**Chemical Engineering (GATE & PSUs)**

# Postal Correspondence

## GATE & Public Sectors

# Mechanical Operations

## GATE 2015 Top Results

## Chemical Engineering

**1st Rank**

**Archhit Trichal**

**2nd Rank**

**Keval Pareta**

GATE 2015 Result

Name: ARCHHIT TRICHAL

Registration Number: CH88041S1135

Gender: Male

Examination Paper: Chemical Engineering (CH)

Marks out of 100#: 65.67

All India Rank in this paper: 1

Qualifying Marks##: 27.52 General, 24.77 OBC (NCL), 18.34 SC/ST/PwD

GATE Score: 947

**Highest Result in GATE 2015**

**Rank 1, 2, 7, 8…….**

**Total 39 Ranks under AIR 100**

## GATE 2014 Topper

## Chemical Engineering

**1st Rank**

**Sandeep Kumar**

**To Buy Postal Correspondence Package call at**

**0-9990657855**

| GATE 2015 Cut-off Marks | | | | |
|---|---|---|---|---|
| **BRANCH** | **GENERAL** | **SC/ST/PD** | **OBC(Non-Creamy)** | **Total Appeared** |
| **Chemical Engineering** | 27.52 | 18.34 | 24.77 | 15874 |

# CONTENT

1. INTRODUCTION ………………………………………………… 03-03

2. PROPERTIES OF PARTICULATE SOLIDS ……………….04-19

3. STORAGE OF SOLIDS AND CONVEYING……………….. 20-25

4. MECHANICAL SEPARATION ……………………………. 26-31

5. SIZE REDUCTION LAWS …………………………………. 32-38

6. SIZE REDUCTION EQUIPMENTS ………………………. 39-45

7. SIZE SEPARATION ………………………………………. 46-57

8. FILTRATION ……………………………………………… 58-73

9. FLUIDISATION ........................................................................ 74-76

10. PRACTICE SET with Solution ……………………………… 77-87

11. GATE BASED QUESTIONS with Solution ………………. 88-99

# CHAPTER-1

# INTRODUCTION

- Chemical and its related company have first rank among all manufacturing industries both in capital assets and national economy.
- Chemical industries provide material for preparation of drugs, fertilizer, textile, paints and refinery operation.
- Chemical industry differs from many industries because it is not assembly industry. But in this industry raw material convert into useful product through series of unit operation and unit process.

## Mechanical Physical Separation Process:

The separation of mixture into their component is frequently necessary in chemical engineering practice. Various separation methods are classified in following two categories:

### 1. Mechanical Separation

(*a*) Applicable to heterogeneous mixture not to homogeneous solution.

(*b*) Technique is based on physical properties such as size, shape or composition & density.

*** Size Affects:** Surface area per unit volume, rate of settling of particle in a fluid.

*** Shape:** Regular (example spherical, cubical, Irregular (example piece of broken glass)

* Composition: It determines density.

**2. Molecular Separation:** Involve phase change or transfer of material from one phase to another. Example is distillation, etc.

**The mechanical methods of separation may be grouped into two general class:**

(*a*) Those whose mechanism is controlled by fluid mechanics such as classification, sedimentation etc.

(*b*) Those whose mechanism is not described by fluid mechanics such as screening.

(c) Mechanical processes include solids transportation, crushing and pulverization, screening and sieving

# CHAPTER-2

# PROPERTIES OF PARTICULATE SOLID

## Characterization of solids particles:

Individual solid particles are characterized by their size, shape and density. Particles of homogeneous solids have the same density but particles of a composite solid line have various density. Size and shapes are easily specified for regular particles, but for irregular particles, the size is defined in terms of the size of an equivalent sphere.

## 1. Particle Shape:

The shape of a particle is expressed in terms of sphericity, $\phi_s$. (which is independent of particle size)

$$\text{Sphericity } \boxed{\phi_s = \frac{\text{Surface to volume ratio of sphere of } D_{eq}}{\text{Surface to volume ratio of particle}}}$$

If, $S_P$ = Surface area of one particle

$V_P$ = Volume of one particle

$D_{eq}$ = Equivalent dia of one particle

$$\left.\begin{array}{l}\text{Volume of a sphere } V_P = \dfrac{\pi}{6} D_P^3 \\ \text{Surface area of sphere } S_P = \pi D_P^2\end{array}\right] \Rightarrow \frac{V_P}{S_P} = \frac{6}{D_P} \text{ or } \frac{6}{D_{eq}}$$

So, $$\boxed{\phi_s = \frac{6/D_{eq}}{S_P/V_P} = \frac{6V_P}{D_{eq}S_P}}$$

$\phi_s = 1$ for sphere and between 0 and 1 for all other particle.

