushers.

Roll crusher

- Roll Crusher (Figure 14) consists of two smooth heavy horizontal cylinders revolving towards each other.
- The feed material is nipped between the rolls and pulled downward through the rolls by friction.
- The distinguished feature of a roll crusher is that the material is crushed one time only whilst it is passing through the crushing chamber.
- The reduction ratio of a roll crusher varies from 2 to 4, the lowest among all the crushers.
- Production of fines are generate minimum.
- They can handle friable, dry, wet, sticky, frozen, and less abrasive feeds well.

For the selection of size of roll crusher for the reduction of different sizes of feed, two expressions are given by:

$$\cos\frac{n}{2}=\frac{D+s}{D+d} \text{----------------} (4)$$

$$\tan\frac{n}{2}=\mu \text{------------------} (5)$$

Where,

n = angle of nip (Figure 15)

D = diameter of the rolls

d = diameter of the spherical feed particle

s = distance between the two rolls (set)

μ = coefficient of friction between the roll and the particle

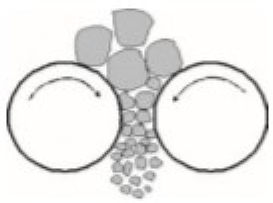


Fig.14 Roll crusher.

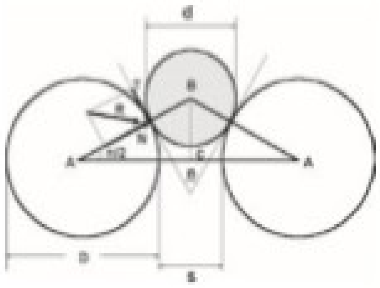


Fig.15 Angle of nip of roll crusher.

- ❖ Smooth-surfaced roll crushers are generally used for fine crushing whereas corrugated or toothed roll crushers are used for coarse crushing of soft materials.
- ❖ Single toothed roll crusher and Double toothed roll crusher are the two types of toothed roll crushers used for crushing coal.

Hammer mill

- ❖ Impact crushers reduce the particles by impact forces applied through sharp blows of fixed or free swinging hammers revolving about central rotor at high speed to the free falling particles against stationary surfaces.
- ❖ They are used for relatively soft, friable, and sticky ores such as phosphates, limestone, clay, graphite and coal.
- ❖ Hammer mill (Figure 16) is one type of impact crusher.

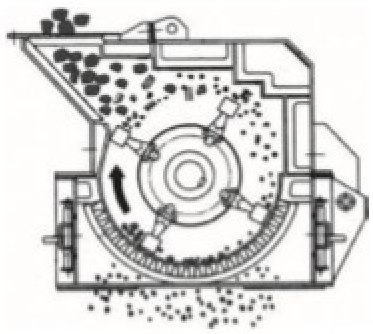


Fig.16 Hammer mill.

Optimization of crushing circuits

- ❖ Usually each stage of size reduction is followed by a screen which forms a circuit.

Crushing may be conducted in open or closed circuit. Figure 17 shows the typical open and closed circuit operations:

open circuit

- ❖ In an open circuit crushing operation, the feed material is reduced by one crusher.

- The product of this crusher is screened and only oversize material is crushed by another crusher of small size as the throughput (the quantity of material crushed in a given time) is less.
- The crushed product from the second crusher and undersize material from the screen together form the final product.

closed circuit

- In a closed circuit crushing operation, the oversize material from the screen is fed back to the same crusher.
- The quantity of the oversize material fed back to the crusher is called as circulating load.
- The undersize material from the screen is the required final product.
- Initially the quantity of final product produced is less than the quantity of the feed material.
- As the operation proceeds further the quantity of the final product gradually increases and will be equal to the quantity of the feed material after some time.
- After attaining this equilibrium condition, the quantity of the final product is always equal to the quantity of the feed material and the circulating load is constant.
- The circulating load is expressed as a percentage of the quantity of feed material.
- It is to be noted that the throughput of the crusher is more than that of the crusher used in open circuit crushing operation and equal to the quantity of feed material plus the quantity of oversize material fed back from the screen.

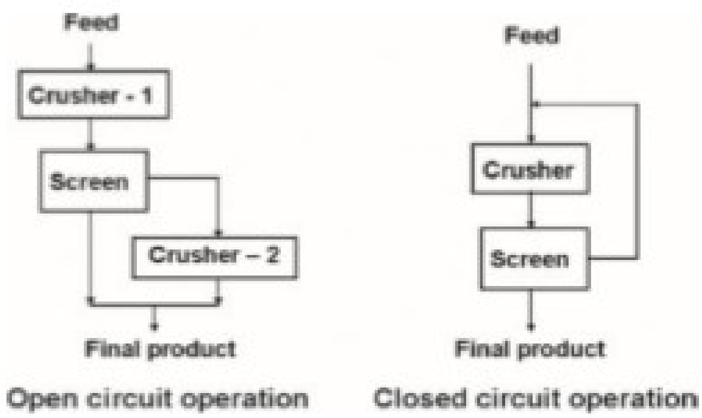


Fig.17 Crushing circuits.

