PROC 5071:
Process Equipment Design I

Particle Size Measurement

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1 Methods for Particle Size Measurement

- Both classical and modern instrumentations, based on a broad spectrum of physical principles are available for measurement of particle size.
- The typical measuring systems may be classified according to their operation mechanisms.
- mechanical
  - sieving
- optical and electronic
  - microscopy, laser Doppler phase shift, Fraunhofer diffraction, transmission electron miscroscopy [TEM], and scanning electron microscopy [SEM]
- dynamic
  - sedimentation
- physical and chemical
  - gas adsorption
- The methods are briefly summarized in Table 1.

- In this course only the sieving method, which is also known as screen analysis, will be discussed.

Table 1: Particle size measurement methods

Method	Size ranges (μm)
Sieving	
Woven wires	37-5660
Electroformed	5-120
Punched plate	50-125,000
Microscopy	
Optical	0.8-150
Electron	0.001-5
Sedimentation	
Gravitational	5-1000
Centrifugal	0.001-1000
Fraunhofer diffraction	0.1-1000
Doppler phase shift	1-10,000

2 Sieving (Screen analysis)

- A bulk of particles is separated on vertically stacked standard screens arranged in order of opening size. Particles either go through or remain on a screen based on their size.

- Simple and widely used technique to measure size and size distribution.
- Based on the size of the particles and independent of other properties e.g. density, roughness or optical properties.

2.1 Sieve structure and dimensions

- Sieves are made of woven wire screens.
- The mesh and dimensions of the sieve openings have been standardized.
- Currently two different sets of standard series, the Tyler Standard and the U.S. Series ASTM Standard, are used.
- The openings are square.
- Each screen is identified in meshes per inch.
- Thus, the higher the mesh number the smaller the aperture.
- Typical mesh numbers, aperture sizes, and wire diameters are given for the Tyler sieves and the U.S. ASTM sieves in Table 2.

- Sieve analysis covers the approximate size range of 37 μm to 5,660 μm using standard woven wire sieves.
- Electroformed micromesh sieves extend the range down to $5\mu m$ or less.
- Punched plate sieves extend the upper limit.

2.2 Tyler standard screen series

- The Tyler standard screen series is based on the 200-mesh screen.
- 200-mesh screen means 200 openings per inch.
- 1/200 is 0.005. However, the actual clean opening is 0.0029 inch or 0.074 mm because of the wires.
- Diameters of the wires are different for screens with different mesh number.
- For 200-mesh screens wire diameter is 0.0021 in.
- The area of the opening in any one screen is exactly twice that of the opening of the screen

below it.

- The ratio of the actual mesh dimension of any screen to that of the next smaller screen is $\sqrt{2} = 1.41$.
- For closer sizing intermediate screens are available, each of which has a mesh dimension $\sqrt[4]{2} = 1.189$ times that of the next smaller standard screen.

Table 2: Tyler screen scale (†refers to intermediate screens inserted between standard screens).

Mesh	Opening (in)	Opening (mm)	Mesh	Opening (in)	Opening (mm)
-	1.050	26.67	16 †	0.0390	0.991
†	0.883	22.43	20	0.0328	0.833
-	0.742	18.85	24 †	0.0276	0.701
†	0.624	15.85	28	0.0232	0.589
-	0.525	13.33	32 †	0.0195	0.495
†	0.441	11.20	35	0.0164	0.417
-	0.371	9.423	42 †	0.0138	0.351
$2\frac{1}{2}$ †	0.312	7.925	48	0.0116	0.295
3	0.263	6.680	60 †	0.0097	0.246
$3\frac{1}{2}$†	0.221	5.613	65	0.0082	0.208
4	0.185	4.699	80 †	0.0069	0.175
5†	0.156	3.962	100	0.0058	0.147
6	0.131	3.327	115 †	0.0049	0.124
7†	0.110	2.794	150	0.0041	0.104
8	0.093	2.362	170 †	0.0035	0.088
9†	0.078	1.981	200	0.0029	0.074
10	0.065	1.651	270	0.0021	0.053
12†	0.055	1.397	325	0.0017	0.044
14	0.046	1.168	400	0.0015	0.037

2.3 Procedure for screen analysis

- Choose the screens based on the particle size range you are interested in.
- Weight the empty screens and note the weights.
- Arrange the screens in a stack with the one with the largest opening at the top and with the smallest opening at the bottom. A pan is placed at the bottom of the stack.
- Place the samples on the top screen and shake the stack mechanically for a definite time (~ 20 minutes).
- Remove the screens from the stack and weight the screens with the particles in it.
- Calculate the masses of particles in individual screens and the mass fractions of particles in each screen.

