4.1 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. However, machine sieving is preferred for routine analysis as hand sieving is long and tedious. Table model sieve shaker and Ro-tap sieve shaker (Figures 4.3 and 4.4) are the two principal machines used in a laboratory for sieve analysis.

Figure 4.3 Table model sieve shaker.
(Courtesy Jayant Scientific Industries, Mumbai).

Figure 4.4 Ro-tap sieve shaker.
(Courtesy Jayant Scientific Industries, Mumbai).

Owing to irregular shapes, particles cannot pass through the sieve unless they are presented in a favourable orientation, particularly with the fine particles. Hence there is no end point for sieving. For all practical purposes, the end point is considered to have been reached when there is little amount of material passing through after a certain length of sieving.
Sieving is generally done dry. Wet sieving is used when the material is in the form of slurry. When little moisture is present, a combination of wet and dry sieving is performed by initially adding water.

4.2 TESTING METHOD

The sieves chosen for the test are arranged in a **stack**, 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 4.5 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. Particle size distribution refers to the manner in which particles are quantitatively distributed among various sizes; in other words a statistical relation between quantity and size. Particle size distribution data is presented in a tabular form as shown in Table 4.2.

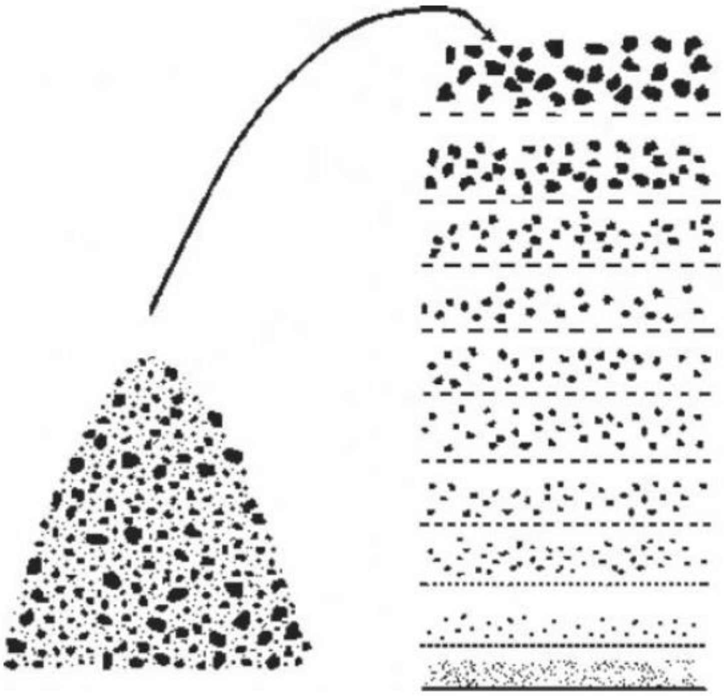


Figure 4.5 Sieve analysis at the end of sieving.

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.
All the fractions are fairly closely sized (except first fraction). Hence the size of the particles in each fraction may be calculated as arithmetic mean of the limiting sizes.

For example, the size of –14 + 22 mesh fraction is $\frac{1200 + 710}{2} = 955$ 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 4.3 shows all values.
The average size of the material is determined by using the following simple arithmetic formula where *w* is the weight percent of the material retained by the sieve and *d* is the mean size of the material retained by the same sieve.

