EP 316 – Separation Process Fundamentals

Lesson 4

UCSI University®

Screening

- Screening is a method of separating particles according to size alone.
- A single screen make a single separation into 2 fractions. These is called unsized fractions, because although either the upper or lower limit of the particle sizes is known, the other limit is unknown.
- Material passed through a series of screens of different sizes is separated into sized fractions. The process also known as fractionation.
- The obtained fractions easily to know the max. and min. particle sizes.
- Screening is occasionally done wet but much more commonly dry.
- Steel and stainless steel screens are the most common.
- Standard screens range in mesh size 4 inch to 400 mesh.

- In most screens, the particles drop through the openings by gravity; in a few designs they are pushed through the screen by a brush or centrifugal force.
- Coarse particles drop easily through large openings in a stationary surface, but with fine particles the screen surface must be agitated (e.g shaking, gyrating, vibrating; mechanically or electrically).

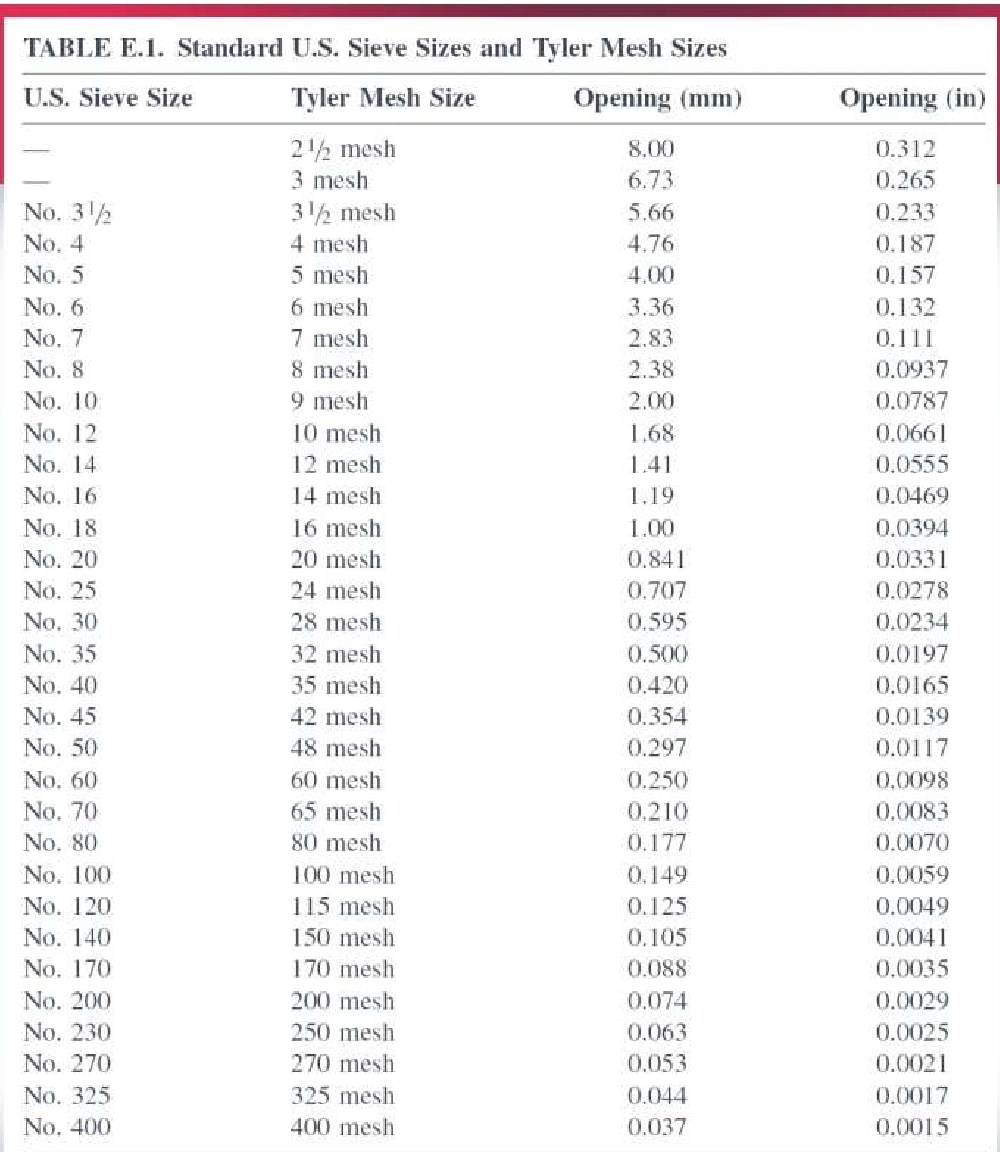
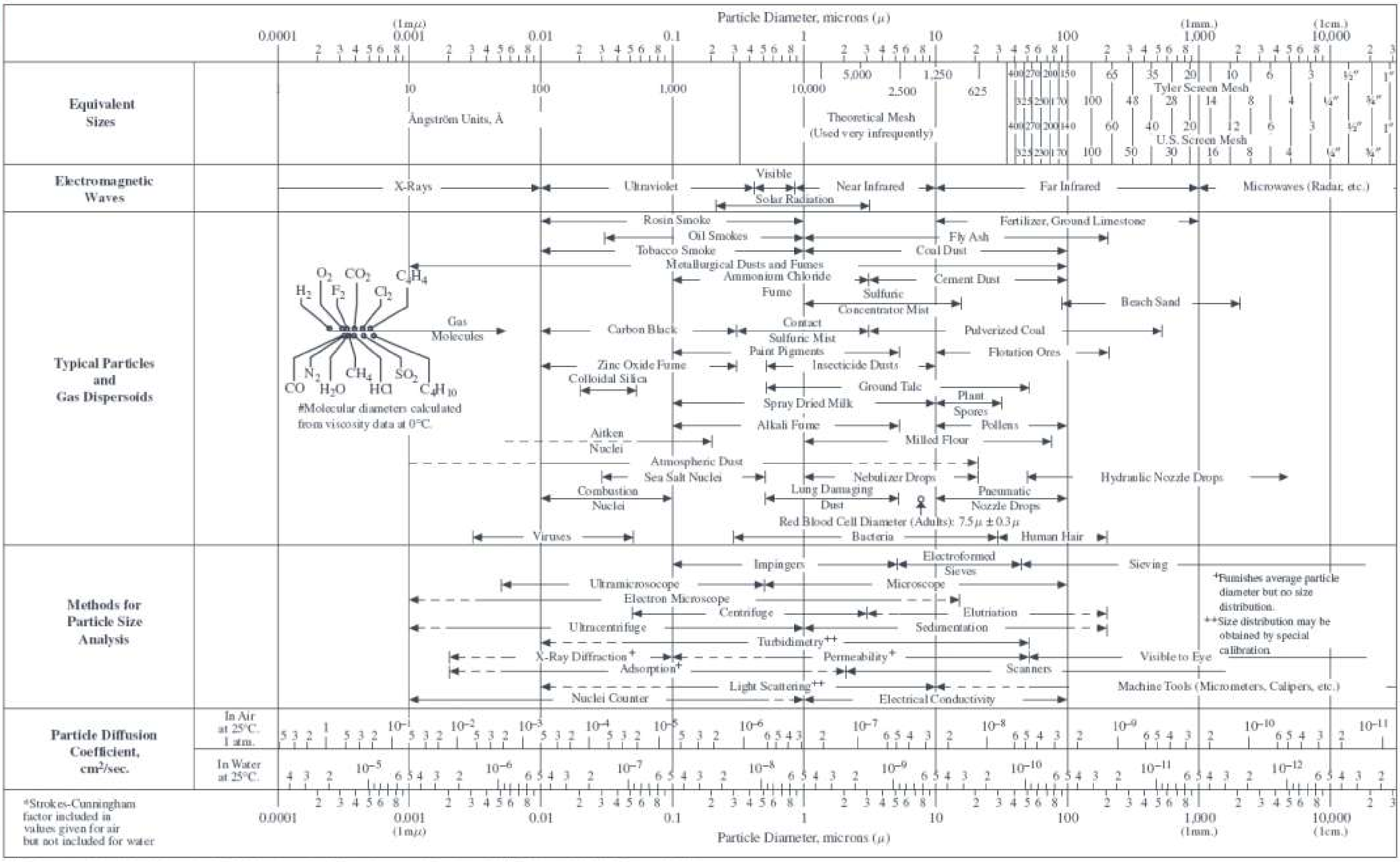