2.4 Results of screen analysis

- Tabulate the mass fraction of each screen increment as a function of the mesh size range

Figure 1: Sieve analysis.

of increment.

- Particles on each screen is characterized by two screens. One on which the particles are in and the one just above that screen.
- Thus 14/20 size means particles through 14-mesh and on 20-mesh.
- The average particle diameter is taken as the mean of the openings of the two screens.
- The results are often presented as a histogram with mass fractions of each increment against particle size. An approximate continuous curve is also drawn to show the distribution.
- A cumulative analysis is often presented to plot

cumulative mass fractions smaller than a particle sizes against those sizes.

- The mass fraction information along with the particle sizes are used to calculate other particle properties, e.g. surface area of particles, number of particles and average particle diameter.

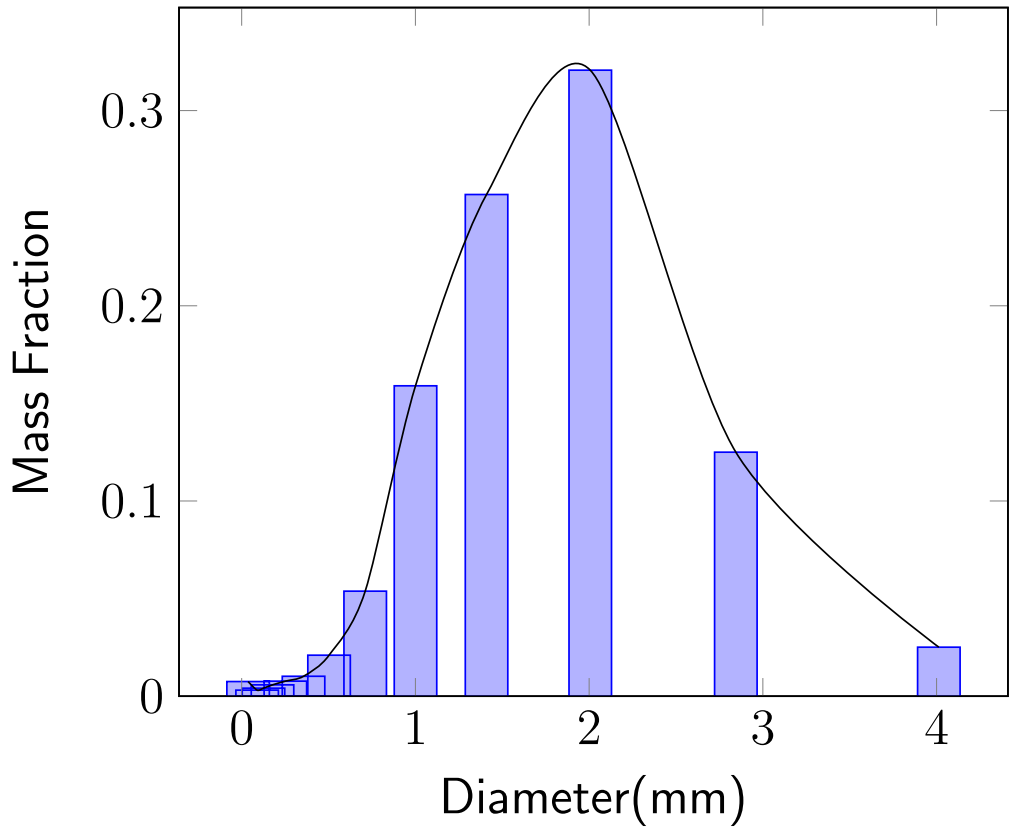

Figure 2: Particle size distribution- differential analysis

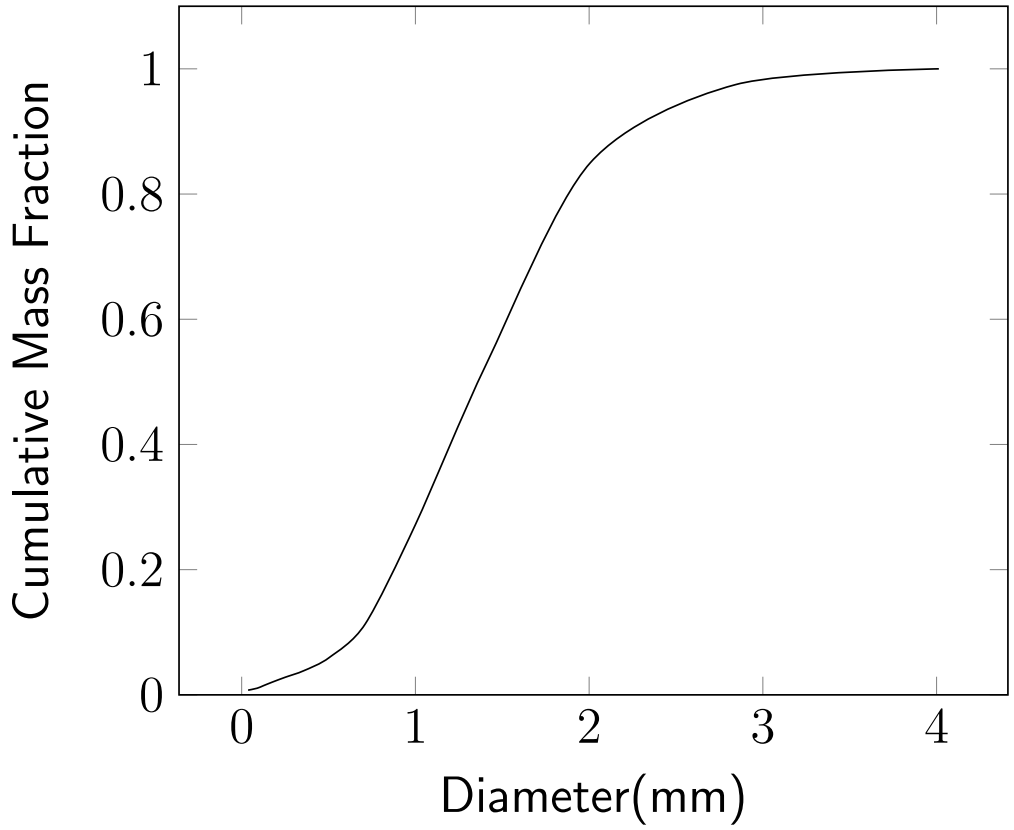

Figure 3: Particle size distribution- cumulative analysis

2.5 Workbook: Screen Analysis

The screen analysis data for a sample of crushed particles are presented in Table 3. For the materials between 4-mesh and 28-mesh, calculate the followings:

1. Specific surface area.
2. Arithmetic mean diameter.
3. Volume mean diameter.
4. Number of particles per gram.

The density of the particles is $2.5 \times 10^3 kg/m^3$. The shape factor and the sphericity of particles are 0.79 and 0.58, respectively.

Solution

- Given information
  - Mesh # - particle size
  - Mass fractions