For crushed particles, $\phi_S$ is between 0.6 and 0.8. For particles rounded by abrasion, $\phi_s = 0.95$

- $S_P$ is found from adsorption measurements or from pressure drop in a bed of particles
- **Equivalent diameter of particle:** Diameter of that sphere having equal volume as that of the particle.
- **Nominal diameter of particle:** for fine granular particles, it is difficult to determine exact volume and surface area, so diameter is taken based upon screen analysis and microscopic examination.

**2. Particle Size:** In general diameter may be specified for any equi-dimensional particle. Particle that are not equi-dimensional, that is, that are longer in one direction than in other are sometimes characterized by the second longest major dimension.

Particle size is expressed in different units depending upon the size range involved.

| Particles | Particle size |
|---|---|
| Coarse particles | Inches, mm |
| Fines | In terms of screen size |
| Very fine | µm, nm |
| Ultrafine | Surface area per unit mass ($m^2/g$) |

**2. Practical size analysis:** It determines the size range and / or average, or mean size of the particles in a powder or liquid sample

$$D_p = \frac{D_{P_1} + D_{P_2} + D_{P_3} + \dots D_N}{N}$$

**3. Specific surface area (SSA):** It is defined as surface area per unit mass. The SI units are $m^2/kg$: It is important for the design of chemical processes that involve surface reaction.

$$\boxed{S_m = \frac{\text{Total surface area of all fraction}}{\text{Total mass of mixture}}}$$

- It is defined by surface area divided by mass ($m^2/kg$) or surface area divided by volume $A = N\,S_p$

**4. Number of particles in the sample:** If a sample having particles of uniform dia, then number of particles in that sample can be defined as:

$$\boxed{N = \frac{m}{\rho_p V_p}}$$

where , m = Total mass of the sample

$\rho_p$ = Density of particle

$V_p$ = Volume of one particle

$\frac{m}{\rho_p}$ = Total volume of one particle.

**5. Total Surface Area of the Particle (A):** It can be defined as the product of number of particles and surface area of one particle.

$$A = NS_p$$

$$A = \left(\frac{m}{\rho_P V_P}\right)\left(\frac{6V_P}{\phi_s D_P}\right)$$

$$\boxed{A = \frac{6m}{\phi_s \rho_P D_P}}$$

**6. Specific Surface of Mixture:** If the particle density 'ρ' and sphericity $\phi_s$ are known the the specific surface area of the mixture can be defined as:

$$A_W = \frac{6x_1}{\phi_s \rho_p D_{p_1}} + \frac{6x_2}{\phi_s \rho_p D_{p_2}} + \frac{6x_3}{\phi_s \rho_p \bar{D}_{p_3}}$$

$$\boxed{A_W = \frac{6}{\phi_s \rho_p} \sum_{i=1}^{n} \frac{x_i}{\bar{D}_{pi}}}$$

where, $x_i$ – Mass fraction in a given increment

$n$ – Number of increments

$\bar{D}_{P_i}$ – Average particle diameters taken as arithmetic average of smallest and largest particle dia in increments.

**(7) Average Particle Size:** Average particle size for a mixture of particles is defined in several different ways:

**(i) Volume Surface Mean Diameter** $(\bar{D}_s)$

$$\bar{D}_s = \frac{6}{\phi_s \rho_P A_w} = \frac{1}{\sum_{i=1}^{n}\left(\frac{x_i}{\bar{D}_{P_i}}\right)}$$

It is defined as the diameter of sphere that has same volume/surface area ratio as a particle of interest.

**(ii) Mass Mean Diameter** $(\bar{D}_w)$

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

**(iii) Average Volume of a Particle** = $\dfrac{\text{Total volume of the sample}}{\text{No. of particles in the mixture}}$

**(iv) Volume Mean Diameter:**

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

**(v) Arithmetic mean diameter** $(\bar{D}_N)$:

$$\bar{D}_N = \frac{\sum_{i=1}^{n} N_i D_{Pi}}{N_T}$$

where, $N_T$ is the number of particles in entire sample.

**(vi) Number of Particle in the Mixture**

$$N_w = \frac{1}{a\rho_P}\sum_{i=1}^{n}\frac{x_i}{\bar{D}_{P_i}^3} = \frac{1}{a\rho_P\,\bar{D}_V^3}$$

where $a$ = Volume shape factor

: $N_w$ is the total population in one unit mass of sample, obtained by summation over all fractions

Also $\boxed{V_P = a\,D_P^3}$

**(vii) Sauter Mean Diameter: [S.M.D.]**

- It is a common measure in fluid dynamic as a way to estimate the average particle size.
- It is defined as the diameter of a sphere that has the same volume/surface area ratio as the particle of interest.
- Sauter mean diameter is typically defined in terms of

surface dia, $\boxed{d_s = \sqrt{\frac{A_P}{\pi}}}$ and

Volume diameter, $\boxed{d_V = \left(\frac{6V_P}{\pi}\right)^{\frac{1}{3}}}$

where, $A_P$ and $V_P$ are the surface area and volume of particle.