It is obvious that two size reduction machines are used in an open circuit operation whereas only one machine is employed in a closed circuit operation to get the final product. The objectives of employing a closed circuit operation are to minimize the production of fines and to reduce the energy consumption by avoiding size reduction of already reduced particles to the required size.

High compression roll:

Construction:

- In a roll crusher, the force of compression and friction makes the particles to crush.

- In High Pressure Grinding Rolls (Figure 18), rolls are subjected to high pressure so that comminution takes place by compressive forces as well as by inter-particle breakage.
- The force applied to the crushing zone is controlled by a hydro-pneumatic springs.
- As the product size from HPGR is fine, it can replace the conventional secondary and tertiary crushers.

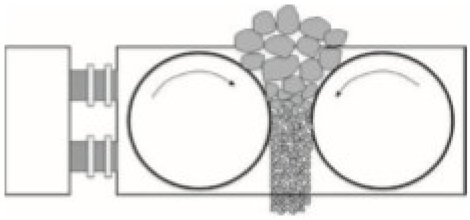


Fig.18High pressure grinding rolls (HPGR).

<u>Operation maintenance and performance aspects</u>

Crushers are usually operated dry. When the material fed to the crusher is at a slow rate, the individual particles are crushed freely. The crushed product is quickly removed from the crushing zone known as free crushing. To avoids the production of excessive fines by limiting the number of contacts.

When the material fed to the crusher is at a high rate, the crusher is choked and it prevents the complete discharge of crushed product. This results in crushing between the ore particle and the crushing surface as well as between the ore particles. This type of operation increases the amount of fines produced. This type of choked feeding is preferred in some cases as it reduces the reduction stages.

Usually crushing is performed for any ore in two or three stages depending on the size of the feed particles and the size of the product particles required.

MODULE-IV

Grinding:

<u>Grinding mills principles</u>

- Grinding is the last stage of the comminution process.
- The particles are reduced from a maximum upper feed size of 3/8 inch.
- The some upper limiting product size ranging between 35 mesh and 200 mesh (420 microns and 74 microns).
- Grinding is performed in rotating steel vessels knows as tumbling mills or grinding mills.
- A grinding mill consists of a horizontal rotating steel shell supported by end bearings on which hallow trunnions revolve.
- Loose crushing bodies, known as grinding medium, are placed inside the shell.

- ❖ The steel balls/rods or pebbles are used as grinding medium.
- ❖ They are free to move inside the rotating shell making the particles break by repetitive blows and by rolling and sliding one over the other.
- ❖ Attrition, or shearing, forces which result from the application of forces by rolling.
- ❖ The sliding bodies tend to produce more fine particles than impact forces applied on particles by repetitive blows.

Construction and their operation

- ❖ Grinding mills can be operated wet or dry, batch-wise or continuously.
- ❖ The equipment is robust and the loose grinding medium can usually be added without stopping the mill. On the other hand, grinding mills are relatively high in power consumption and require expensive foundations.
- ❖ Grinding mills are normally loaded to approximately 50 percent of its volume with grinding medium.
- ❖ Grinding mills are classified as Ball mill, Rod mill, Tube or Pebble mill, and Autogenous mill on the basis of grinding medium and shell proportions.
- ❖ In ball mills, the grinding medium is steel balls; in rod mills, steel rods; in tube or pebble mills, pebbles of hard rock or other nonmetallic material; in autogenous mills, coarse ore particles.

Mill liners

- ❖ The interior of tumbling mill is lined by replaceable liners usually made of alloy steel but sometimes of rubber.
- ❖ Some types of liners are smooth, shiplap, wave, wedge bar, rib, stepped, osborn, lorain, etc.
- ❖ Smooth liners favour abrasion resulting in fine grinding but high metal wear.
- ❖ Liners other than smooth are designed to help in lifting the ball load as the mill is revolved and sometimes to minimize the slip between the layers of balls.
- ❖ Liners protect the mill body from wear and damage.

Feed entry and product discharge mechanisms

- ❖ Usually the material is fed at one end of the mill and discharged at the other end.
- ❖ The dry grinding mill, the feed is by vibrating feeder.
- ❖ The three types of feeders (Spout, Drum and Scoop feeders) are in use to feed the material to the wet grinding mills such as:

(a) spout feeder

In a spout feeder, the material is fed by gravity through the spout.

(b) drum feeder

In drum feeder, the entire mill feed enters the drum and an internal spiral carries it and fed to the mill.

(c) scoop feeder

Grinding balls are conveniently added through this feeder during operation. In case of scoop feeder, material is fed to the drum and the scoop picks it up and fed to the mill.

