Evaluation of Particle Size, size distribution curves and their significance

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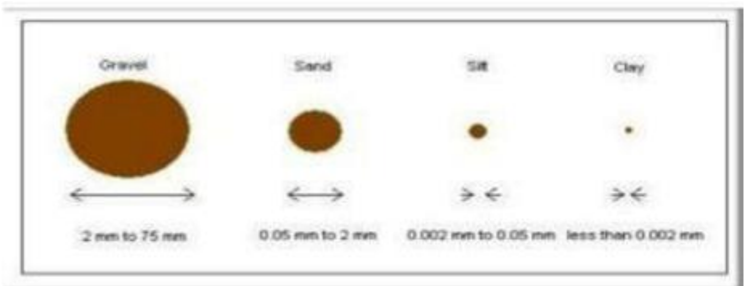
Objective

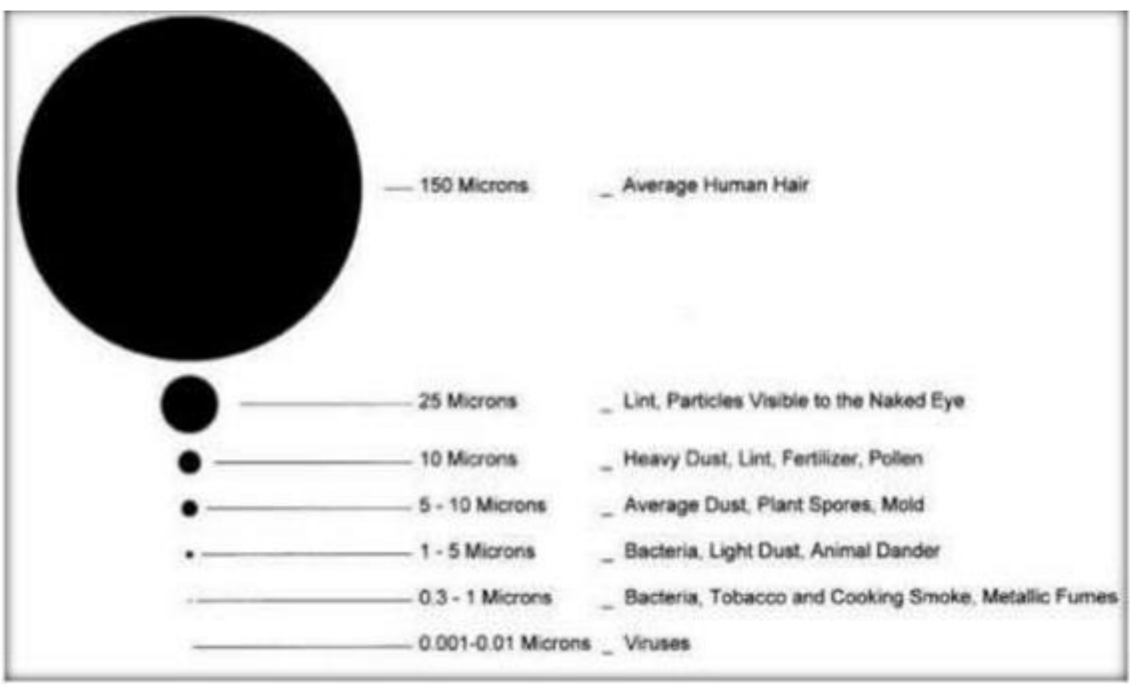
- Understanding of Particle Size and Particle Shape
- Particle Size Distribution (PSD)
- Significance of Particle Size Distribution (PSD)
- Particle Size Distribution: Sampling
- Particle Size Distribution: Measurement Techniques
- Particle Size Distribution: Graphical Representation

Understanding of Particle Size and Particle Shape

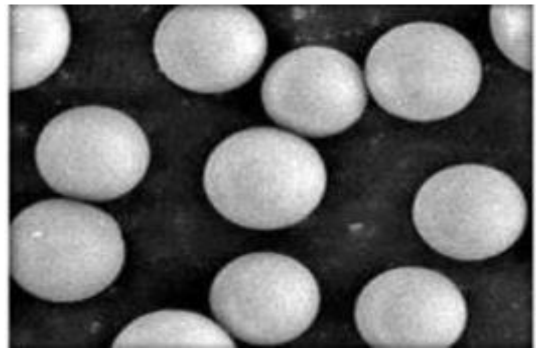
Particle Size

Particle size or grain size refers to the diameter of a grain of granular material





- The size of a spherical homogeneous particle is uniquely defined by its diameter.
- For regular, compact particles such as cubes or regular tetrahedral, a single dimension can be used to define size.