TABLE E.1. Standard U.S. Sieve Sizes and Tyler Mesh Sizes

U.S. Sieve Size	Tyler Mesh Size	Opening (mm)	Opening (in)
—	2½ mesh	8.00	0.312
—	3 mesh	6.73	0.265
No. 3½	3½ mesh	5.66	0.233
No. 4	4 mesh	4.76	0.187
No. 5	5 mesh	4.00	0.157
No. 6	6 mesh	3.36	0.132
No. 7	7 mesh	2.83	0.111
No. 8	8 mesh	2.38	0.0937
No. 10	9 mesh	2.00	0.0787
No. 12	10 mesh	1.68	0.0661
No. 14	12 mesh	1.41	0.0555
No. 16	14 mesh	1.19	0.0469
No. 18	16 mesh	1.00	0.0394
No. 20	20 mesh	0.841	0.0331
No. 25	24 mesh	0.707	0.0278
No. 30	28 mesh	0.595	0.0234
No. 35	32 mesh	0.500	0.0197
No. 40	35 mesh	0.420	0.0165
No. 45	42 mesh	0.354	0.0139
No. 50	48 mesh	0.297	0.0117
No. 60	60 mesh	0.250	0.0098
No. 70	65 mesh	0.210	0.0083
No. 80	80 mesh	0.177	0.0070
No. 100	100 mesh	0.149	0.0059
No. 120	115 mesh	0.125	0.0049
No. 140	150 mesh	0.105	0.0041
No. 170	170 mesh	0.088	0.0035
No. 200	200 mesh	0.074	0.0029
No. 230	250 mesh	0.063	0.0025
No. 270	270 mesh	0.053	0.0021
No. 325	325 mesh	0.044	0.0017
No. 400	400 mesh	0.037	0.0015

TABLE E.2. Particle Characteristics for Different Sizes



[1] Reference: Modified from the CRC Handbook of Chemistry and Physics, 83rd Edition 2002-2003, pp.15-31

Factors Affecting the Effectiveness of Screening

- Mesh size and wire diameter
- Capacity
- Blinding
- Moisture
- Direction of approach of particle to screen surface
- Cohesion
- Adhesion

Particle Size Distribution

- Most particulate system consist of particles of a wide range of sizes and it is necessary to be able to give a quantitative indication of the mean size and of the spread of sizes.
- The results of a size analysis can be represented by means of a ***cumulative mass fraction curve***, in which the proportion of particles (*x*) smaller than a certain size (*d*) is plotted against that size (*d*).
- A typical curve for size distribution on a cumulative basis is shown in Figure 1.5.
- This curve rises from zero to unity over the range from the smallest to the largest particle size present.