Table 4.2 **Particle size distribution data from size analysis test.**

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.*

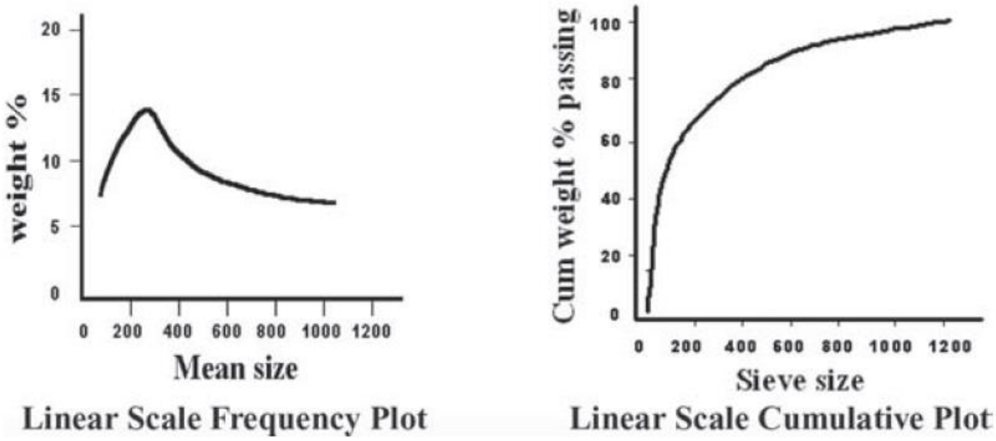


Figure 4.6 **Graphical presentation of particle size distribution data.**

4.3 PRESENTATION OF PARTICLE SIZE DISTRIBUTION DATA

Particle size distribution data is best presented for use in the form of graphs (Figure 4.6).

A graph is plotted between the weight percent of the material as ordinate and the arithmetic mean size as abscissa. It is called a **linear scale frequency plot**. It gives the quantitative picture of the relative distribution of the material over the entire size range. In many cases, the data is more commonly plotted as cumulative weight percent passing versus actual size of opening. It is called a **linear scale cumulative plot**.

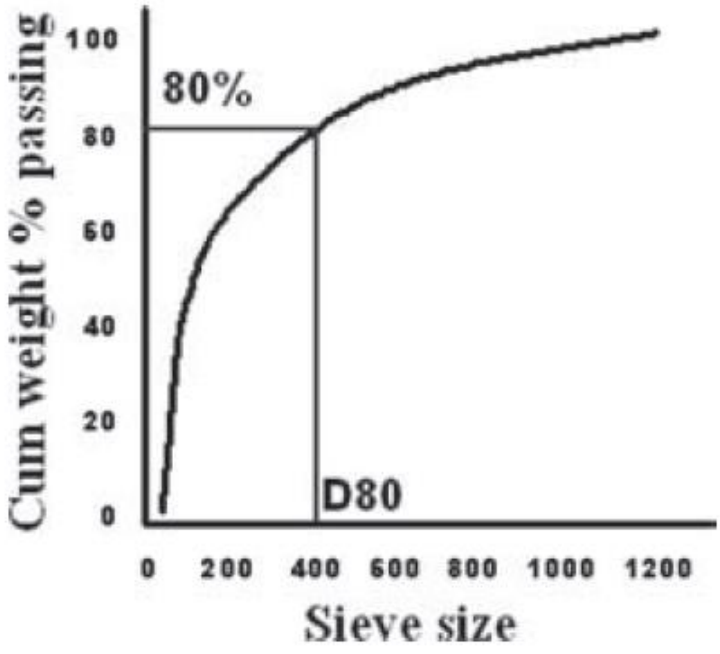


Figure 4.7 **Plot for determination of 80% passing size D80.**

The same graphs can also be drawn on semi-logarithmic graph paper for satisfactory spreading of the data on fine size region.

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 percent passing versus sieve size as shown in Figure 4.7.

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.

4.4 APPLICATIONS OF PARTICLE SIZE DISTRIBUTION DATA

1- Comparative efficiencies of comminution units by relating the work done and the product sizes can be studied.

2- Particle surface areas can be calculated from size analysis.

3- 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.

4- The calculation of the sizing efficiency of a classifier or cyclone can be closely estimated from size analyses of the feed and the products.

4.5 SUB-SIEVE SIZING

Sizing of the particles having size less than 40 microns is known as **Sub-sieve sizing**.