Open and closed-circuit grinding:

Ball mill construction

- ❖ Ball mill uses steel or iron balls as grinding medium.
- ❖ Ball mills usually have a length to diameter ratio of 1.5 to 1.0.
- ❖ According to the shape of the mill, the ball mills are classified as cylindroconical and cylindrical mills (Figure 19).

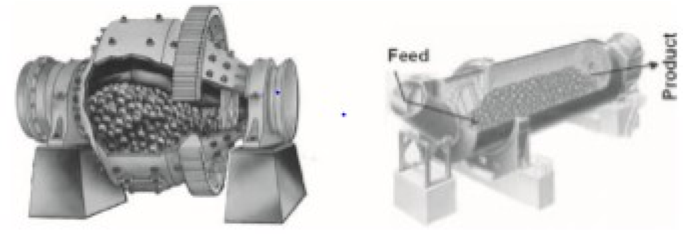


Fig.19 (a) Cylindroconical ball mill; (b) Cylindrical ball mill. (Courtesy Metso Minerals); (Courtesy www.mine-engineer.com).

Ball mill Operation

- ❖ As the mill rotates, the balls are lifted to certain height and then dropped.
- ❖ Grinding of ore particles takes place due to simple rolling of one ball over the other (cascading) and by the free fall of balls (cataracting).
- ❖ Cascading leads to fine grinding whereas cataracting leads to coarse grinding. Figure 20 shows the motion of the charge in the ball mill.
- ❖ The speed of the mill increases, the balls are lifted higher and a stage is reached where the balls are carried around the shell and never allowed to fall. That means centrifuging occurs.
- ❖ The balls will rotate as if they are part of the shell.
- ❖ The speed at which centrifuging occurs is known as critical speed.

An expression for the critical speed is given by:

Critical speed = $N_c = \frac{42.3}{\sqrt{(D-d)}}$ revolutions/minute----------------------------(6)

Where,

D and d the diameter of the mill and the ball in meters

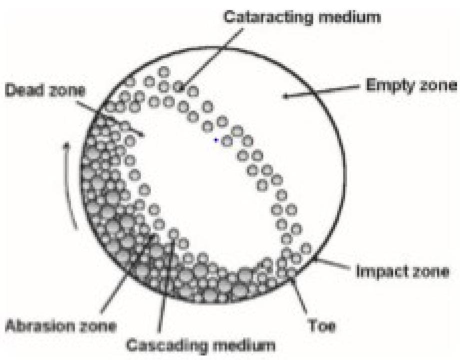


Fig.20 Motion of the charge in a ball mill.

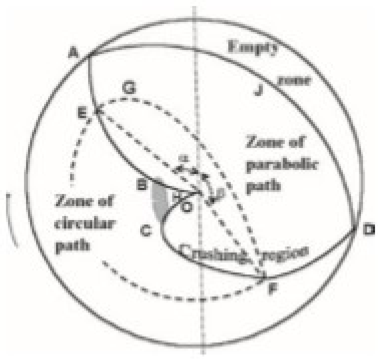


Fig.21 Zones in a ball mill.

- ❖ Davis has given an exhaustive mathematical analysis of the action in a ball mill and explained various zones in a ball mill (Figure 21).

  From the figure it observed that:
- ❖ In Figure 21, FE is the circular path and EGF is the parabolic path of a ball placed at point F or E.
- ❖ The locus of the point E where the ball changes from circular path to parabolic path for all positions of the balls from center of the mill to the periphery is OBEA.
- ❖ The locus of the point F, the end of the parabolic path for all positions of the balls is DFCO.
- ❖ Davis has shown that the arcs CO and BO correspond to unstable equilibrium.
- ❖ The zone BCH is a dead zone where there is no effective motion, hence no grinding takes place.

The inside of the ball mill consists of four zones:

1. An empty zone where no balls occupy this zone during operation.

2. A dead zone where no grinding takes place.

3. A zone of circular path where balls roll on each other and grinding takes place by slippage between ball layers before they are lifted.

4. A zone of parabolic path where the balls spread out and fall down.

- When the speed of the mill exceeds the critical speed, all these zones disappear, the balls will centrifuge and no grinding takes place anywhere inside the mill. Hence the mill should be operated at a speed below the critical speed. The usual range is 60–80% of critical speed.

  Ball size
- Balls vary in size from 1 to 6 inches.
- The largest balls are used for coarser grinding.
- Initially, at the start of a ball mill, balls of various sizes, known as seasoned charge, are introduced.
- As the balls wear out gradually, only the largest balls are added as make up media.

Rod mill

- A rod mill uses rods as a grinding medium.
- Length to diameter ratio is between 1.5 and 2.5.
- Rods are a few (centimetre) shorter than the length of the mill to avoid any jamming of rods in the mill.
- The rods are kept apart by the coarsest particles.
- The grinding action results from line contact of the rods on the ore particles and is exerted preferentially on the coarsest particles.
- Smaller and fine particles do not grind till the coarsest particle is reduced in size. This can clearly be observed in Figure 22.
- The rod mill produces a more closely sized product with little oversize or slimes. Hence the rod mills may be considered as coarse grinding machines.