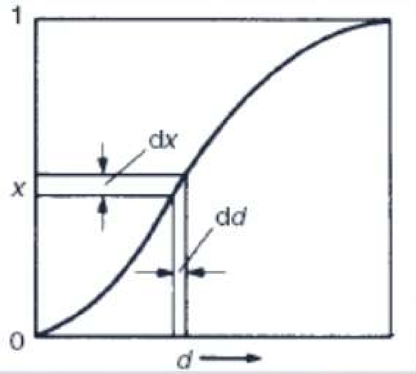


Figure 1.5

- The distribution of particle sizes can be seen more readily by plotting a *size frequency curve*, such as that shown in Figure 1.6, in which the slope (dx/dd) of the cumulative curve (Figure 1.5) is potted against particle size (d).

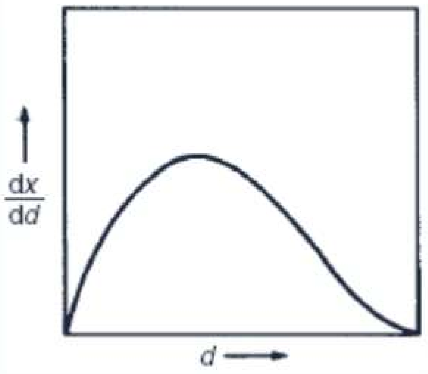
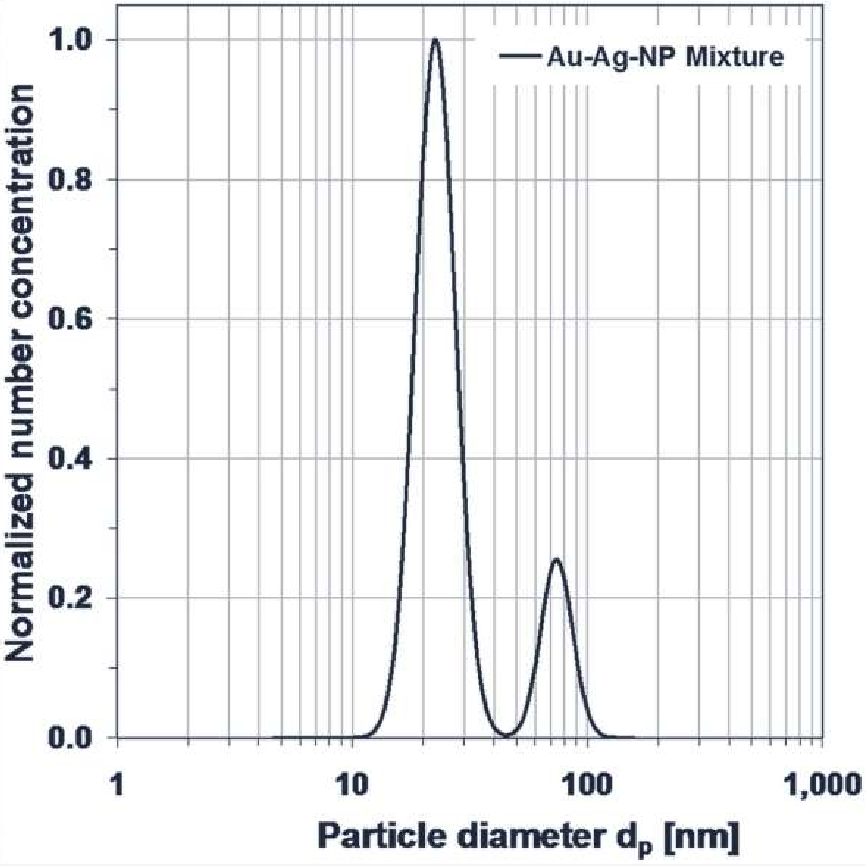


Figure 1.6

- The most frequently occurring size is then shown by the maximum of the curve.
- For naturally occurring materials the curve will generally have a single peak.
- For mixtures of particles, there may be as many peaks as components in the mixture.
- If the particles are formed by crushing larger particles, the curve may have 2 peaks, one characteristic of the material and the other characteristic of the equipment.