The particles at fine sizes are termed as slimes and colloids. The following are the approximate size ranges of different particles:

Particles	*Size ranges*
Sands	2 mm to 74 microns
Slimes	74 microns to 0.1 microns
Colloids	0.1 micron and 0.001 micron

Size analysis methods used for the particles less than 40 microns are shown in Table 4.4.

Table 4.4 **Size analysis methods for sub-sieve sizing.**

Method	*Approximate range, μm*
Sedimentation (gravity)	40–1
a Beaker decantation	
b Andresen pipette	
Elutriation	40–5
Sedimentation (centrifugal) Cyclosizer	5–0.05
Microscope (optical)	150–1
Electron microscope	1–0.005
Electrical Resistance method	
Coulter counter	400–0.5

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).

5.1 PURPOSE OF SCREENING

Industrial screening is used:

1- To remove oversize material before it is sent to the next unit operation as in closed circuit crushing operations.

2- To remove undersize material before it is sent to the next unit operation which is set to treat material larger than this size.

3- To grade materials into a specific series of sized (finished) products.

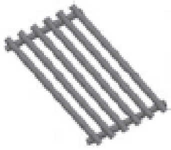
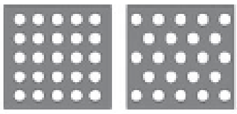
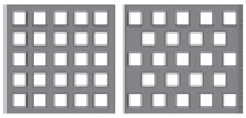
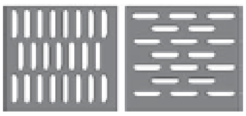
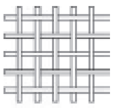
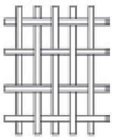
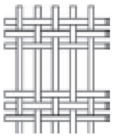
4- To prepare a closely sized (the upper and lower size limits are very close to each other) feed to any other unit operation.

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) but recent developments in the Sieve Bend Screen have made the wet screening possible at the 50 micron size.

5.2 SCREEN SURFACES

Screen surface is the medium containing the apertures for the passage of the undersize material. Several types of screen surfaces are described in Table 5.1.

Table 5.1 Types of screen surfaces.

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

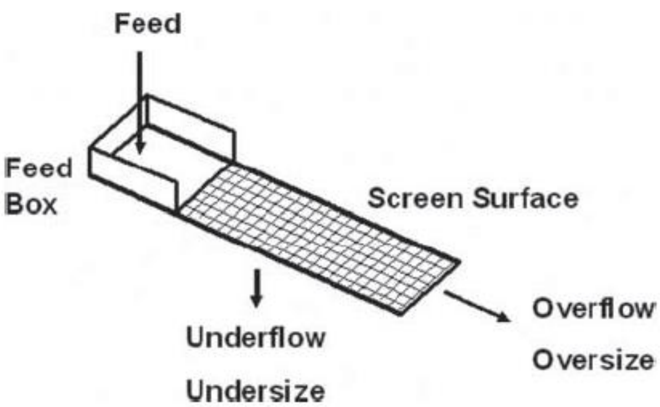


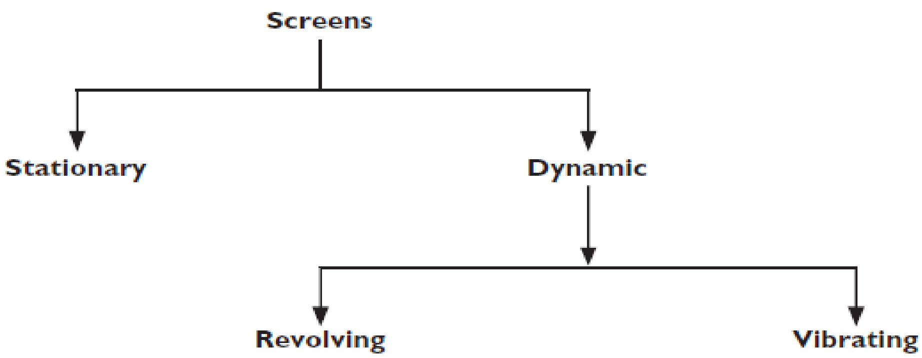
Figure 5.1 Simplified screen.

