# 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 ($\mu m$) |
|---|---|
| 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 $\mu m$ to 5,660

$\mu m$ 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 ($\sim 20$ 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.


Figure 1: Sieve analysis.

## 2.4 Results of screen analysis

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

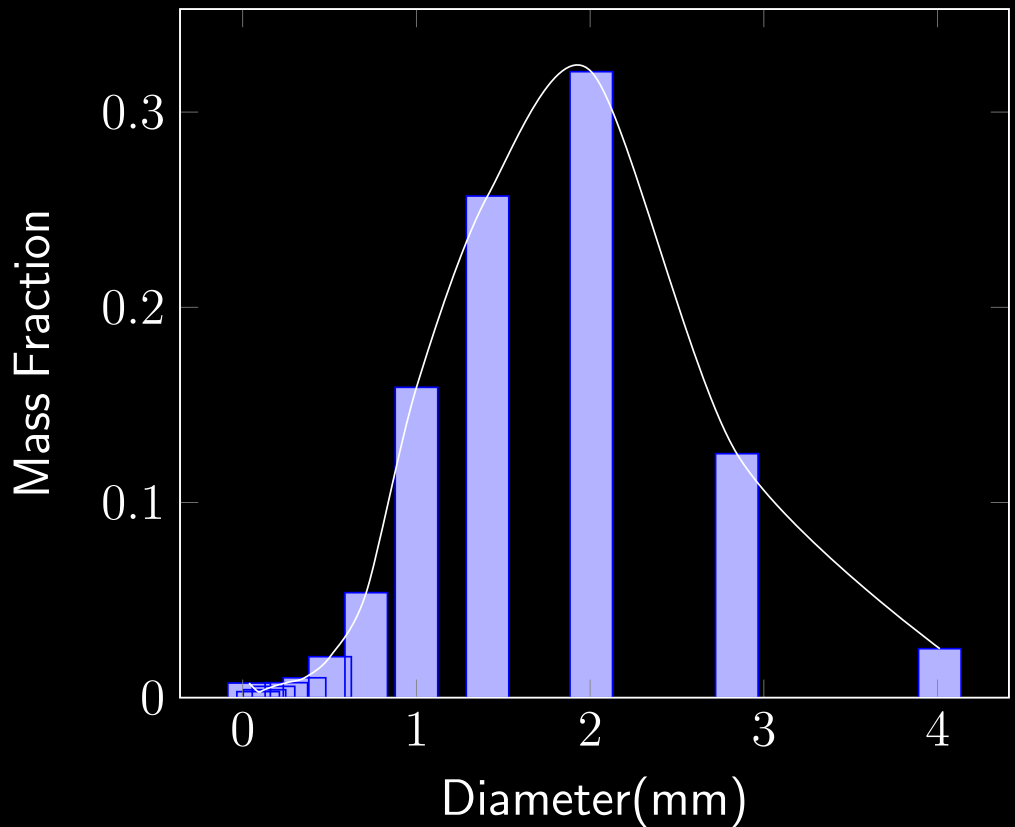


Figure 2: Particle size distribution- differential analysis

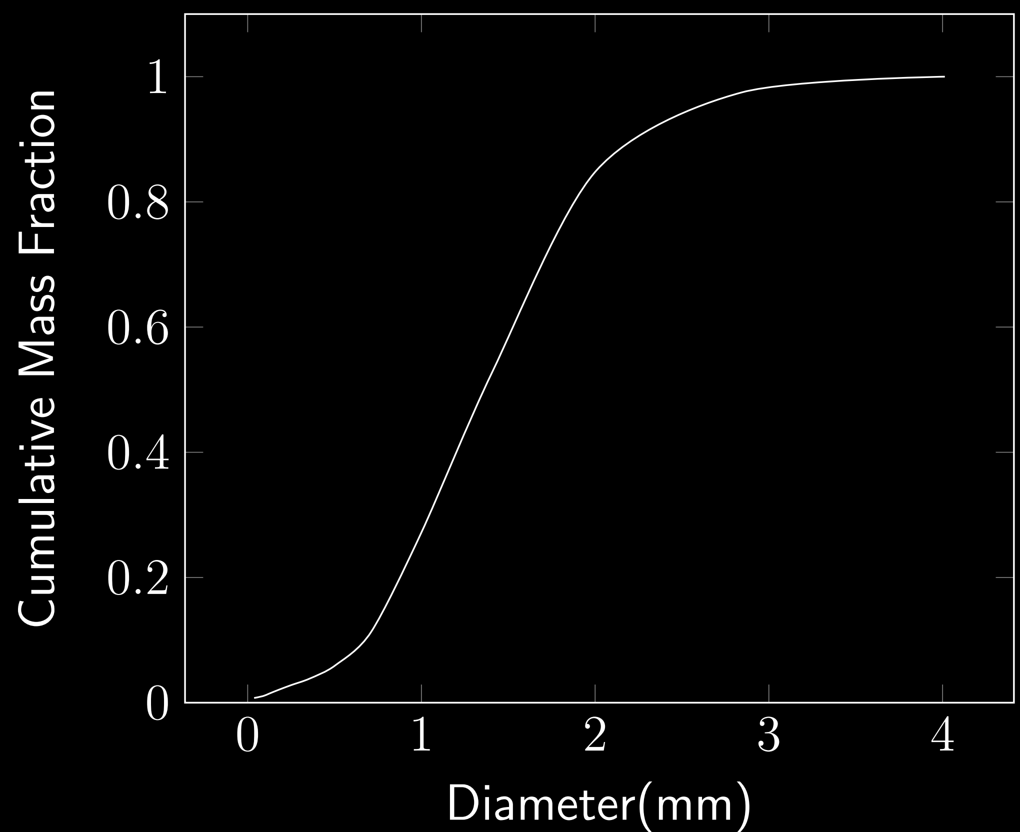


Figure 3: Particle size distribution- cumulative analysis

## 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

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

$$=$$

$$=$$

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) | $x_i$ | $\overline{D}_{p_i}$ $(mm)$ | $cum\ x_i$ $< D_{p_i}$ | $\frac{x_i}{\overline{D}_{p_i}}$ | $\frac{x_i}{\overline{D}_{p_i}^3}$ | $x_i\overline{D}_{p_i}$ | $N_i$ | $N_iD_{p_i}$ |
|---|---|---|---|---|---|---|---|---|---|
| 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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