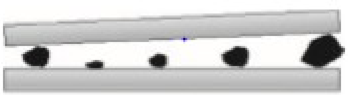


Fig.22 Grinding action of rods.

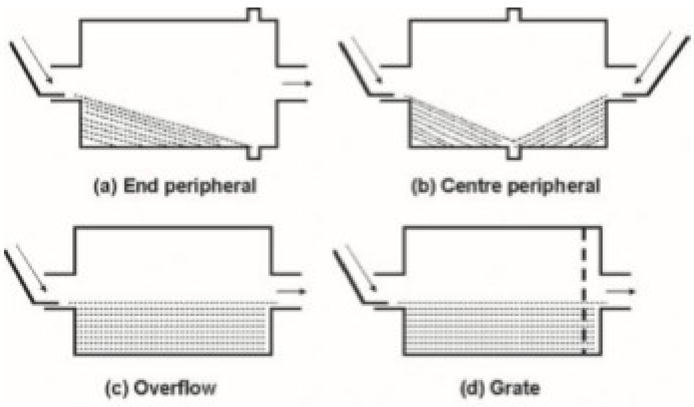


Fig.23 Types of rod mills according to method of discharge.

- If the material inside the mill is made to discharge through the periphery of the mill shell, it passes through quickly and less over-grinding takes place.

- ❖ Rod mills are classed according to the method of the discharge of ground product as Peripheral, Overflow and Grate discharge mills (Figure 23).

  Types of discharge mill

There are two types in peripheral discharge mills such as:

(a) End peripheral discharge

The material is fed at one end of the mill and the ground product is discharged from the other end by means of several peripheral apertures into a close-fitting circumferential chute.

(b) Centre peripheral discharge mill

The material is fed at both ends of the mill and the ground product is discharged through a circumferential port at the centre of the shell.

(c) Overflow discharge mill

The material is fed at one end and the product is discharged through the other end by overflow in overflow discharge mill.

(d) Grate discharge mill

The discharge grates are fitted through which pulp flows freely and lifted up to the level of the discharge trunnion.

- ❖ Rod mills are normally run at 50–65% of the critical speed so that the rods cascade rather than cataract.

<u>Pebble mill</u>

- ❖ A tube mill is a grinding mill where length to diameter ratio is 3 to 5. It is also known as a pebble mill as it uses ceramic pebbles made of flint or porcelain as the grinding media.
- ❖ As pebbles are fragile, pebble mills are smaller in diameter. Because of low specific gravity of pebbles, large quantity of pebbles has to be used to attain required grinding for equivalent duty as compared with ball mills.
- ❖ Pebble mills are used when iron contamination in the product is highly objectionable such as in the manufacture of paints, pigments, cosmetics, etc.
- ❖ Tube mills are sometimes divided into several longitudinal compartments, each having a different charge composition.
- ❖ The charge can be steel balls, rods or pebbles and they are often used dry to grind cement clinker, gypsum and phosphate.

<u>Autogenous mill</u>

- ❖ The autogenous mill use coarse ore particles as grinding medium.
- ❖ Grinding is achieved by the action of ore particles on each other when particles of ore of different sizes are rotated together in a tumbling mill.
- ❖ The mill is of very large in diameter.

- The larger particles in the feed must be sufficient in size and number to break the smaller particles as fast as they themselves are broken down in the mill.
- Autogenous grinding greatly reduces metal wear and also reduces the number of crushing and grinding stages as compared to conventional size-reduction operations.
- It is possibilities of large savings in capital and operating costs. However, it is practical for only a limited number of ore types.
- Autogenous grinding differs from grinding with metal balls or rods in that the breakage is much more confined to zones of weakness in the rock, such as crystal surfaces and fine cracks.
- An ore with a pronounced natural grain size, or crystal size, may be ground autogenously to that size with comparative ease, but is ground finer only with difficulty.

Semi-Autogenous mill (SAG mill)

Semi-Autogenous mill (SAG mill) uses a combination of the ore and a reduced charge of balls or rods as a grinding medium to overcome the difficulties encountered in autogneous grinding.

Application of these mills for specific processing equipments:

Effect of process parameters on mill performance

The grinding may be wet or dry depending on the subsequent process and the nature of the product.

Wet grinding

- Wet grinding is generally used in mineral beneficiation plants as subsequent operations for most of the ores are carried out wet.
- Wet grinding is usually carried out with 20–35% water by weight.
- The chief advantages of wet grinding are increased capacity (as much as 15%) for a given size of equipment and less power consumption per ton of the product.
- Low power consumption is due to the penetration of water into the cracks of the particles which reduces the bond strength at the crack tip.

Dry grinding

- It is used whenever physical or chemical changes in the material occur if water is added. It causes less wear on the liners and grinding media.
- It is often employed to produce an extremely fine product. This arises from the high settling speed of solids suspended in air as compared with solids suspended in water.

