Separation Processes

ChE 4M3

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Some context

Three important characteristics of an individual solid particle are its composition, its size and its shape.

Composition: affects density, conductivity, and other physical properties important to separating it.

We will consider shape and size characterization now.

Particle shape characterization

A particle may be regular shaped, e.g.

- *spherical* or *cubic* objects are capable of precise definition using equations

Irregular shaped: e.g. broken glass, sand, rock, most solids

- properties of irregular shapes are expressed ito a regular shaped particle's characteristics

So we will spend time characterizing spherical particles, then expressing other particles in terms of an*equivalent spherical particle*

Particle shape: Sphericity

Why use a sphere?

- it has the same shape from all angles
- behaves the same way from all angles

Other particles behave less ideally; we define sphericity as one metric of a particle's shape:

$$\psi = \frac{\text{surface area of sphere with same volume as particle}}{\text{surface area of particle}}$$

For all particles: $0 < \psi \leq 1$

To try: calculate the sphericity of a cube with side length $= c$

Answer: $\psi = 0.806$

Other shape metrics

Find the diameter of a sphere that has the same ______ as the irregularly-shaped particle

- volume
- surface area
- surface area per unit volume
- area in the projected direction of travel [drag diameter]
- projected area, but in a position of maximum stability
- settling velocity [Stokes' diameter]
- will fit through the same size square aperture [sieve diameter]

Shape metrics example

For example, how would you quantify yourself if measured by:

1. Circumference around your waist?
2. Diameter of a sphere of the same surface area as your body?
3. Length of your longest chord (height)?

The measured values will have different meanings. e.g.

1. used to size a life jacket
2. (perhaps?) used to estimate heat losses through your skin
3. if you are buying a sleeping bag I suggest the last one.

[Adapted from: George G. Chase, The University of Akron]

Particle size characterization

So far we have assumed particles to be separated are of a single size. This is never true: there is always a size distribution.

Particle size: affects surface per unit volume (mass transfer), rate of settling in a fluid (separation), *etc*

Aims

How do we measure this distribution?

How do we describe (characterize) a size distribution?

What is the "**average**" particle size?

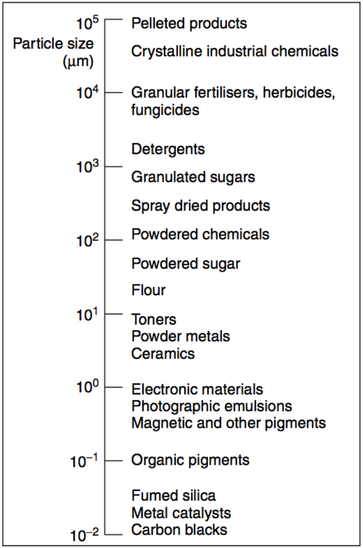
Other reasons to consider particle size distributions?

- Understand your colleagues: "After crushing, the feed may be ground in several stages from a size of 5 to 6 cm to a powder of 75 to 90 percent passing a 200-mesh sieve."
- Solid material handling industry: we must deal with distributions
  - What kind of industries are we referring to here?
  - e.g. activity of a powdered drug $= f(\text{particle size})$
  - e.g. "hiding power" of a paint/pigment $= f(\text{particle size})$

We will require this understanding for future sections: filtration, flow of fluids through packed beds, cyclones, centrifuges, membranes, and so on.

Some typical particle sizes

We typically work in microns. 1 micron = 1 μm



[Richardson and Harker, 5ed, p4]

Standard screens

Mesh 10 screen = 2.00 mm opening = 10 openings per linear inch.

Standard screen sizes

The US standard (Tyler series). Selected screens from Tyler sequence:

Mesh number	Square aperture opening (μm)
3.5	5600
$\vdots$	$\vdots$
10	2000
$\vdots$	$\vdots$
20	850
25	710
30	600
$\vdots$	$\vdots$
140	106
170	90
200	75
230	63
$\vdots$	$\vdots$
450	32

Tyler standard:

- e.g. 75μm opening: called 200 mesh screen
- i.e. apertures per inch $=$ 200 mesh screen

- Successive apertures decrease by factor of $\sim \sqrt[4]{2}$

- Other standards: British I.M.M. and U.S. A.S.T.M.

Screens

Stack screens: apertures from largest on top to smallest

[http://en.wikipedia.org/wiki/File:Laborsiebmaschine_BMK.jpg]

Screens

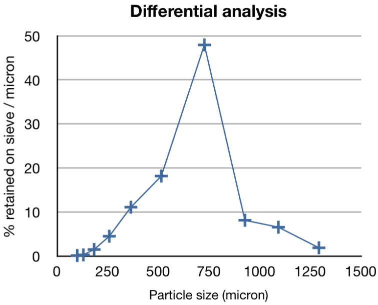
- Select top screen to (usually) have 100% material passing through
- Shaken for a predetermined time; or rate of screening levels out
- Shake intensity must be balanced: not too aggressive to break particles apart
- Smaller particles tend to stick to each other, so small size fractions inaccurate
- One can have wet or dry screen systems
- Wet screening: washes smaller particles off larger ones

