Unit Operations:-

i) Mechanical Operations: Sise reduction, conveying, filtration etc

ii) Fluid flow operations: pressure difference acts as driving force

iii) Heat Transfer Operations: Temperature difference acts as driving force. eg. evaporation

iv) Mass Transfer Operations:- Concentration difference acts as driving force. eg. distillation.

→ Unit operations of chemical Engineering are directed towards separating a ~~substance~~ substance into its component parts

→ For heterogeneous mixtures, such separations may be entirely mechanical

Ex: The separation of solid particles according to their size or the filtration of solid from a separation in a liquid

→ Many unit operations involve particulate solids as well as fluids. In many cases, the solids are an integral part of the material being processed/treated.

Ex: Feeding pulverised coal (in air) at a burner.

→ Mechanical operations involving particulate solids are

1) Size reduction - crushing and grinding
2) Mixing solid-solid, liquid-liquid, solid-liquid
3) classification - screening, froth flotation, magnetic separation, electrostatic separation, jigging, tabling and wet classification
4) Solid-fluid Separation - filtration, sedimentation and centrifugal separation.
5) Gas-solid separation - Dust collection, bag filtration, electrostatic precipitation
6) Solid handling - storage, feeding and conveying
7) Size enlargement - pelletization, agglomeration, granulation and extrusion

Mechanical Separations:- For heterogeneous mixtures

1) Separation of solids from solids
2) Separation of solids from solids in liquids
3) Separation of solids from liquids
4) Separation of solids or liquid drops from gases
5) Separation of liquids from liquids

Surface shape factor:- The reciprocal of sphericity.

Specific surface ratio:- The ratio of specific surface of the particle to the specific surface of the spherical particle of the same diameter.

$$N_{SSR} = \frac{A_{ssp}}{\left[\frac{6}{S_p \times D_{p\,avg}}\right]}$$

$A_{sp} \rightarrow$ specific surface of the particle.

Volume mean diameter:- $\frac{\text{Total volume of the sample}}{\text{number of particles in the sample}}$

$$\bar{D}_V = \left[\frac{1}{\sum_{i=1}^{n}\left(\frac{x_i}{D_{p_i\,avg}}\right)}\right]^{1/3}$$

→ Size is linear dimension of the particle

→ Sphere is the ideal example and size is defined by its diameter

→ For irregular particle, the size may be found as the average of the shortest and the longest dimension of the particle or, as the second largest dimension.

→ For sometimes, the irregular particle size is defined in terms of the equivalent/nominal diameter.

Equivalent Diameter:- The size of the spherical particle having the same controlling characteristics [surface area volume, surface area per unit ~~[illegible]~~ volume, settling velocity etc] as the particle ~~of~~ under consideration.

(or)

The diameter of a sphere of equal volume

→ Depending on various controlling characteristics, the particle size can be expressed as surface mean diameter, mass mean diameter, volume surface mean diameter [or Sauter mean] dia

Volume Surface mean diameter

It is related to specific surface area

$$A_w = \frac{6}{\phi \rho_p D_p}$$

$$\bar{D}_{vs} = \frac{6}{\phi A_w \rho_p}$$

$$\bar{D}_{vs} = \frac{1}{\sum_{i=1}^{i=n} \frac{x_i}{\bar{D}_i}}$$

Sauter mean diameter

Mass - Mean Diameter:-

$$\bar{D}_w = \sum_{i=1}^{n} x_i \bar{D}_{p_i}$$

Arithmetic Mean Diameter:-

In $\bar{D}_{vs}$ 'N_i' is (number of particles) instead of mass fr.

$$D_N = \frac{\sum_{i=1}^{n} (N_i \bar{D}_{p_i})}{\sum_{i=1}^{n} N_i} = \frac{\sum_{i=1}^{n} (N_i \bar{D}_{p_i})}{N_T}$$

$N_T \rightarrow$ Total number of particle

Average volume of a particle = $\frac{\text{total volume of sample}}{\text{no. of particles in the mixture}}$

Number of particles in the mixture:-

Volume of ~~particle~~ proportional to its diameter

$$V_p = a D_p^3$$

$a \rightarrow$ volume shape factor

$N_w \rightarrow$ Total population in one mass unit

$a \rightarrow$ is independent of size

$$N_w = \frac{1}{a \rho_p} \sum_{i=1}^{n} \frac{x_i}{\bar{D}_{p_i}^3} = \frac{1}{a \rho_p \bar{D}_v^{3}}$$

$$\bar{D}_v = \left[\frac{1}{\sum_{i=1}^{n} (x_i / \bar{D}_{p_i}^3)} \right]^{1/3}$$

~~Size separation~~:-

problem:- ①

Finely divided clay is used as a catalyst in the petroleum industry. It has a density of 1.2 g/cc and a sphericity of 0.5. The size analysis is as follows

Average Dia (cm)	0.0252	0.0178	0.0126	0.0089	0.0038
Mass fraction (x_i) g/g	0.088	0.178	0.293	0.194	0.247

) Find the specific surface area and the sauter mean diameter of the clay material.