Closed & open circuit grinding optimization

- Mesh of grind (m.o.g.) is the term used to designate the size of the grounded product in terms of the percentage of the material passing through a given mesh.
- In grinding, there are always some particles which may repeatedly be reduced to fine size whereas some other particles may not be reduced.

- The primary objective of a grinding mill is to reduce all particles to the stated size i.e., mesh of grind.

Open circuit grinding

- When a grinding mill is fed with a material, it should be at a rate calculated to produce the correct product in one pass in which case it is known as Open circuit grinding (Figure 24).
- There is no control on product size distribution in the open circuit grinding.

Closed circuit grinding

- In closed circuit grinding (Figure 25), the material of the required size is removed by a classifier from the ground product to send to the subsequent operation and oversize is returned to the same grinding mill.
- The removal of the product from the grinding mill as soon as the material is grounded to the required size so that overgrinding (grinding to the size finer than required) is avoided.
- In case of a rod mill, rods exert sizing action, hence the use of closed circuit grinding is not necessary.
- In closed circuit grinding, the amount of solids by weight fed back to the grinding mill is called circulating load. The weight is expressed as a percentage of the weight of new feed.

$$\text{Percent circulating load} = \left(\frac{U}{NF}\right) X\ 100 ------------ (7)$$

Where,

U is the circulating load

NF is the amount of new feed solids fed to the mill

- The grinding mills are generally operated at circulating loads of 200–500% in order to have the grinding to the required size.

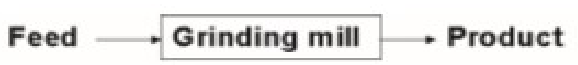


Fig.24 Open circuit grinding.

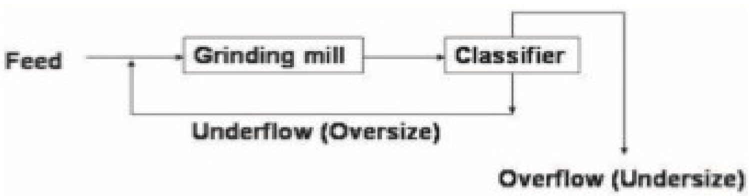


Fig.25Closed circuit grinding.

MODULE-V

Classification:

- Classification is a method of separating mixtures of particles of different sizes, shapes and specific gravities into two or more products on the basis of the velocity with which the particles fall through a fluid medium i.e., settling velocity.
- Generally classification is employed for those particles which are considered too fine to be separated efficiently by screening.

Principle

The basic principle of classification is:

- The coarser, heavier and rounder particles settle faster than the finer, lighter and more angular particles
- In classification, certain particles are only allowed to settle in the fluid medium in order to separate the particles into two fractions.

Introducing to different types of classifiers used in mineral industry and Their construction and maintenance

CLASSIFIERS

The units in which the separation of solids in fluid medium is carried out are known as classifiers. These classifiers may be grouped into three broad classes as:

1. Sizing classifiers.

2. Sorting classifiers.

3. Centrifugal classifiers.

Let us reconsider Figure 26 by assigning the numbers in the order of increasing size as shown in Figure 27 to explain how the particles can be separated.

From the figure it observed that:

- Under free settling conditions, if sufficient time for the light particle 5 is not given for settling, all the light particles of 1 to 5 and heavy particles of 1 to 4 will be at the top of the classifier.
- The light particles of 6 to 8 and heavy particles of 5 to 8 will be at the bottom of the classifier.
- Top and bottom fractions are removed by suitable means without giving time for the light particle 5 to settle.

The two fractions obtained from the classifier contain:

(a) Top fraction – light particles of 1–5 and heavy particles of 1–4.

(b) Bottom fraction – light particles of 6–8 and heavy particles of 5–8.

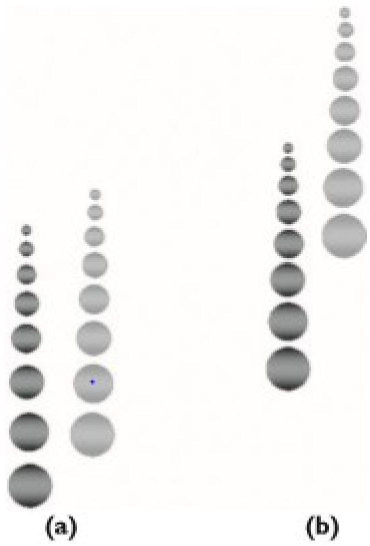


Fig.26 (a)Free settling(b)Hindered Settling.