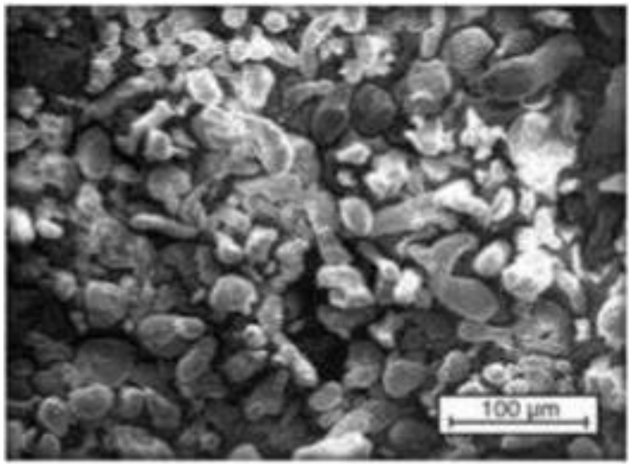
- With some regular particles it may be necessary to specify more than one dimension: For a cone the base diameter and height are required whilst for a cuboid three dimensions are needed.

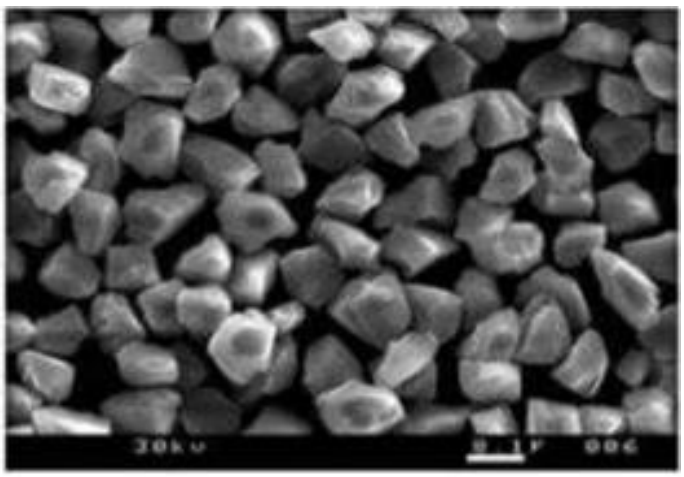
- For irregular particles, it is desirable to quote the size of a particle in terms of a single quantity, and the expression most often used is the equivalent diameter".

- This refers to the diameter of a sphere that would behave in the same manner as the particle when submitted to some specified operation.

- The assigned equivalent diameter usually depends on the method of measurement, hence the particle-sizing technique should, wherever possible, duplicate the process one wishes to control.

- Several equivalent diameters are commonly encountered. For example, the Stokes' diameter is measured by sedimentation and elutriation techniques; the projected area diameter is measured microscopically and the sieve aperture diameter is measured by means of sieving.