Formulae: $A_w = \frac{6}{\phi \rho_p} \sum_{i=1}^{i=n} \frac{x_i}{D_{p_i avg}}$ and $\bar{D}_{vs} = \frac{1}{\sum_{i=1}^{i=n} \frac{x_i}{D_{p_i avg}}}$

Avg Dia $D_{p_i avg}$ (cm)	Mass fra	x_i / D_n
0.0252	0.088	3.492
0.0178	0.178	10.00
0.0126	0.293	23.254
0.0089	0.194	21.797
0.0038	0.247	65.000
	$\Sigma x_i = 1.00$	$\Sigma \frac{x_i}{D_{p_i avg}} = 123.543$

Specific surface

$$A_w = \frac{6}{\phi \rho_p} \sum_{i=1}^{i=n} \frac{x_i}{D_{p_i avg}} = \frac{6(123.543)}{0.5 \times 1.2} = 1235.43 \text{ cm}^2/g$$

$$\bar{D}_{vs} = \frac{1}{\sum_{i=1} x_i / D_{p_i avg}} = \frac{1}{123.543} = 0.0080904 \text{ cm} = 8.094 \times 10^{-3} \text{ cm}$$

problem: 2

→ The size analysis of a powdered material on a weight basis is represented by a straight line from 0% weight at 1 micron particle size to 100% weight at 101-micron particle size. Calculate the Sauter mean diameter of the particles.

Soln: The Sauter mean diameter

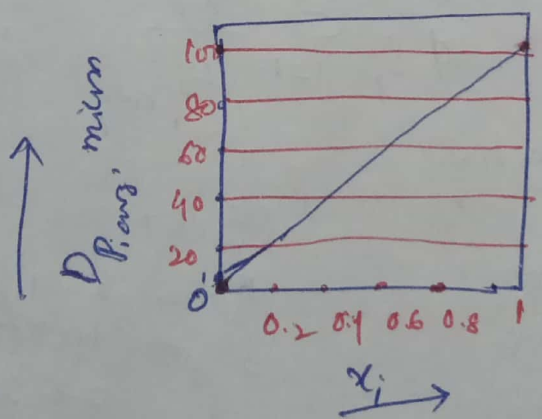
$$\bar{D}_{vs} = \frac{1}{\sum_{i=1}^{n} x_i / D_{pi\,avg}}$$

Given that at $x = 0$, $D_{pi\,avg} = 1\,\mu m$ and

$x = 1$, $D_{pi\,avg} = 101\,\mu m$

The $D_{pi\,avg}$ vs x_i line (~~Fig. 2~~) is given by

$$D_{pi\,avg} = m x_i + c$$



$D_{pi\,avg}$ vs x_i

$$\text{Slope} = \frac{101-1}{1-0} = \frac{100}{1} = 100$$

$D_{pi\,avg} = 1$, $x_i = 0$ then $c = 1$ micron

$$D_{pi\,avg} = 100 x_i + 1$$

x_i	$D_{pi\,avg}$	$x_i/D_{pi\,avg}$
0	1	0
0.1	11	0.0091
0.2	21	0.0091
0.3	31	0.0095
0.4	41	0.0097
	51	0.0098
	61	0.0098
	71	0.0099
	81	0.0099
	91	0.0099
	101	0.0099
		Sum = 0.0972

$$\bar{D}_{vs} = \frac{1}{\sum_{i=1}^{n} \frac{x_i}{D_{pi\,avg}}} = 1/0.0972 = 10.29 \text{ microns}$$

Solids in Bulk

→ The properties of solids in bulk are dependent on the properties of the individual particles including their shape and size, and the way in which they interact with each other.

→ For homogeneous solid particles, the ratio of the normal pressure, P_N to the applied pressure, P_A is a constant

$$K = \frac{P_N}{P_A}$$

'K' is the characteristic of the material and it is nearly independent of the particle size

'K' is coefficient of flowability.

K depends on:
i) shape and interlocking tendencies of particles
ii) Degree of packing
iii) Stickiness of the particles

→ The value of 'K' is nearly zero for cohesive solids

→ for free flowing ~~particle~~ granular materials it varies b/n 0.3 – 0.6

Angle of repose and angle of internal friction:-

→ The frictional force within the particles is measured by using, the angle of internal friction 'α_i'.

→ The tangent of 'α_i' is coefficient of friction between two ~~type~~ layers of particles

→ It determines the flowing characteristic of the particle and it is important for design of storage vessels like bins, silos and hopper

The Angle of repose:- The angle at which the sides of the 'pile' make with the horizontal when solids are 'piled' up on a plane surface

→ It is useful for determing the capacity of a bin or a pile and it also useful in during transport

→ For homogeneous solids these two angles are nearly same, but in practice, the angle of repose is less than the angle of internal friction, because the solid particles at the exposed surface are more loosely packed than the material inside the pile and, are drier and less sticky.