Data analysis from a screen sample

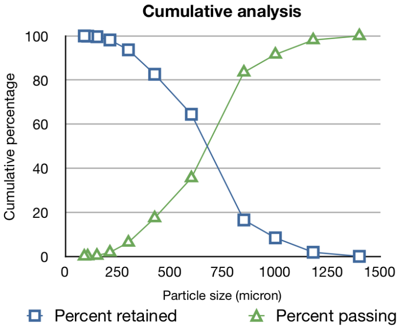
Mesh	Aperture [μm]	Mass retained [g]	Avg size*	Cuml. % passing
14	1400	0	-	100
16	1180	9.1	1290	98.1
18	1000	32.1	1090	91.6
20	850	39.8	925	83.5
30	600	235.4	725	35.5
40	425	89.1	513	17.4
50	300	54.4	363	6.3
70	212	22.0	256	1.8
100	150	7.2	181	0.4
140	106	1.2	128	0.1
Pan	0	0.5	53	0.0
Sum		**491**		

∗ *average screen size used for differential plots*

Differential and Cumulative analysis



Plot using average screen sizes



Plot using actual screen sizes

Theory:

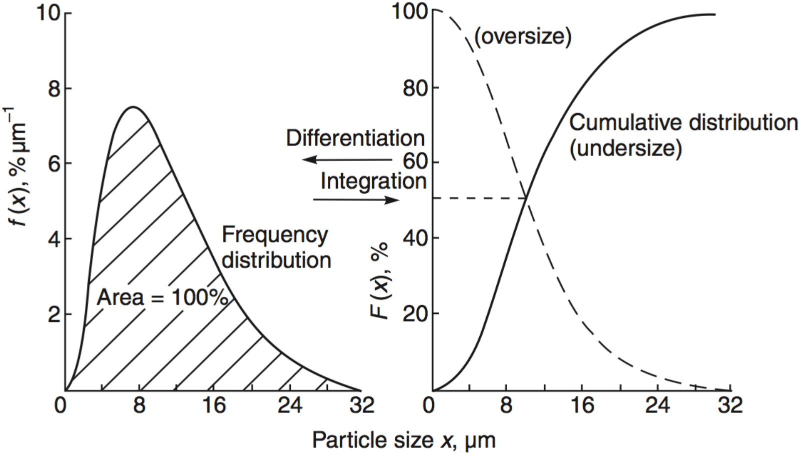
$$f(x) = \frac{dF(x)}{dx}$$

x is the avg particle size (bin)

$F(x) =$ percent passing curve

$1 - F(x) =$ percent retained curve

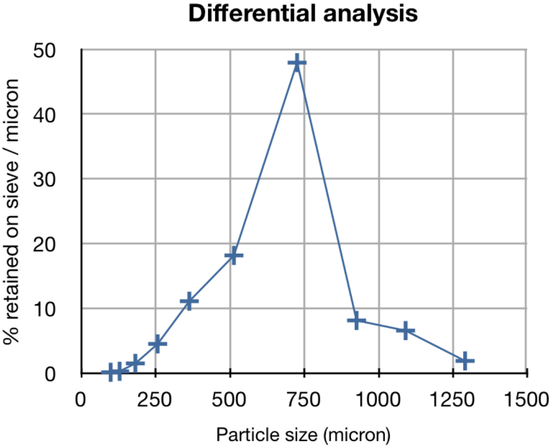
Theoretical view



[Svarovsky, 4ed, p42]

Mean diameter calculations

A number of mean diameters can be calculated. These can be derived from the cumulative analysis plot:



- Arithmetic mean = 318 μm
- Volume mean diameter = 430 μm
- Surface mean diameter (Sauter mean diameter) = 565 μm
- Weight or mass-mean diameter = 666 μm

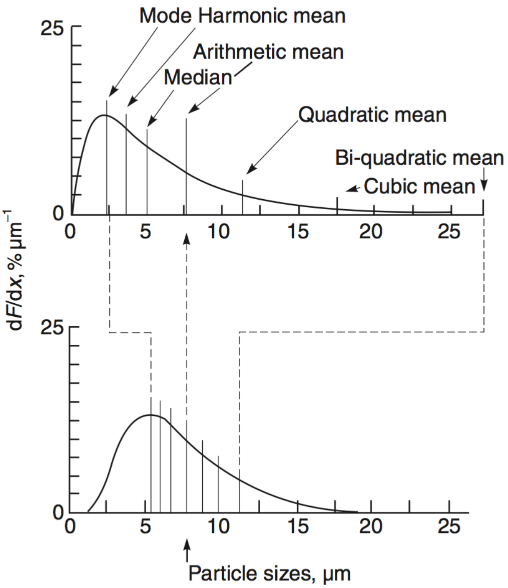
Our aim is not to calculate all these (the formulae are messy, and error prone). Your lab will have these already set up in their analysis software.

- Seader, 3ed, p 678 - 679 [for worked example]
- Svarovsky, 4ed, p37 - 43 [for descriptions of many means]

Which mean should I use?

- Rather use the distribution curve, if available
- If one has to resort to a single number, use what is appropriate
  - volume mean diameter: used for packing estimation
  - surface mean diameter: used for skin friction, and mass transfer calculations
- The idea is that if two materials had the same "mean diameter", that they would behave the same way in the application being considered.

Two distributions, same arithmetic mean



[Svarovsky, 4ed, p59]

Sampling a stream

Particle size measurements are strongly dependent on the sample taken. The "golden" rules of sampling:

1. take sample from a moving stream: dry powders and slurry
2. sample *whole* stream for many short periods (not part of stream for whole time)

There are books written on the topic of sampling. Consult an experienced person if important decisions rest on the sample taken.

References

1. Richardson and Harker, "Chemical Engineering, Volume 2", 5th edition, chapter 1
2. Perry's Chemical Engineers' Handbook, 8th edition, chapter 21.1
3. Seader, Henley and Roper, "Separation Process Principles", page 675 to 679 in 3rd edition
4. Svarovsky, "Solid-Liquid Separation", 4th edition.