1.5 MINERAL BENEFICIATION OPERATIONS

The following are some of the synonymous terms used for Mineral Beneficiation:

Mineral Dressing
Mineral Processing
Ore Dressing
Ore Processing
Ore Preparation
Ore Concentration
Ore Upgradation
Ore Enrichment
Milling

The principal steps involved in beneficiation of Minerals are:

1- **Liberation:** Detachment or freeing of dissimilar particles from each other i.e. valuable mineral particles and gangue mineral particles.

Operations: Crushing
Grinding

2- **Separation:** Actual separation of liberated dissimilar particles i.e., valuable mineral particles and gangue mineral particles.

Operations: Gravity concentration
Heavy Medium Separation
Jigging
Spiraling
Tabling
Flotation
Magnetic separation
Electrical separation
Miscellaneous operations like hand sorting

Supporting Operations: Preliminary washing
Screening
Classification
Thickening
Filtration
Handling of materials
Storage
Conveying

Feeding
Pumping
Pneumatic and Slurry transport

Supporting operations (one or the other) are essential operations of any plant without which no plant exists. A road metal crusher, for example, can perform its job only when proper arrangements are made to feed the metal to the crusher and to convey the crushed metal for separating it into different sizes.

1.6 UNIT OPERATIONS

The operations conducted on any material that involve physical changes are termed as: **Unit Operations**

Ore formation, identification and analysis

2.1 ORE FORMATION

Ores in the earth's crust have been formed by several processes. These ore-forming processes have been classified from time to time by several workers. However, in 1950, Bateman proposed a classification of the processes as shown below [3]:

1- Magmatic concentration.
2- Sublimation.
3- Contact metasomatism.
4- Hydrothermal processes.
5- Sedimentation.
6- Evaporation.
7- Residual and mechanical concentration.
8- Oxidation and supergene enrichment.
9- Metamorphism.

According to the manner of formation, ore deposits are divided into three great types as given below:

1- Igneous.
2- Sedimentary.
3- Metamorphic.

2.2 IDENTIFICATION OF MINERALS

The following are the some of the physical properties of minerals through which minerals can be identified before they are put to use:

1- Characters dependent upon light
a- Colour
b- Streak
c- Lustre

d- Transparency
e- Phosphorescence
f- Fluorescence
2- Taste, odour and feel
3- State of aggregation
a- Form
b- Habit
c- Pseudomorphism, Polymorphism
d- Cleavage
e- Fracture
g- Hardness
h- Tenacity
4- Specific gravity (density)
5- Magnetic susceptibility
6- Electrical conductivity
7- Radioactivity
8- Surface property

The identification of minerals by their physical properties is termed as Megascopic Identification. Minerals are also identified by their optical properties under a microscope.
Transparent minerals are identified under a Petrological or Mineralogical microscope whereas opaque minerals are identified under an Ore microscope.
Texture of mineral occurrences is an important property useful for separation of valuable minerals from their ores. Textures are mainly of three types:

Fine-grained <1 mm
Medium-grained 1–5 mm
Coarse-grained >5 mm

2.3 MINERAL ANALYSIS
Minerals are analyzed by conventional chemical analysis. Two types of chemical analysis are:
1- **Qualitative Analysis,** in which elements present in the sample are identified.
2- **Quantitative Analysis,** in which the quantity of elements, or compounds, present in the sample is estimated.

Sampling

A Mineral Beneficiation plant costs thousands of dollars to build and operate. The success of the plant relies on the assays of a few small samples. Representing large ore bodies truly and accurately by a small sample that can be handled in a laboratory is a difficult task. The difficulties arise chiefly in collecting such small samples from the bulk of the material.

The method or operation of taking the small amount of material from the bulk is called **Sampling**. It is the art of cutting a small portion of material from a large lot.

The small amount of material is called **Sample** and it should be representative of the bulk in all respects (in its physical and chemical properties).