Effect of Particle Shape

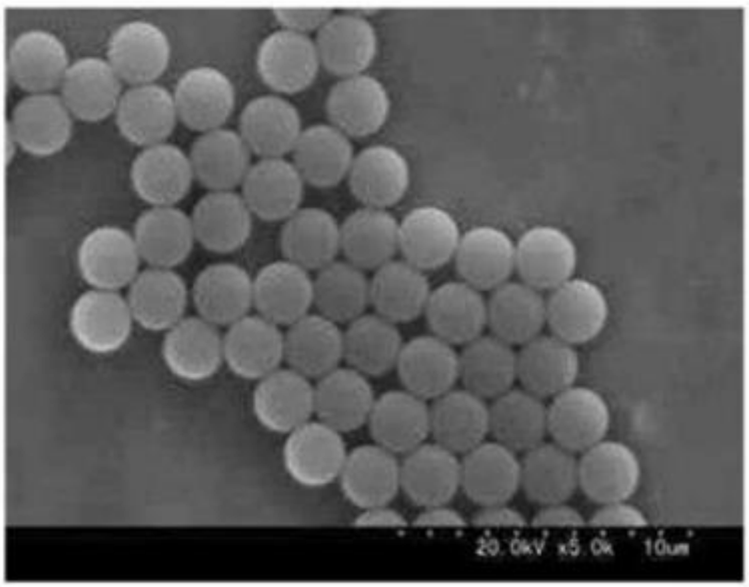
- Particle shape influences such properties as:

➢ Flowability of powders
➢ Packing
➢ Interaction with fluids and the covering power of pigments

- The variation between the diameters increases as the particles diverge more from the spherical shape.

- Different results from different techniques can be compared by applying shape factors and shape coefficients.

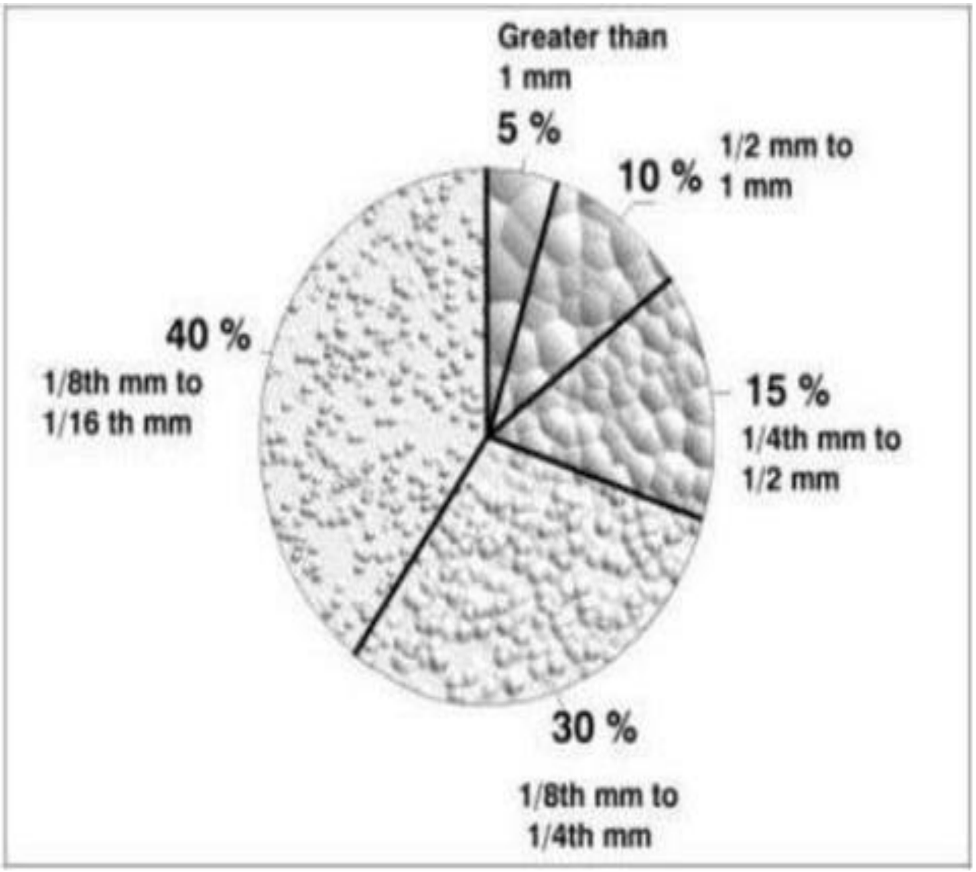
SEM picture of Polystyrene



Particle Size Distribution

- The particle size distribution (PSD) may be defined as
- "Particle size distribution (PSD) of a powder, or granular material, or particles dispersed in fluid, is a list of values or a mathematical function that defines the relative amounts of particles present, sorted according to size."