5.3 SCREEN ACTION

Consider a simplified screen as in Figure 5.1. The material is fed at one end of the screen. Screening is effected by continuously presenting the material to be sized (the feed) to the screen surface which provides a relative motion with respect to the feed. The screen surface can be fixed or moveable. Agitation of the bed of material must be sufficient to expose all particles to the screen apertures several times during the travel of the material from feed end to the discharge end of the screen. At the same time the screen must act as a transporter for moving retained particles from the feed end to the discharge end. Particles of size more than the aperture size of the screen are retained and smaller particles are passed through the apertures. Both the oversize and undersize particles are collected as overflow and underflow separately.

5.4 TYPES OF SCREENS

Most commonly, 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. However, 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

Stationary Screens

Figure 5.2 Grizzly.

Grizzly
Equally spaced parallel rods or bars running in flow direction.
Sloped to allow gravity transport.

Applications
Lumpy or coarse separations.
Scalping before crushing.
Dry separation.

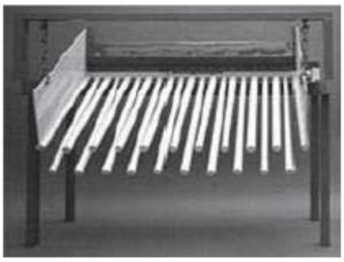


Figure 5.3 Divergator.
(Courtesy Mogensen).

Divergator
Parallel rods running in flow direction.
Fixed at one end.
Gap increases from fixed to free end.
Alternate rods diverge at 5°–6°.

Applications
Separations in the range 400 to 25 mm size.
Self cleaning and blockage free.
Dry separation.

Figure 5.4 Sieve bend.
(Courtesy Deister Concentrator, LLC).

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

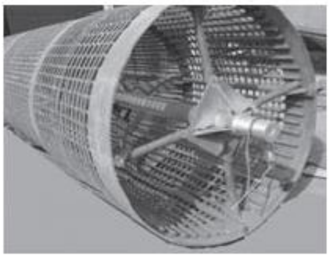


Figure 5.5 Trommel.
(Courtesy Qingzhou Yuanhua Machinery Manufacture Co.).

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

Figure 5.6 Vibrating grizzly. (Courtesy Mogensen).

Vibrating Grizzly
Similar to stationary grizzly.
Mechanical or Electrical vibrations.

Applications
Coarse and Dry separations.
Also used as feeders.

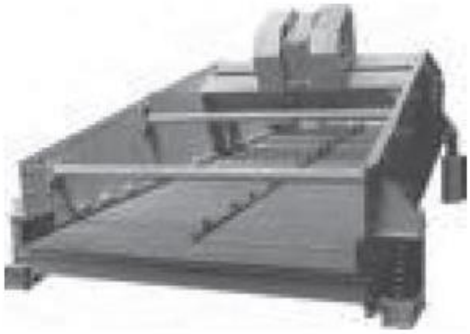


Figure 5.7 Vibrating screen. (Courtesy Robert Cort Ltd, UK).

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.

Sometimes, as in the case of Iron ores, screening yields sized material of the required grade. Hence screening becomes a beneficiation operation, as practiced at almost all Iron Ore Beneficiation plants in India where beneficiation is done at coarser sizes.

5.5 FACTORS AFFECTING THE RATE OF SCREENING

A number of factors determine the rate at which particles pass through a screen surface and they can be divided into two groups: those related to particle properties and those dependent on the machine and its operation. Some important factors are:

Material factors
1 Bulk density of the material.
2 Size and size distribution of the particles.
3 Size of the particle relative to the aperture.
4 Shape of the particle.
5 Moisture content of the material.