Real Result for Particle Size Distribution

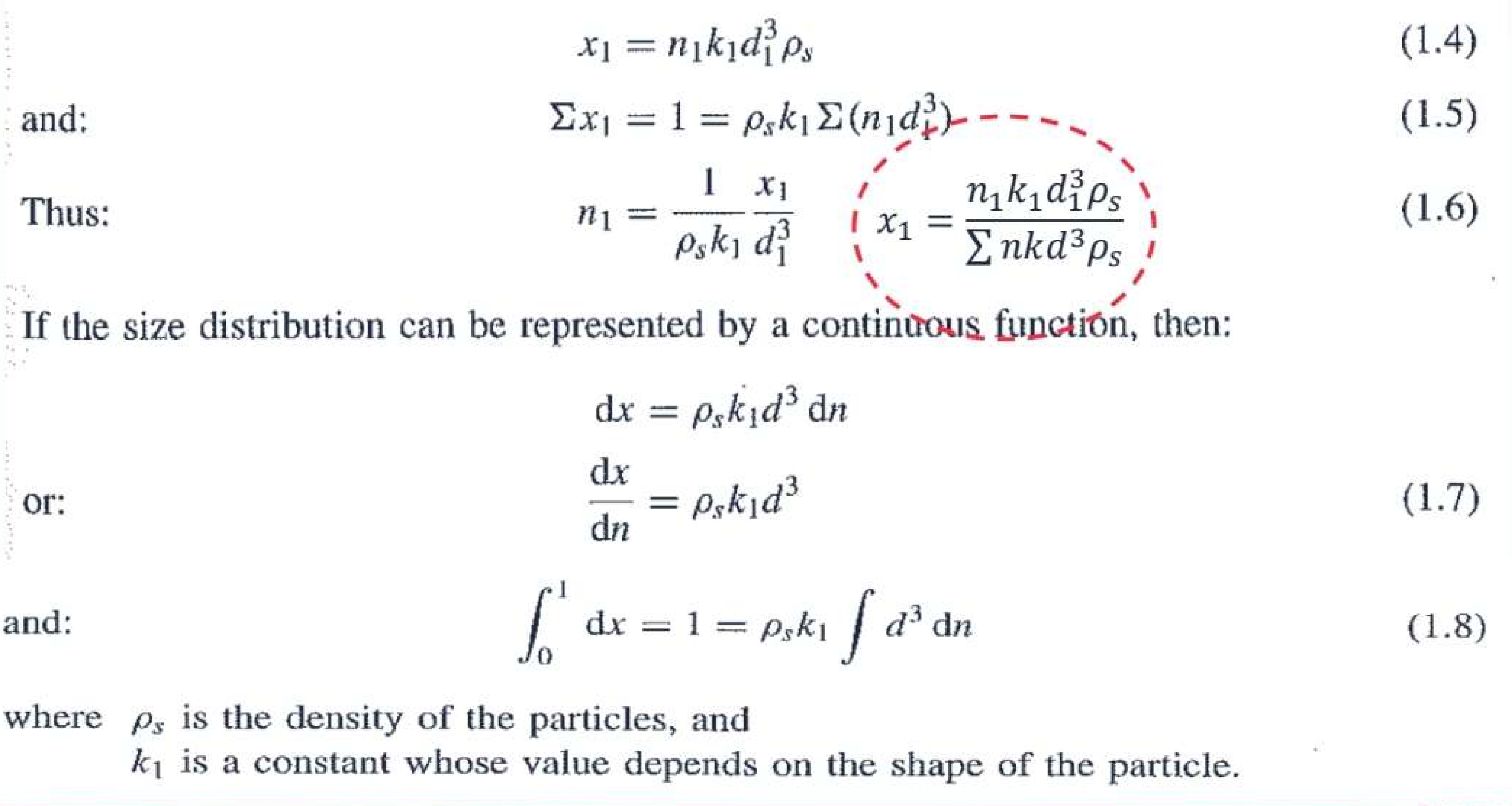


Zeta Sizer

Mean Particle Size

- For coarse particles, *BOND* has somewhat arbitrarily chosen the size of the opening through which 80% of the material will pass.
- This size d_{80} is a useful rough comparative measure for the size of material which has been passed through a crusher.
- A mean size will describe only one particular characteristic of the powder and it is important to decide what that characteristic is before the mean is calculated.
- Thus, it may be desirable to define the size of particle such that its mass or its surface or its length is the mean value for all the particles in the system.
- In the following discussion it is assumed that each of the particles has the same shape.

- Considering unit mass of particles consisting of n1 particles of characteristic dimension d_1, constituting a mass fraction x_1, n_2 particles of size d_2, and so on, then:



$$x_1 = n_1 k_1 d_1^3 \rho_s \tag{1.4}$$

and:

$$\Sigma x_1 = 1 = \rho_s k_1 \Sigma (n_1 d_1^3) \tag{1.5}$$

Thus:

$$n_1 = \frac{1}{\rho_s k_1} \frac{x_1}{d_1^3} \qquad x_1 = \frac{n_1 k_1 d_1^3 \rho_s}{\sum n k d^3 \rho_s} \tag{1.6}$$

If the size distribution can be represented by a continuous function, then:

$$\mathrm{d}x = \rho_s k_1 d^3 \, \mathrm{d}n$$

or:

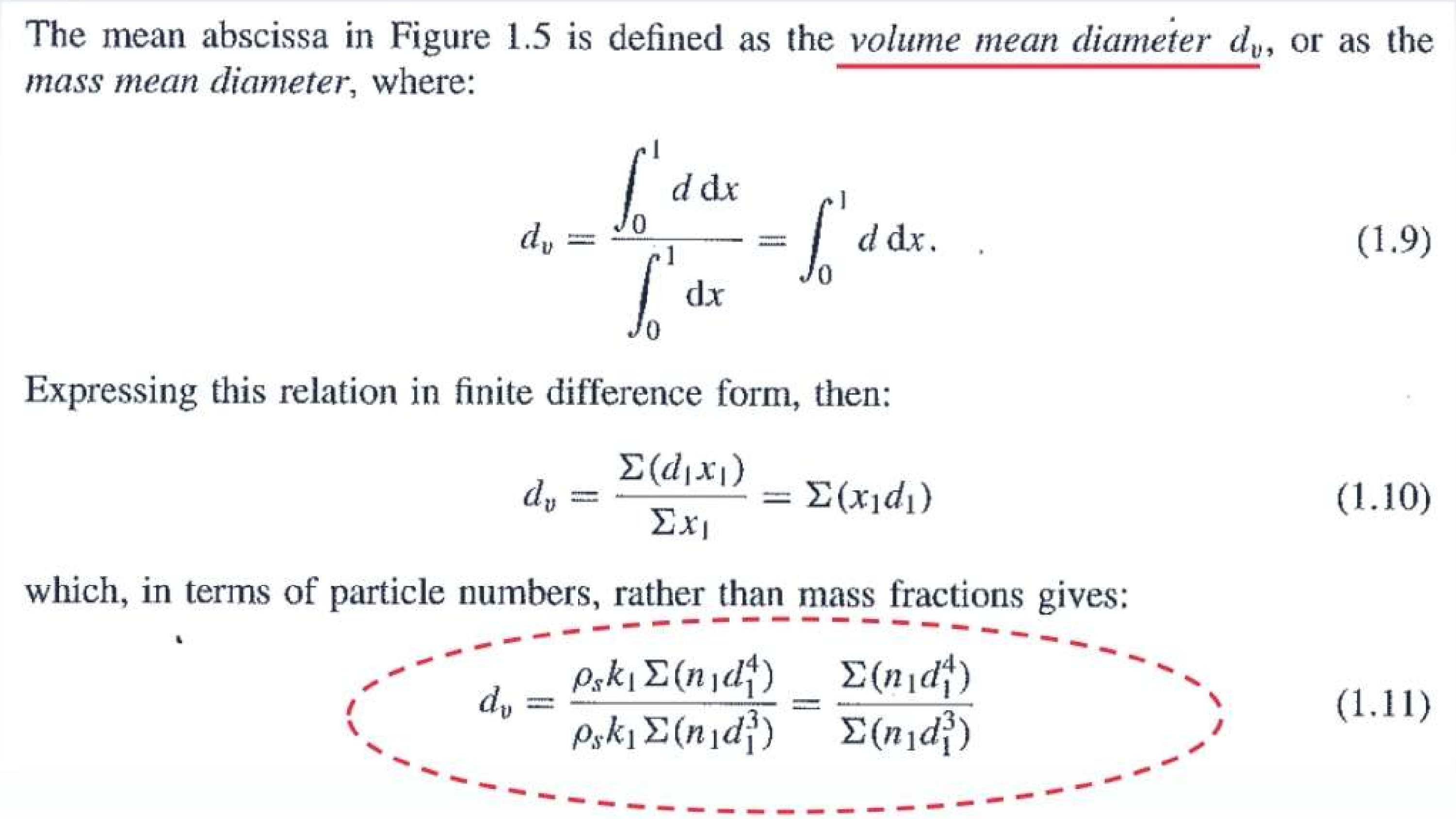
$$\frac{\mathrm{d}x}{\mathrm{d}n} = \rho_s k_1 d^3 \tag{1.7}$$

and:

$$\int_0^1 \mathrm{d}x = 1 = \rho_s k_1 \int d^3 \, \mathrm{d}n \tag{1.8}$$

where ρ_s is the density of the particles, and
k_1 is a constant whose value depends on the shape of the particle.

Mean Sizes based on Volume



The mean abscissa in Figure 1.5 is defined as the *volume mean diameter* d_v, or as the *mass mean diameter*, where:

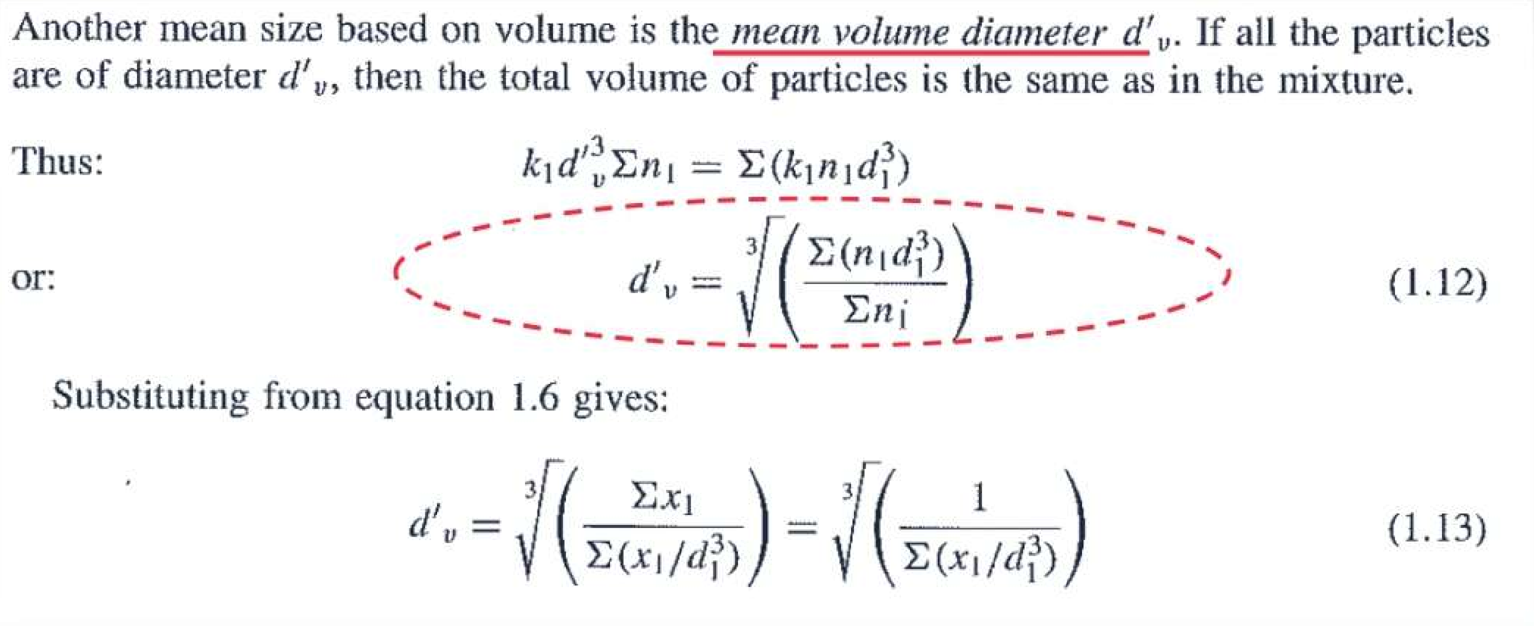
$$d_v = \frac{\int_0^1 d\,\mathrm{d}x}{\int_0^1 \mathrm{d}x} = \int_0^1 d\,\mathrm{d}x. \qquad (1.9)$$

Expressing this relation in finite difference form, then:

$$d_v = \frac{\Sigma(d_1 x_1)}{\Sigma x_1} = \Sigma(x_1 d_1) \qquad (1.10)$$

which, in terms of particle numbers, rather than mass fractions gives:

$$d_v = \frac{\rho_s k_1 \Sigma(n_1 d_1^4)}{\rho_s k_1 \Sigma(n_1 d_1^3)} = \frac{\Sigma(n_1 d_1^4)}{\Sigma(n_1 d_1^3)} \qquad (1.11)$$



Another mean size based on volume is the *mean volume diameter* d'_v. If all the particles are of diameter d'_v, then the total volume of particles is the same as in the mixture.

Thus:

$$k_1 d'^3_v \Sigma n_1 = \Sigma(k_1 n_1 d_1^3)$$

or:

$$d'_v = \sqrt[3]{\left(\frac{\Sigma(n_1 d_1^3)}{\Sigma n_i}\right)} \tag{1.12}$$

Substituting from equation 1.6 gives:

$$d'_v = \sqrt[3]{\left(\frac{\Sigma x_1}{\Sigma(x_1/d_1^3)}\right)} = \sqrt[3]{\left(\frac{1}{\Sigma(x_1/d_1^3)}\right)} \tag{1.13}$$

Mean Sizes based on Surface

In Figure 1.5, if, instead of fraction of total mass, the surface in each fraction is plotted against size, then a similar curve is obtained although the mean abscissa d_s is then the *surface mean diameter*.