- Particle size distribution is also known as grain size distribution.



Significance of Particle Size Distribution (PSD)

- The PSD of a material can be important in understanding its physical and chemical properties.
- It affects the strength and load-bearing properties of rocks and soils.
- It affects the reactivity of solids participating in chemical reactions, and needs to be tightly controlled in many industrial products such as the manufacture of printer toner and cosmetics.

Particle-size distribution curve

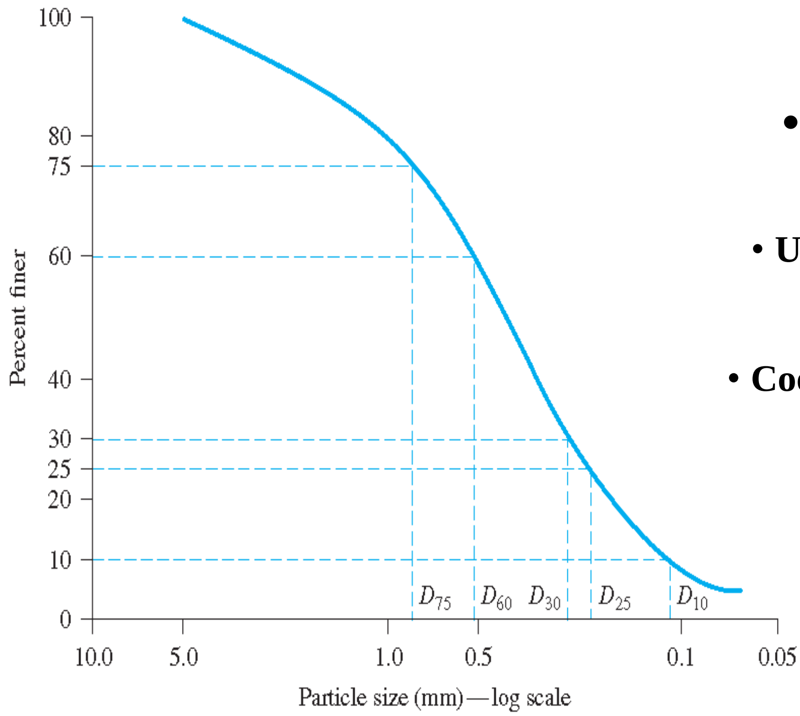


Figure 2.26 Definition of D_{75}, D_{60}, D_{30}, D_{25}, and D_{10}

- **Equivalent opening size:** D10, D25, D30, D60, D75
- **Uniformity coefficient (Cu):** Cu=D60/D10
- **Coefficient of gradation (Cc):** Cc=(D30)2/(D60×D10)
- **Sorting coefficient (S0):** S0=(D75/D25)0.5

Semilogarithmic plot
Percent finer as the ordinate (arithmetic scale) and
Sieve opening size as the abscissa (logarithmic scale)

Particle-size distribution curve

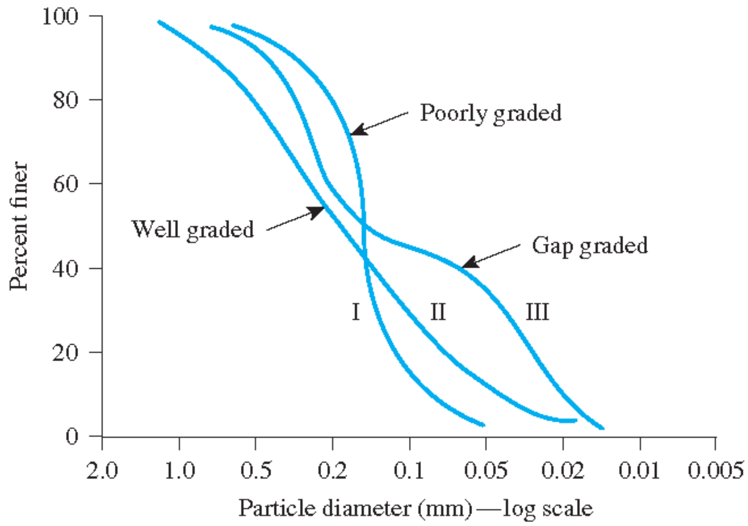


Figure 2.27 Different types of particle-size distribution curves

• Curve I poorly graded soil

• Curve II well graded soil
Uniformity coefficient greater than about 4 for gravels and 6 for sands, and a coefficient of gradation between 1 and 3 (for gravels and sands)