The prerequisite for the development of a satisfactory flow sheet is the acquisition of a fully representative ore sample, even though, in respect of a new ore-body, this sample may have to be something of a compromise. A bad sample will result in wastage of all test work and can lead to a completely wrongly designed mill.

A sample can be taken from any type of material dry, wet or pulp. But, in each case, the method of sampling and the apparatus necessary for them are different.

A sample is collected from huge lot of dry material in stages. At first, a large quantity sample is collected from a lot, known as **primary sample** or **gross sample**, by means of various types of sampling equipment such as mechanical or hand-tool samplers using appropriate sampling methods and techniques.

The two methods used to obtain a gross sample are **Random sampling** and **Systematic sampling**. The various hand-tool samplers used are Drill, Shovel, Scoop, Auger, Pipe and Slot samplers. The gross sample is reduced to a quantity that can be handled with ease by **alternate shoveling** or **fractional shoveling** in stages depending upon the quantity of the gross sample. It is essential that the gross sample be thoroughly mixed before reduction in order to obtain a representative sub-sample or laboratory sample.

Such reduced samples are called **secondary sample** and **ternary sample** depending upon the number of stages used. Figure 3.1 shows the stages of sampling. Reduction of this reduced sample to a quantity necessary for analysis, known as **final sample** or **test sample**, is called **sample preparation**. It is the process of reducing the quantity by splitting.

Sample preparation is done by **Coning and quartering** or by using **paper cone splitter, riffle splitter, rotary cone splitter, rotary table splitter** or **micro splitter.** The sampler’s knowledge, experience,

judgment and ability are of greater value because instructions cannot cover every point or combination of circumstances encountered on each preparation.
When it is required to collect samples from streams of solids and/or pulps, **manual** or **mechanical sample cutters** are employed to cut and withdraw small quantities from a stream of traveling material at predetermined frequencies and speeds to form a gross sample.

The sample cutter should travel across the material stream and intersect the stream perpendicular to the flow so that the material from the entire width of the stream is collected. The cutter width should be 3 times the top size of the particle and should travel at constant speed.

The procedure to be adopted for taking a sample and the amount of the sample depends on:
1- the size of the original material, 2- particle size of the material,3- the method of sampling 4- the purpose for which the sample is taken.

Table 3.1 is one of the early sampling studies that proposed to relate the particle size of the material being sampled to the sample size required for a representative sample.
The basis for the sample for this theory was 100 tons of ore. As one can see, the finer the material being sampled, the smaller the size of sample required. Owing to the statistical fact that the finer particles have many more individual particles per pound than the coarser particles do and, since ore is made up of many different materials, the finer particles are much more likely to contain all of the individual elements of the whole sample.

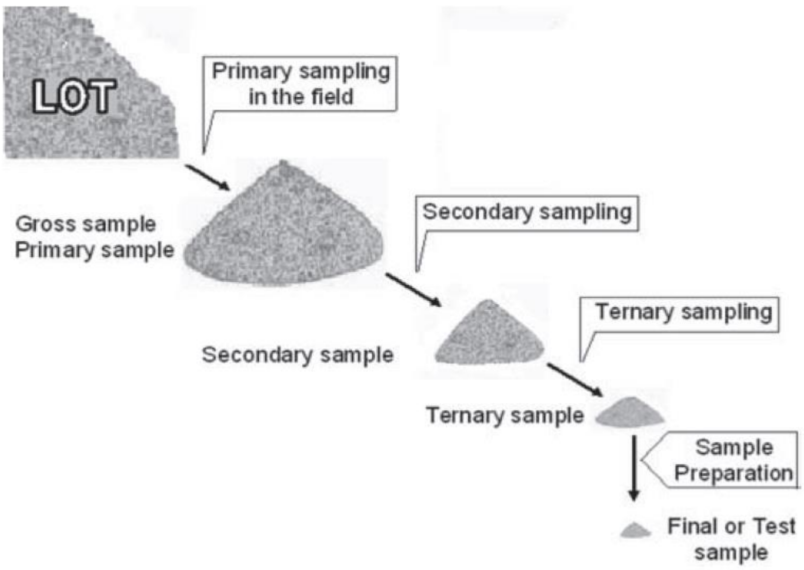

Figure 3.1 **Sampling process.**

Table 3.1 Particle size and minimum weight of the sample.