Machine factors
1- Size of the aperture.
2- Shape of the aperture.
3- Size of the screen surface.
4- Percent opening area.
5- Angle of incidence of the particle on the screen surface.
6- Speed at which the particle strikes the screen surface.
7- Thickness of the material on the screen surface.
8- Blinding of the screen surface.
9- Type of screening, i.e., wet or dry screening.
10- Type of motion given to the screen surface.
11- Slope of the screen deck.
12- Mechanical design for supporting and tightening the screen deck.

5.6 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,

$$\text{Screen efficiency} = \eta = \frac{\text{Weight of actual oversize material present in the feed}}{\text{Weight of overflow material obtained from the screen}}$$

For the undersize material,

$$\text{Screen efficiency} = \eta = \frac{\text{Weight of underflow material obtained from the screen}}{\text{Weight of actual undersize material present in the feed}}$$

The other two ways of representing 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:

$$\eta = \frac{c(f-u)(1-u)(c-f)}{f(c-u)^2(1-f)} \qquad 5.6.1$$

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:

$$\eta = \frac{u(u-f)(1-c)(f-c)}{f(u-c)^2(1-f)} \qquad 5.6.2$$

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/m2.

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.

Liberation

Liberation is the first and the most important step in Mineral Beneficiation. The second step, separation, is impracticable if the first step, liberation, is not accomplished successfully.

Liberation: It can be defined as the freeing or detachment of dissimilar mineral grains. The operation employed to liberate the dissimilar mineral grains is Size reduction or Comminution.

Free particles: If the particles of ore consist of a single mineral, they are termed as Free particles.

Locked particles: If the particles of ore consist of two or more minerals, they are termed as locked particles. If the locked particles contain valuable minerals at considerable quantity, they are termed as middling particles.

Grain size: It is the size of a mineral as it occurs in the ore.

Particle size: It is the size of any particle whether free or locked particle.

Grain and Grain size pertain to uncrushed ore and Particle and Particle size pertain to crushed or ground ore.

Liberation size: It is the size of a mineral particle at which that mineral is completely liberated. It is the size of a free particle of required (valuable) mineral.

Various mineral grains, present in the ore, exist in physical combination with each other. To detach the valuable mineral grains from all other gangue mineral grains, it is essential to reduce the size of the ore particles.
If one mineral species in an ore is to be separated physically from all other species in the ore, all grains of the desired species must be physically detached from all remaining species in the ore.
In an ore containing mineral A, B and C (Figure 6.1) if all grains of mineral A (considered as valuable mineral) are to be separated from the ore, all grains of A must be detached from minerals B and C (gangue minerals).
When such detachment is complete, mineral A is said to be liberated. However liberation of mineral A does not require liberation of minerals B and C in the ore.

If the physical properties of the adjacent minerals are sufficiently dissimilar, or if the bond between them is notably weaker than either of them, fracture may take place (when it is comminuted) preferentially at the boundary.
Comminution results in true freeing or detachment of minerals.

Then it is known as **Liberation by detachment** or suppose if the fracture takes place across the grains as shown in Figure 6.2(b), it yields 25 particles out of which 4 particles E, F, G, H are of 1 × 1 cm size, 12 particles are of 2 × 1 cm size and remaining 9 particles are of 2 × 2 cm size. Here:

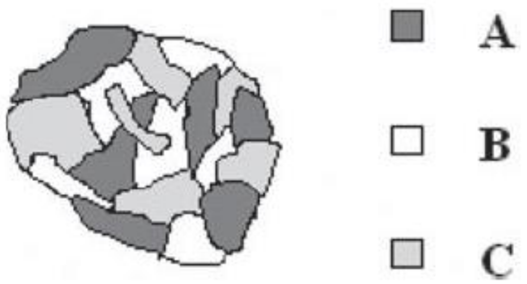


Figure 6.1 A particle of an ore containing A, B and C minerals.