• Curve III gap graded soil
Particles of some grain sizes are missing. It is a combination of two or more uniformly graded fractions

Particle Size Distribution: Measurement Techniques

There is a wide range of instrumental and other methods of particle size analysis available. Some of the more common methods are:

1. Sieve Analysis

2. Sedimentation Methods

3. Elutriation Techniques

4. Microscopic Sizing and Image Analysis

5. Electrical Impedance Method

6. Laser Diffraction Methods

1. Sieve Analysis

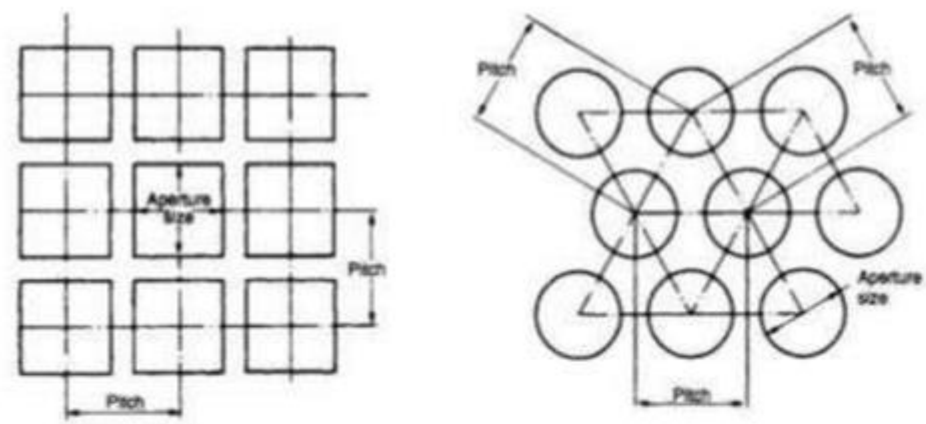
- Sieve analysis is one of the oldest methods of size analysis.
- Sieve analysis is accomplished by passing a known weight of sample material successively through finer sieves and weighing the amount collected on each sieve to determine the percentage weight in each size fraction.
- Sieving is carried out with wet or dry materials and the sieves are usually agitated to expose all the particles to the openings.

Process of Sieving

- The process of sieving may be divided into two stages.
- First, the elimination of particles considerably smaller than the screen apertures, which should occur fairly rapidly and, second, the separation of the so-called "near-size" particles, which is a gradual process rarely reaching final completion.
- The effectiveness of a sieving test depends on the amount of material put on the sieve (the "charge") and the type of movement imparted to the sieve.

Test Sieves

- Test sieves are designated by the nominal aperture size, which is the nominal central separation of opposite sides of a square aperture or the nominal diameter of a round aperture,



- The woven sieve is the oldest design, and it is normally made by weaving fine metal wire into a square pattern, then soldering the edges securely into a flattish cylindrical Container.
- Woven-wire sieves were originally designated by a mesh number, which referred to the number of wires per inch, which is the same as the number of square apertures per square inch.

(2) Sieve fractions wt (g)	(3) wt %	(4) Nominal aperture size (µm)	(5) Cumulative % undersize	(6) oversize
0.02	0.1	250	99.9	0.1
1.32	2.9	180	97.0	3.0
4.23	9.5	125	87.5	12.5
9.44	21.2	90	66.3	33.7
13.10	29.4	63	36.9	63.1
11.56	26.0	45	10.9	89.1
4.87	10.9			

Table shows:

(1) The sieve size ranges used in the test.

(2) The weight of material in each size range, e.g. 1.32 g of material passed through the 250 um sieve, but was retained on the 180 um sieve: the material therefore is in the size range -250 to +180 pm.

(3) The weight of material in each size range expressed as a percentage of the total weight.

(4) The nominal aperture sizes of the sieves used in the test. The cumulative percentage of material passing through the sieves, e.g. 87.5% of the material is less than 125 um in size.