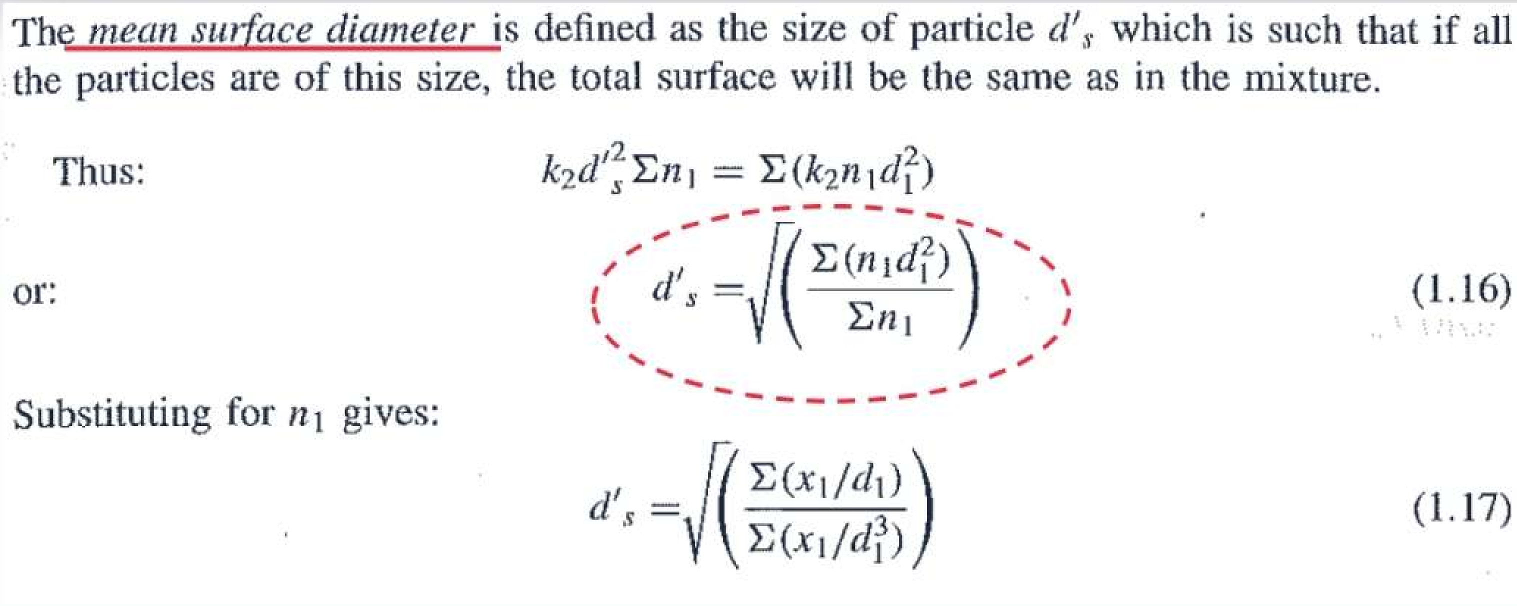
Thus:

$$d_s = \frac{\Sigma[(n_1 d_1)S_1]}{\Sigma(n_1 S_1)} = \frac{\Sigma(n_1 k_2 d_1^3)}{\Sigma(n_1 k_2 d_1^2)} = \frac{\Sigma(n_1 d_1^3)}{\Sigma(n_1 d_1^2)} \tag{1.14}$$

where $S_1 = k_2 d_1^2$, and k_2 is a constant whose value depends on particle shape. d_s is also known as the *Sauter mean diameter* and is the diameter of the particle with the same specific surface as the powder.

Substituting for n_1 from equation 1.6 gives:

$$d_s = \frac{\Sigma x_1}{\Sigma\left(\dfrac{x_1}{d_1}\right)} = \frac{1}{\Sigma\left(\dfrac{x_1}{d_1}\right)} \tag{1.15}$$



The *mean surface diameter* is defined as the size of particle d'_s which is such that if all the particles are of this size, the total surface will be the same as in the mixture.

Thus:

$$k_2 d'^2_s \Sigma n_1 = \Sigma(k_2 n_1 d_1^2)$$

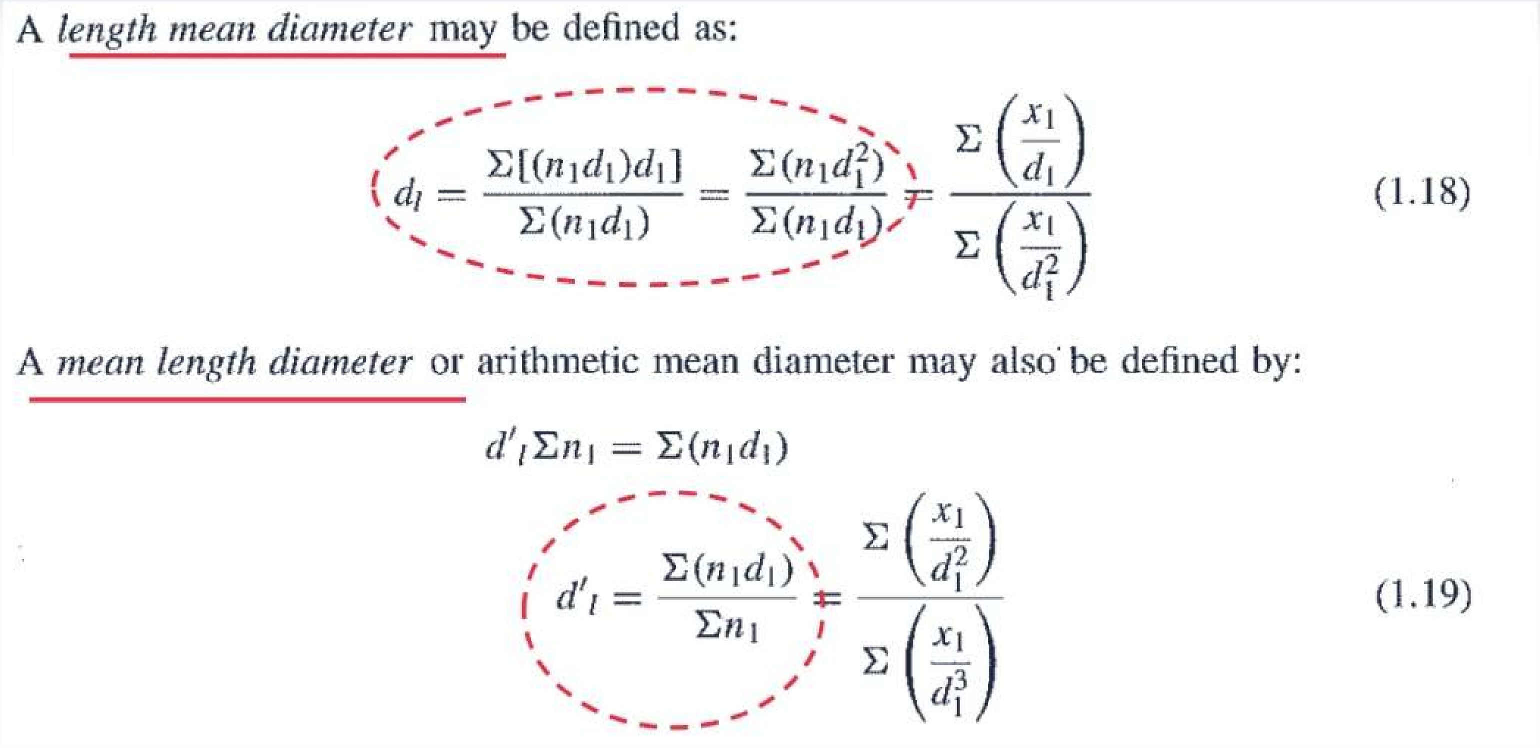
or:

$$\boxed{d'_s = \sqrt{\left(\frac{\Sigma(n_1 d_1^2)}{\Sigma n_1}\right)}} \tag{1.16}$$

Substituting for n_1 gives:

$$d'_s = \sqrt{\left(\frac{\Sigma(x_1/d_1)}{\Sigma(x_1/d_1^3)}\right)} \tag{1.17}$$

Mean Dimensions based on Length



A *length mean diameter* may be defined as:

$$d_l = \frac{\Sigma[(n_1 d_1) d_1]}{\Sigma(n_1 d_1)} = \frac{\Sigma(n_1 d_1^2)}{\Sigma(n_1 d_1)} = \frac{\Sigma\left(\frac{x_1}{d_1}\right)}{\Sigma\left(\frac{x_1}{d_1^2}\right)} \qquad (1.18)$$

A *mean length diameter* or arithmetic mean diameter may also be defined by:

$$d'_l \Sigma n_1 = \Sigma(n_1 d_1)$$

$$d'_l = \frac{\Sigma(n_1 d_1)}{\Sigma n_1} = \frac{\Sigma\left(\frac{x_1}{d_1^2}\right)}{\Sigma\left(\frac{x_1}{d_1^3}\right)} \qquad (1.19)$$

Exercise

(1) The size distribution of a dust as measured by a microscope is as follows. Convert these data to obtain distribution on mass basis, and calculate the specific surface, assuming spherical particles of density 2650 kg/m^3.

Size range (micron)	**Number of particle in range**
0-2	2000
2-4	600
4-8	140
8-12	40
12-16	15
16-20	5
20-24	2

Exercise

2. A crusher was used to crush a material with a compressive strength of 22.5 MN/m2. The size of the feed was minus 50mm, plus 40mm and the power required was 13.0 kW(kg/s). The screen analysis of the product was:

	Size of aperture (mm)	Amount of product (%)
Through	6.0	All
On	4.0	26
On	2.0	18
On	0.75	23
On	0.50	8
On	0.25	17
On	0.125	3
Through	0.125	5

(i) What power would be required to crush 1 kg/s of a material of compressive strength 45MN/m^2 from a feed of *minus* 45mm, *plus* 40mm to a product of 0.50mm average size ? (Apply the Kick's Law)

(ii) Calculate the same problem as **part (i)**, using Bond's Law.

Sphericity/ Shape Factor

- **Sphericity** is a measure of how spherical (round) an object is. As such, it is a specific example of a compactness measure of a shape. Defined by Wadell in 1935, the sphericity, Ψ, of a particle is the ratio of the surface area of a sphere (with the same volume as the given particle to the surface area of the particle:

$$\Psi = \frac{\pi^{\frac{1}{3}}(6V_p)^{\frac{2}{3}}}{A_p}$$

- where *Vp* is volume of the particle and *Ap* is the surface area of the particle

First we need to write surface area of the sphere, *As* in terms of the volume of the particle, *Vp*

$$A_s^3 = \left(4\pi r^2\right)^3 = 4^3\pi^3 r^6 = 4\pi\left(4^2\pi^2 r^6\right) = 4\pi\cdot 3^2\left(\frac{4^2\pi^2}{3^2}r^6\right) = 36\pi\left(\frac{4\pi}{3}r^3\right)^2 = 36\,\pi V_p^2$$

therefore

$$A_s = \left(36\,\pi V_p^2\right)^{\frac{1}{3}} = 36^{\frac{1}{3}}\pi^{\frac{1}{3}}V_p^{\frac{2}{3}} = 6^{\frac{2}{3}}\pi^{\frac{1}{3}}V_p^{\frac{2}{3}} = \pi^{\frac{1}{3}}\left(6V_p\right)^{\frac{2}{3}}$$

hence we define Ψ as:

$$\Psi = \frac{A_s}{A_p} = \frac{\pi^{\frac{1}{3}}\left(6V_p\right)^{\frac{2}{3}}}{A_p}$$