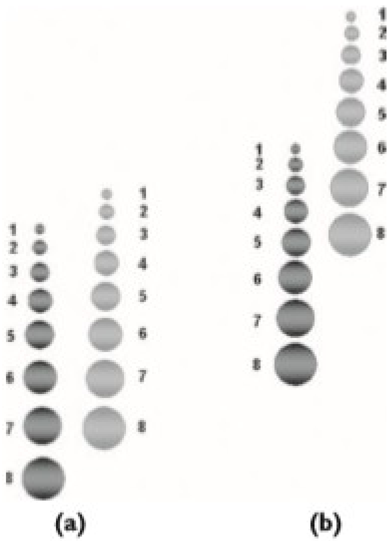


Fig.27 (a)Free settling(b)Hindered Settling.

- ❖ Each fraction contains both light and heavy particles and almost the same size or closely sized particles.
- ❖ It means that all the particles are separated into two size fractions. Hence this type of classification is called sizing classification.

Hindered settling

- ❖ If top and bottom fractions are removed without allowing light particle 8 to settle, the bottom fraction contains solely of heavy particles 6 to 8.
- ❖ As the settling velocity of all the light particles is less than the settling velocity of light particle 8, they remain at the top along with the heavy particles 1 to 5 and get discharged as overflow product.

- If these particles are again classified without allowing light particle 5 to settle, the bottom fraction contains heavy particles 1 to 5 and light particles 6 to 8. Only light particles 1 to 5 remain at the top and get discharged as overflow product.
- It is obvious that heavy particles of 1 to 5 and light particles of 6 to 8 are under hindered settling conditions, which means that they cannot be separated.
- Heavy particles of 6 to 8 can be separated as bottom fraction and light particles of 1 to 5 can be separated as top fraction.

Sizing classifiers

- A typical sizing classifier consists of a sloping rectangular trough.
- Feed slurry is introduced at point 1 as shown in Figure 28 fines overflow at point 2.
- The rate of feed and distance between point 1 and point 2 is selected in such a way that the rate of travel of required fine particles must be more than the rate of their settling so that all the required fine particles overflow at point 2.

  Spiral and Rake classifiers

  The coarse particles settle to the bottom. To remove these coarse particles, a mechanical means such as spiral or rake is placed at the bottom of the trough. Figure 29 shows how the particles are separated in Spiral and Rake classifiers.

  Horizontal current classifiers
- Sizing classifiers are the mechanical classifiers. Since the stream of slurry consists of fines flow horizontally from the feed inlet to the overflow weir, these are also called as horizontal current classifiers.
- They are also called pool classifiers as the classification takes place in the pool.
- These classifiers are extensively used in closed circuit grinding operation with a ball mill where underflow coarse product is directly fed to the inlet of the ball mill. Another type of classifier is of tank type such as Dorr Bowl.

These classifiers are:

• Free settling classifiers.

• Uses relatively dilute aqueous suspension.

• Perform mostly sizing.

• Percent solids are usually 5–10%.

• Yields only two products.

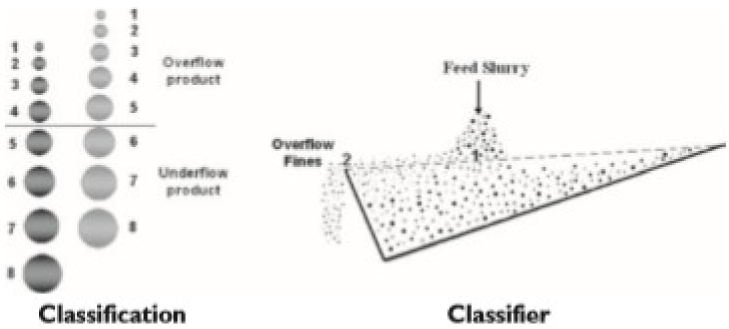


Fig.28Principle of mechanical classifier.

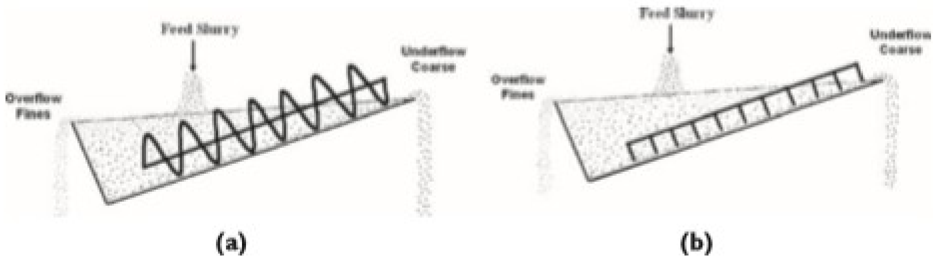


Fig.29(a) Spiral classifier;(b)Rake classifier

Sorting classifiers

- Sorting classifiers employ the hindered settling conditions to increase the effect of density in order to separate the particles according to their density rather than size.
- A typical sorting classifier consists of a series of sorting columns as shown in Figure 30.