(5) The cumulative percentage of material retained on the sieves.

Technique Advantages

1) This technique is well-adapted for bulk materials.
2) It is required to produce a separated size fraction for further study.
3) The material flows easily as discrete particles.
4) The material is fairly coarse, e.g. above 100 um, and contains few fines.
5) The powder is composed of materials with a range of different densities, different refractive indices or is water soluble.

Technique Disadvantages

1) Much fine material below 100 um is present, unless specialized microsieving equipment is available.
2) The particles are fragile.
3) The particles are in the form of elongated needles.
4) The material adheres to the sieve or forms clumps.
5) The powder easily acquires an electrostatic charge.

Hydrometer Analysis

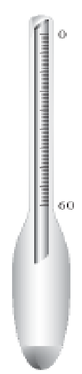


Figure 2.23 ASTM 152H hydrometer (*Courtesy of ELE International*)

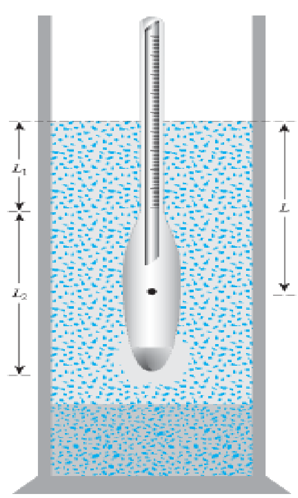
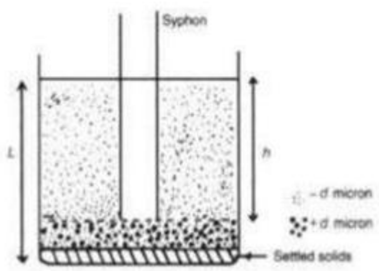


Figure 2.24 Definition of L in hydrometer test

- The specific gravity is a function of the amount of soil particles present per unit volume of suspension in the vicinity of the bulb of hydrometer.
- At a time t, the soil particles in suspension at a depth L will have a diameter smaller than D.
- Viscosity of water η is dependent on the temperature of the test, so a temperature calibration for test result is needed.

2. Sedimentation Methods

Sedimentation methods are based on the measurement of the rate of settling of the powder particles uniformly dispersed in a fluid and the principle is well illustrated by the common laboratory method of "beaker decantation".



Beaker decantation

The material under test is uniformly dispersed in low concentration in water contained in a beaker. A wetting agent may need to be added to ensure complete dispersion of the particles.

A syphon tube is immersed into the water to a depth of 'h' below the water level, corresponding to about 90% of the liquid depth 'L'.

- The terminal velocity 'v' is calculated from Stokes' law for the various sizes of particle in the material, say 35, 25, 15, and 10 pm.

- The time required for a 10 um particle to settle from the water level to the bottom of the syphon tube, distance 'h', is calculated (t = h/v).

- The pulp is gently stirred to disperse the particles through the whole volume of water and then it is allowed to stand for the calculated time.

- The water above the end of the tube is syphoned off and all particles in this water are assumed to be smaller than 10 um diameter.

$$v = \frac{\rho_s - \rho_w}{18\eta} D^2$$

Technique Advantages

- The method is simple and cheap.
- This method has the advantage over many other sub-sieve techniques in that it produces a true fractional size analysis.

Technique Disadvantages

This method is, however, extremely tedious, as long settling times are required for very fine particles, and separate tests must be performed for each particle size.

Andreasen Pipette Technique

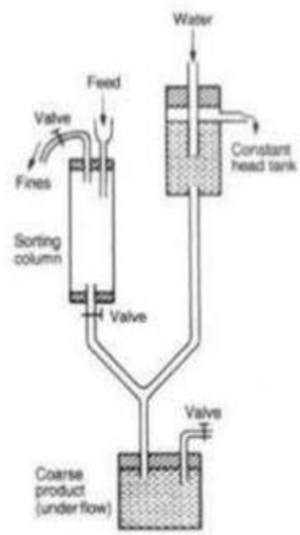
A much quicker and less-tedious method of sedimentation analysis is the Andreasen Pipette Technique

The method is much quicker than beaker decantation, as samples are taken off successively throughout the test for increasingly finer particle sizes.