Particle size inches	*Minimum weight of the sample, pounds*
0.04	0.0625
0.08	0.5
0.16	4
0.32	32
0.64	256
1.25	2048
2.50	16348

When a sample is to be taken for chemical analysis to determine the assay value of the ore, the sample should be re-crushed sufficiently between each cutting down of the sample so that the ratio of the diameter of the largest particles to the weight of the sample to be taken shall not exceed a certain safe proportion. It is to be noted that no amount of mixing and careful division can make the sample and reject alike in value when the lot before division contains an uneven number of large high grade ore particles.

The material collected each time is called an **increment**. How the sample is obtained, the number of increments and the size of each increment, will often determine the degree of probability that a sample is indeed representative.

The **sampling ratio**, which is defined as the ratio of the weight of the sample taken by the sampling system to the weight of the lot from which that sample is taken, is the most important indicator of the performance of the sampling system.

When the sample is taken, and subjected to analysis, there exists some chance of error in a single sample. One must take the number of samples to reduce the error and to keep the overall error within the tolerable working limits.

Size

Size of the particle is an important consideration in Mineral Beneficiation because of the following main reasons:
*Energy consumed for reducing the size of the particles depends on size.
*Size of the particles determines the type of size reduction equipment, beneficiation, equipment and other equipment to be employed.

The size of the particle of standard configuration like sphere and cube can easily be specified. For example, the size of a spherical particle is its diameter (d) and that of a cubical particle is the length of its side (l) as shown in Figure 4.1.

As the mineral particles are irregular in shape, it is difficult to define and determine their size. A number of authors have proposed several empirical definitions to particle size. Feret [4], in 1929, defined the size of an irregular particle as the distance between the two most extreme points on the surface of a particle. Martin [4], in 1931, defined the length of the line bisecting the maximum cross-sectional area of the particle. During later years, the size of a particle is defined by comparison with a standard configuration, normally a spherical particle.

Equivalent size or **equivalent diameter** of an irregular particle is defined as the diameter of a spherical particle which behaves similar to an irregular particle under specified conditions.

Surface diameter is defined as a diameter of a spherical particle having the same surface area as the irregular particle.

Volume diameter is defined as the diameter of a spherical particle having the same volume as the irregular particle.

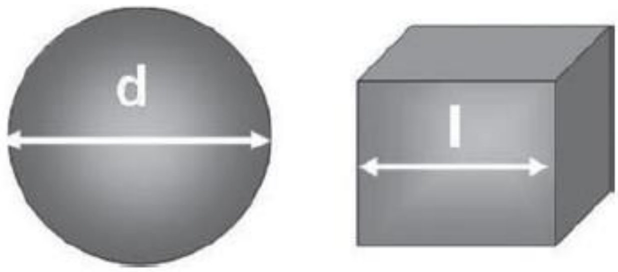

Figure 4.1 **Spherical and cubical particles.**

Figure 4.2 **Test sieve.**

In mineral industry, the side of a square aperture through which a particle just passes is taken as the size of the particle even though little or no importance is given to its shape. 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.

Test Sieve is a circular shell of brass having an 8 inch diameter and being about 2 inch high as shown in Figure 4.2.

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.

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 interchangeability of results and data. In this standard sieve scale, the sizes of successive sieves in series form a geometric progression.

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 $\sqrt{2}$, which means that the area of the opening of any sieve in the series is twice that of the sieve just below it and one half of the area of the sieve above it in the series.

For closer sizing work the sieve ratio of $\sqrt[4]{2}$ is common.

The different standards in use are:

American Tyler Series

American Standards for Testing and Materials, ASTM E-11-01 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, however, follow a different type of designation. For an IS sieve, 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 4.1 shows the comparison of test sieves of different standards.

Table 4.1 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 4.1 (*Continued*).

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	–