Operation

- The feed slurry is introduced centrally near the top of the first sorting column.
- A current of water known as hydraulic water. It is introduced at the bottom of the sorting column at a velocity slightly less than the smallest heavy particle among the particles required to be discharged in the first sorting column.
- All those particles having settling velocity less than that of rising water velocity will not settle and rise to the top of the column and fed to the second column.
- The particles, having a settling velocity more than that of the rising water velocity, settle to the bottom of the first sorting column and get discharged through the spigot.
- The velocity of the hydraulic water in the second sorting column is less than that of the velocity in the first sorting column.
- The particles of low settling velocity settle to the bottom of the second sorting column and get discharged through the spigot.
- The particles with still low settling velocity are obtained through the spigot of third sorting column and remaining particles are obtained as overflow from the third sorting column.

From the figure it observed that:

Figure 27:

- Explanation with reference to Figure 27 has already been given as to how the particles are separated.
- Under hindered settling conditions by using two sorting columns where it is clear that fine heavy and coarse light particles are together discharged as spigot product of the second sorting column.

Figure 31

The coarse heavy as spigot product of the first sorting column and fine light as overflow product of the second sorting column. Figure 31 shows this separation.

Figure 32

If the free settling conditions are maintained, a series of spigot products with decreasing size of particles from first spigot are obtained as shown in Figure 32.

❖ As these classifiers use the rising current of water, they are called hydraulic classifiers and vertical current classifiers.

These classifiers are:

• launder type with rectangular boxes attached to it such as the Evans classifier, cylindrical type such as the Anaconda and Richards classifiers, trapezoidal tank type such as the Fahrenwald sizer.

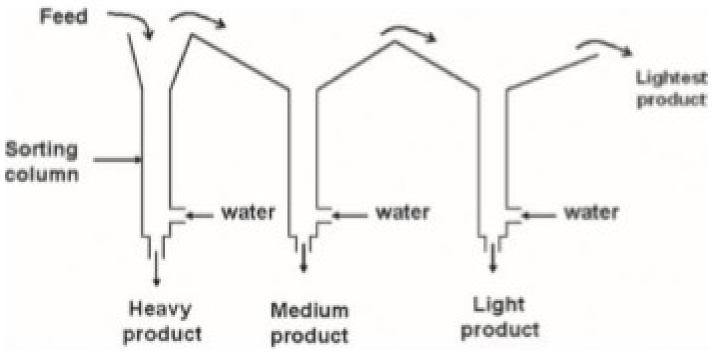


Fig.30(a) Principle of sorting classifier

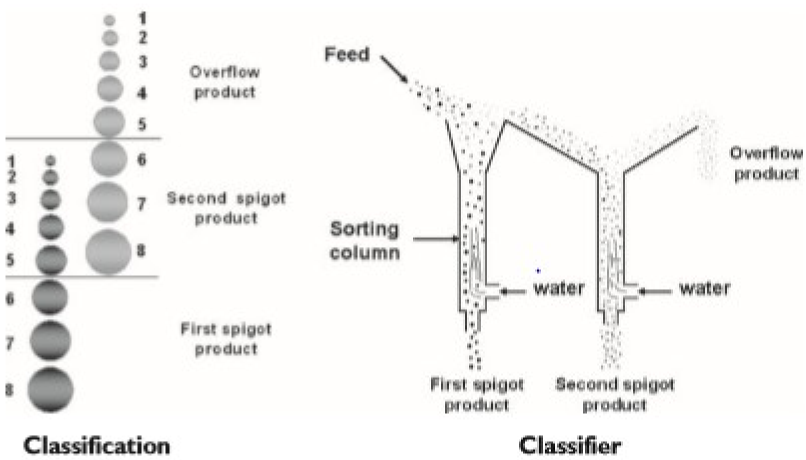


Fig.31 Hydraulic classifier with sorting effect.

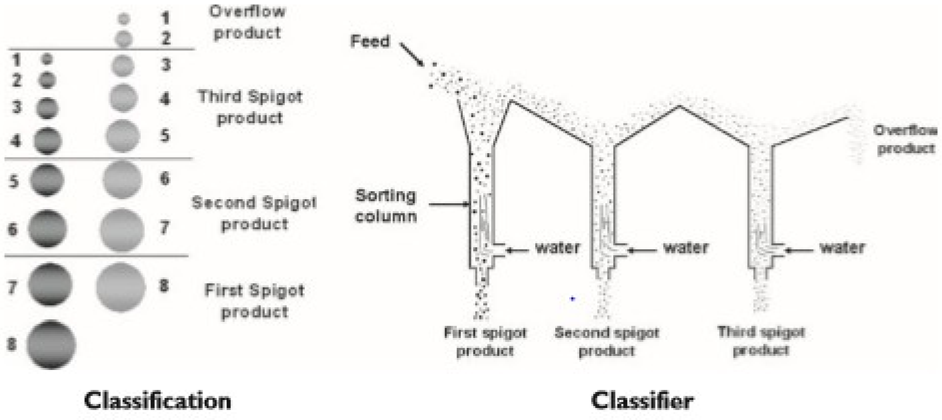


Fig.32 Hydraulic classifier with sizing effect.