Andreasen pipette

3. Elutriation Techniques

- Elutriation is a process of sizing particles by means of an upward current of fluid, usually water or air.
- The process is the reverse of gravity sedimentation, and Stokes' law applies.



Simple elutriator

- All elutriators consist of one or more "sorting columns“ in which the fluid is rising at a constant velocity.

- Feed particles introduced into the sorting column will be separated into two fractions, according to their terminal velocities, calculated from Stokes' law.

- Those particles having a terminal velocity less than that of the velocity of the fluid will report to the overflow, while those particles having a greater terminal velocity than the fluid velocity will sink to the underflow

- Eutriation is carried out until there are no visible signs of further classification taking place or the rate of change in weights of the products is negligible.

Technique Advantages

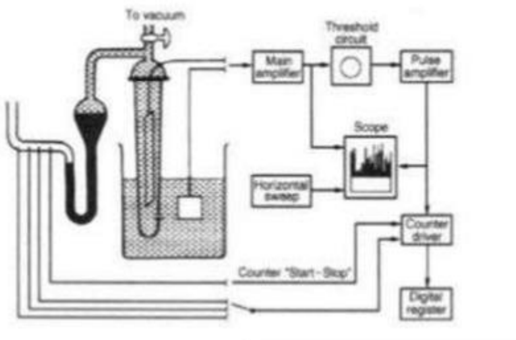
Elutriation appears more attractive than decantation, and has certain practical advantages in that the volume changes need no operator attention.

Technique Disadvantages

The fluid velocity is not constant across the sorting column being a minimum at the walls of the column, and a maximum at the centre. The separation size is calculated rom the mean volume flow, so that some coarse particles are misplaced in the overflow, and some fines are misplaced into the coarse overflow.

4. Electrical Impedance Method

- The Beckman Coulter Counter makes use of current changes in an electrical circuit reduced by the presence of a particle.
- The instrument is applicable in the range 0.4-1200 um.



5. Laser Diffraction Methods

- Laser light is passed through a dilute suspension of the particles which circulate through an optical cell. The light is scattered by the particles, and is detected by a solid state detector which measures light intensity over a range of angles.
- A theory of light scattering is used to calculate the particle size distribution from the light distribution pattern, finer particles inducing more scatter than coarse.

Particle Size Distribution: Graphical Representation

- A histogram is one of the simplest ways to display a particle size distribution.

- It is a particle frequency distribution that shows the percentage of particles found in each size range,

- Frequency can be plotted on the Y-axis by number count. surface area, or mass and particle diameter in um can be plotted on X-axis.

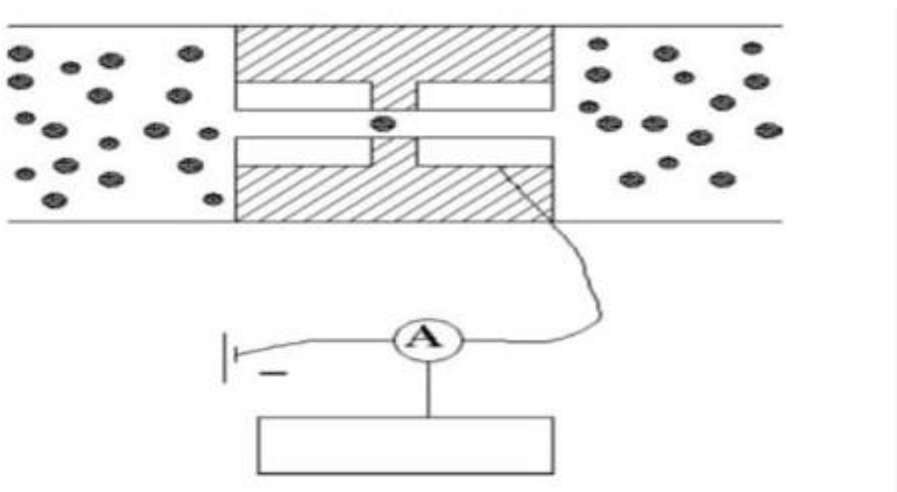
Range of particle sizes

A guide to range of particle sizes applicable to each method is

Particle size	Method
1 µm	Electron microscope, ultracentrifuge, adsorption
1 – 100 µm	Optical microscope, sedimentation, coulter counter, air permeability
>50 µm	Sieving

Particle volume measurement

(range: 0.5-300 um)



In this type of machine the powder is suspended in an electrolyte solution.