  - Density, $\rho_p = 0.0025 g/mm^3$
  - Shape factor, $a = 0.79$

- Sphericity, $\Phi_s = 0.58$

- Here only the particles between 4-mesh and 28-mesh are being considered. As all of the screens are not considered $\sum_{i=1}^{n} x_i \neq 1$ and we will have to use the proper equations for this case.

1. Specific surface area, A_w is given by

$$A_w = \frac{6}{\Phi_s \rho_p} \frac{\sum_{i=1}^{n} \frac{x_i}{\overline{D}_{p_i}}}{\sum_{i=1}^{n} x_i} \tag{1}$$

   - To evaluate A_w we need to calculate $\frac{x_i}{\overline{D}_{p_i}}$ for the corresponding mesh numbers. From the table for particles between 4- and 28-mesh we get

$$\sum_{i=1}^{n} \frac{x_i}{\overline{D}_{p_i}} =$$

   - So we have

$$A_w =$$

$$=$$

2. Arithmetic mean diameter can be calculated by

$$\overline{D}_N = \frac{\sum_{i=1}^{n} N_i \overline{D}_{p_i}}{\sum_{i=1}^{n} N_i} \tag{2}$$

- Using the values calculated in Table 3

$$D_N = \\ =$$

3. Volume mean diameter is given by

$$D_v = \left[\frac{\sum_{i=1}^{n} x_i}{\sum_{i=1}^{n} \frac{x_i}{\overline{D}_{p_i}^3}} \right]^{\frac{1}{3}}$$

$$=$$

$$=$$

4. Number of particles per gram can be obtained

using

$$N_w = \frac{1}{0.79\rho_p} \sum_{i=1}^{n} \frac{x_i}{\overline{D}_{p_i}^3}$$

$$=$$

$$=$$

Table 3: Working data for screen analysis.

Mesh #	Opening (mm)	x_i	$\overline{D}_{p_i}$ (mm)	$cum\ x_i$ $< D_{p_i}$	$\frac{x_i}{\overline{D}_{p_i}}$	$\frac{x_i}{\overline{D}^3_{p_i}}$	$x_i\overline{D}_{p_i}$	N_i	$N_iD_{p_i}$
4	4.699	0		1					
8		0.25	3.531	0.75					
14		0.5			0.2833				
28		0.1					0.0879		66
48	0.295	0.1						586	
Pan		0.05		0		15.581	0.0074		1164

References

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