• Uses rising current of water called hydraulic water.

• Hindered settling classifiers.

• Uses relatively dense aqueous suspension as fluid medium.

• Perform mostly sorting.

• Percent solids are usually 15–30%.

• Yield more products.

Even though sorting classifiers are not truly sizing classifiers, they are sometimes used to sort out the particles in a close size range as shown in Figure 32 which are necessary for gravity concentration operations such as tabling. The Stokes Hydrosizer is commonly used to sort the feed to gravity concentrators.

Hydrocyclones:

Centrifugal classifiers

- ❖ Under gravity force, the settling rate of a particle varies as its effective mass.
- ❖ If a centrifugal force is applied, the effective mass increases and therefore settling rate increases.
- ❖ As particles are ground smaller they reach a size where the surface drag against the surrounding fluid almost neutralizes the gravitational pull.
- ❖ Thus the result that the particle may need hours, or even days, to fall a few inches through still water. This slowing down of the settling rate reduces the tonnage that can be handled and increases the quantity of machinery and plant required.
- ❖ By superimposing centrifugal force, the gravitational pull can be increased from 50 to 500 times depending on the pressure at which the pulp is fed and the size of the vessel.

Operation of the hydrocyclone:

- The hydrocyclone is one which utilizes centrifugal force to accelerate the settling rate of particles.
- Hydrocyclone (Figure 33) has no moving parts.
- It consists of a cylindrical section with a tangential feed inlet.
- A conical section, connected to it, is open at the bottom, variously called the underflow nozzle, discharge orifice, apex or spigot.
- The top of the cylindrical section is closed with a plate through which passes an axially mounted central overflow pipe.
- The pipe is extended into the body of the cyclone by a short.
- The removable section known as vortex finder, which prevents short-circuiting of feed directly into the overflow.
- When a pulp is fed tangentially into a cyclone, a vortex is generated about the longitudinal axis.
- The accompanying centrifugal acceleration increases the settling rates of the particles, the coarser of which reach the cone's wall. Here they enter a zone of reduced pressure and flow downward to the apex, through which they are discharged.
- At the center of the cyclone is a zone of low pressure and low centrifugal force which surrounds an air-filled vortex.
- Part of the pulp, carrying the finer particles with major portion of feed water, moves inward toward this vortex and reaches the gathering zone surrounding the air pocket. Here it is picked up by the vortex finder, and removed through a central overflow orifice (Figure 34).

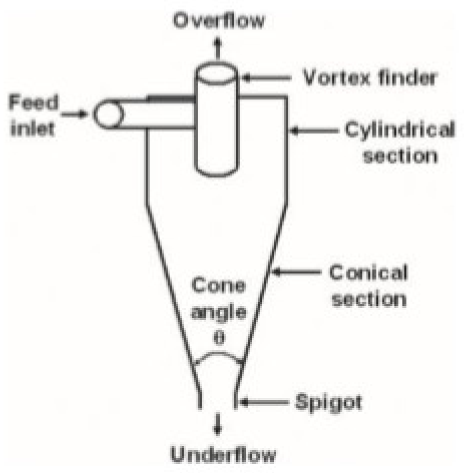


Fig.33 Hydrocyclone.

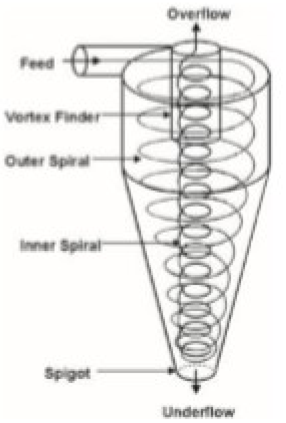


Fig.34 Hydrocyclone operation.

Construction of the hydrocyclone:

- The size of the hydrocyclone is the diameter of its cylindrical section.
- The variables that affect the performance of a hydrocyclone can be divided into two groups as design variables and operating variables.
- Design variables are the size of the hydrocyclone, diameter of feed inlet, vortex finder and apex, and position of the vortex finder.
- Operating variables are feed rate, feed pressure, solid-liquid ratio, density, size and shape of feed solids, and density and viscosity of liquid medium.

Advantages of the Hydrocyclone are:

1. Sharper classification.

2. Saving of floor space.

3. Less power consumption.

4. Less maintenance.

5. Ability to shut down the mill immediately under full load.

6. Ability to bring the circuit rapidly into balance.

7. Elimination of cyclic surging.

Uses of the hydrocyclone

- The main use of the hydrocyclone in mineral beneficiation is as a classifier, which has proven extremely efficient at fine separation sizes (between 150 and 5 microns).
- It is used increasingly in closed-circuit grinding operations.
- It is also used for many other purposes such as de-sliming, de-gritting and thickening.
- It has also found wide acceptance for the washing of fine coal in the form of Heavy Medium Cyclone and Water Only Cyclone.

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