• This suspension is then made to flow through a short insulated capillary section between two electrodes and the resistance of the system is measured.

- . When a particle passes through the capillary there is a momentary peak in the resistance, the amplitude of the peak is proportional to the particle size.

- Counting is done by a computer.

Methods for determining particle size

Many methods available for determining particle size such as optical microscopy, sieving, sedimentation and particle volume measurement.

1. Optical microscopy (range: 0.2-100 um).

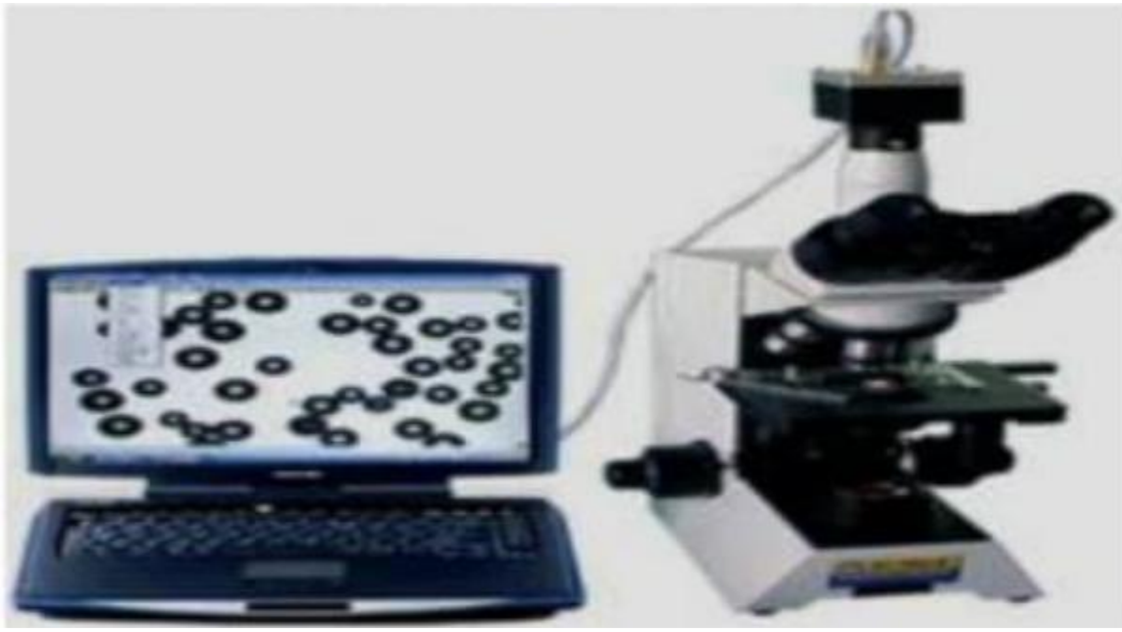
2. Sieving (range: 40-9500 um).

3. Sedimentation (range: 0.08200 um).

4. Particle volume measurement (range: 0.5-300 um).

Optical microscopy (range: 0.2-100 μm)

The microscope eyepiece is fitted with a micrometer by which the size of the particles may be estimated.



Optical microscopy (range: 0.2-100 um)

• According to the optical microscopic method, . an emulsion or suspension is mounted on ruled slide on a mechanical stage.

. The microscope eyepiece is fitted with a micrometer by which the size of the particles can be estimated.

The ordinary microscope used for measurement the particle-size in the range of 0.2 to about 100 um.

Disadvantage of microscopic method

1. The diameter is obtained from only two dimensions of the particle.

2. The number of particles that must be counted (300-500) to obtain a good estimation of the distribution makes the method somewhat slow and tedious.