→ α_r values low for smooth and rounded particles
α_r higher for sticky and angular particles

→ α_i — $15° - 30°$ for granular solids.
α_i — $90°$ for cohesive solids.

→ Dynamic angle of repose & static angle of repose.

$$K = \frac{1 - \sin \alpha_i}{1 + \sin \alpha_i}$$

Storage of bulk solids:-

Generally, a bulk solid is defined as numerous dry or wet solid particles ranging from fine powder to coarse sized particles that being handled in bulk form.

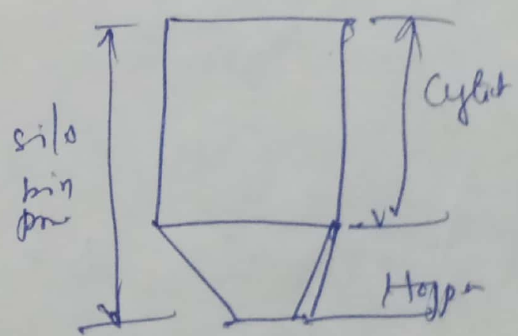
→ vessels like - bins, silos, elevators or process vessels.

→ coarse solids — Coal, gravel, sand and water insoluble materials are stored outside in open and large piles. usually unprotected from weather

→ Rock salt, gunpowder, solid chemicals are stored in bins and silos

→ Bins: Abrasive materials, wider and short in height

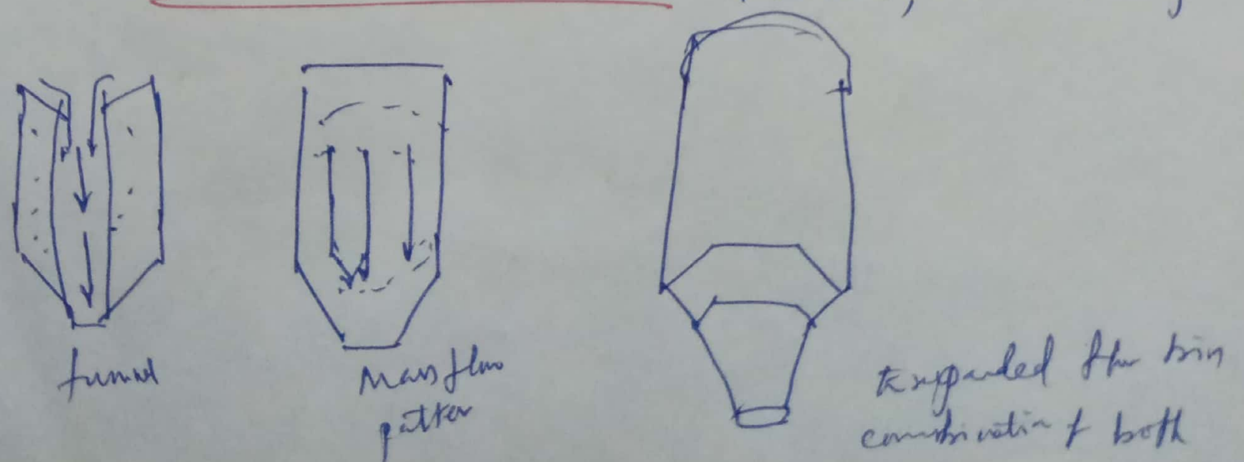
Silos: tall, smaller in dia



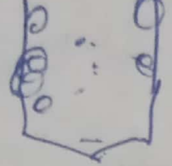
→ fed from open top and discharged at bottom.

Flow of Bulk solids:-

funnel, mass and expanded



1) No flow →
2) Erratic flow → formation and ~~arches~~ collapse of arches
archer ~~formation~~
3) Flushing → when arch collapses
4) Seggregation;



finer particle – center
Larger part. — walls

No flow:- A high pressure often packs the solids more tightly rather than increasing the flows. In some cases, a stable arch is formed over the hopper outlet and solids do not fall even when the material below them is removed. The arch is strongly enough to support the weight of the material above it and it must be broken either by arch breakers or by air jets to induce flow again. It must be noted that vibrations tend to strengthen the arch as they cause more compaction of solid particles.

Erratic flow:- Frequent formation and collapse of arches result in fluctuating discharge causing uneven vibrations which can lead to structural damage and personnel injuries.

Flushing:- When an arch collapses, the solids fall uncontrollably into the open channel under pressure. This situation is refferred to as flushing or flooding.

Segregation:- During the filling of a storage vessel, the finer particles move towards the central portion while the larger particles move towards the wall which causes finer particles to discharge first and coarser particles last.