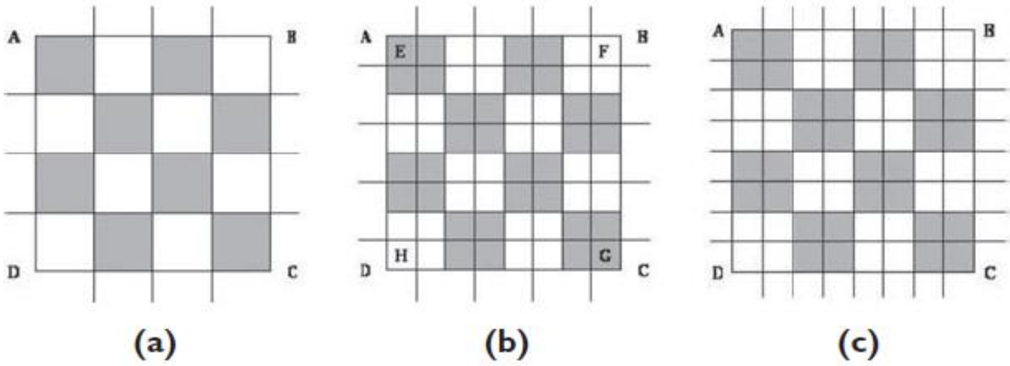


Figure 6.2 Liberation methods.

E and G are free particles of valuable mineral.
F and H are free particles of gangue mineral.
All others are locked particles.
Hence valuable mineral has been liberated partially to a lesser extent.
If the resulting particles are again crushed and fracture takes place along the boundary lines as shown in Figure 6.2 (c), it yields 64 particles, all are free particles of 1 × 1 cm size out of which 32 are valuable mineral particles and 32 are gangue mineral particles.

Here all valuable mineral particles are liberated. This happens when the particles are reduced to 1 × 1 cm size which is less than grain size. 1 × 1 cm is the particle size and also the liberation size.

If the second fracture also does not take place along the boundary lines, it yields still locked particles which need further reduction in size.

This reduction is continued till all valuable mineral particles occur as free particles.

Then the particle size, hence liberation size, is less than 1 × 1 cm. This happens because the fracture takes place across the mineral grain.

This type of liberation is called liberation by size reduction.
In this case, **Liberation size (also Particle size)** is less than the **Grain size**.
It is important to note that the particles are reduced by size reduction in both the cases but it matters whether the fracture takes place along the boundaries or across the grains.
Locked particles will be produced when the fracture takes place across the grains.

Figure 6.3 shows an example of a typical comminution product wherein black refers valuable mineral and white refers gangue mineral.

Only 2 are liberated free valuable mineral particles, 8 are free gangue mineral particles, 6 are locked particles containing valuable and gangue minerals.

These locked particles are known as **middling particles**.

Degree of liberation quantitatively referred to as **percent liberation**, of a certain mineral, is defined as the percent of that mineral liberated and occurring as free particles in relation to the total amount of the same mineral present in the ore.

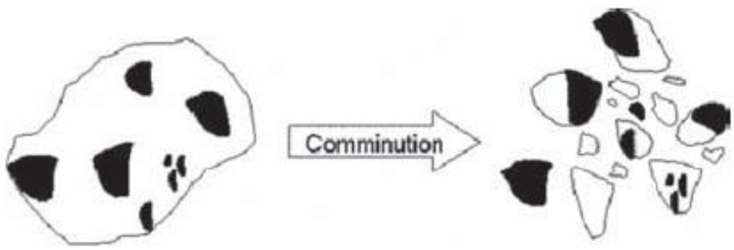


Figure 6.3 Typical comminution product.

For example, the amount of valuable mineral present in one ton of ore is 200 kg.

When it is comminuted to a certain size, the amount of valuable mineral existing as free particles is 196 kg. The remaining 4 kg of valuable mineral exists as locked particles with gangue minerals.

على سبيل المثال ، كمية المعادن الثمينة الموجودة في طن واحد من الخام هي ٢٠٠ كجم.

$$\text{Then the percent libertion } = \frac{196}{200} \times 100 = 98\%$$

Beneficiation is carried out at this size to separate 98% valuable minerals so that 2% of the valuable minerals are lost.

To separate 100% valuable minerals, the ore is to be further reduced in size to get 100% liberation which consumes additional power. If the cost of this additional power is more than the cost of 2% valuable minerals, more than 98% liberation is not desirable.

The beneficiation method to be used depends on liberation size of the ore which in turn depends on type of the ore. Ore types can be conveniently classified as follows:

Massive ores In these ores, reasonable amount of crushing makes the valuables liberated.
Example: Coal, bedded iron ores.

Intergrown ores In these ores, valuables can be freed only partially by crushing and require certain amount of grinding to complete the liberation.
Example: Chrome ore.

Disseminated ores In these ores, valuables are sparely distributed through a waste rock matrix and require fine grinding to liberate the valuables.
Example: Gold ore.

To liberate the valuables, the ore particles are to be reduced in size by the application of the forces. When the forces are applied on the ore particle, fracture takes place depending upon the method of application of the forces.

Comminution

The operation of applying a force on the particle to break it is called size reduction.
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. Thus an industrial comminution operation can be analyzed only in terms of a distribution of feed particles and product particles. However, each individual particle breaks as a result of the stresses applied to it and it alone.

7.1 FRACTURE

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.

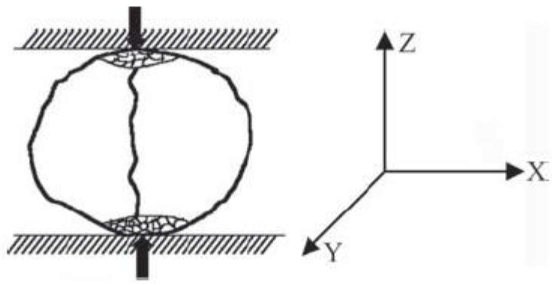


Figure 7.1 Compressive forces.

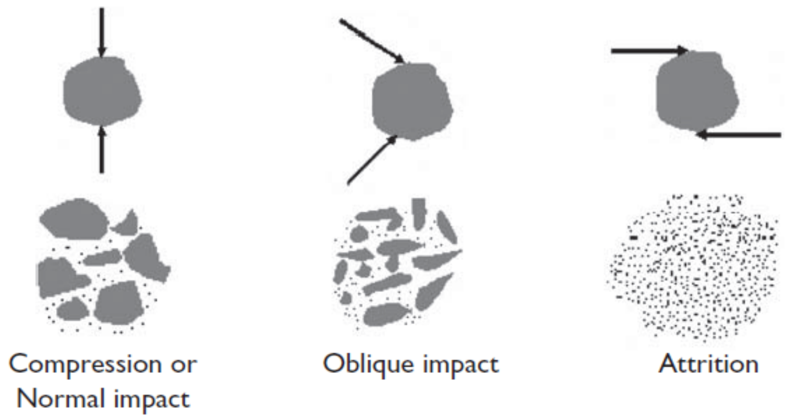


Figure 7.2 Mechanism of fracture.

In practice, these events do not occur in isolation. For example, when the particles are crushed by compression as in the case of a crusher, coarse particles will be produced resulting from the induced tensile stress, fine particles will be produced resulting from compressive stress near the points of loading and by attrition due to particle interaction. All these types of forces and fractures, and sizes of the particles after fracture, are shown in Figure 7.2.

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.

7.3 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.

7.4 TYPES OF COMMINUTION OPERATIONS

The run-of-mine ore is quite coarse and cannot be reduced to fine size in one stage. It may require three or more stages. Each stage requires separate equipment. The comminution operations are divided into two broad groups as follows:

1 **Crushing** Crushing is a size reduction operation wherein large lumps are reduced to fragments or smaller particles.

2 **Grinding** Grinding is considered as size reduction of relatively coarse particles to the ultimate fineness.