- S.M.D. for a given particle is

$$\text{S.D.} = \text{D}[3, 2] = d_{32} = \frac{d_{\text{V}}^3}{d_s^2}$$

If actual surface area $\text{A}_{\text{P}}$ and volume $\text{V}_{\text{P}}$ of the particle are known then equation simplifies as:

$$\frac{\text{V}_{\text{P}}}{\text{A}_{\text{P}}} = \frac{\frac{4}{3}\pi\left(\frac{d_{32}}{2}\right)^3}{4\pi\left(\frac{d_{32}}{2}\right)^2} = \frac{\left(\frac{d_{32}}{2}\right)^3}{3\left(\frac{d_{32}}{2}\right)^2} = \frac{d_{32}}{6}$$

$$\boxed{d_{32} = 6\frac{\text{V}_{\text{P}}}{\text{A}_{\text{P}}}}$$

- S.M.D. is especially important in calculation where the active surface area is important. Such area included catalysis and application in fuel combustion.

**Sieving & Screening:**

- Sieving or screening is a method of separating a mixture of particle into two or more size fraction. The over size materials are trapped above the screen while under size material can pass through the screen.
- Screen can be used in stack to divide sample into various size fractions and hence determine particle size distribution.
- Screen are usually used for large particle sized material *i.e.*, greater than approximately. $50\,\mu\text{m}$ (0.050 mm).
- Two scale that are used to classify particle size are U.S. Sieve series and Taylor's equivalent.
- Taylor's equivalent screen sometimes called **Taylor's standard Sieve Series.**

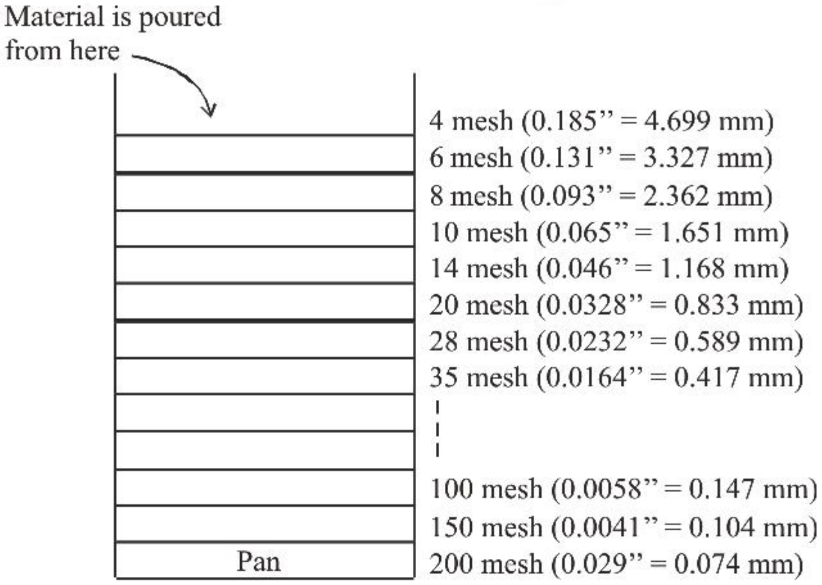
  In Tyler standard screen series

  * Area of openings in any one screen in series is exactly twice that of the openings in next smaller screen.

  * Ratio of actual mesh dimensions in any screen to that of next smaller screen is $\sqrt{2}$ .
- Mesh number of system is a measure of how many opening these are per linear inch in a screen.
- Material that pass through the screen is called the minus (–) material or undersize and the material that is retained on the screen is called (+) plus material or the over size.
- A screen can be called an open container usually cylindrical with uniformly spaced opening at the base. It is normally made of wire mesh cloth, the wire diameter and the interspacing between wire being

accurately specified. The opening are commonly square. The size of the square opening is called the aperture size of screen.

- Screen are usually designated by their mesh no. The mesh number indicate the no. of aperture per linear length.
- For example a screen having 10 square opening per cm may called a 10 mesh screen and in that case aperture size of screen will be (0.1 cm wire dia). Clearly higher the mesh no. smaller will be the size of aperture.
- For example a 200 mesh screen will have a very small aperture width, whereas a 20 mesh screen will have a large aperture size.
- Standard screens have opening from 4inch to 400 mesh size
- Cut diameter = Mesh opening of screen



- The ratio of area of opening of the up:

$$\boxed{\frac{A_1}{A_2}=\frac{2}{1}}$$

- The ratio of dimensions of the up:

$$\frac{D_1}{D_2}=\frac{\sqrt{2}}{1}$$

Example:

$$D_{P_{n-1}} = 4\sqrt{2}$$

$$D_{P_n} = 4$$

$$\frac{D_{P_{n-1}}}{D_{P_n}} = \frac{4\sqrt{2}}{4} = \frac{\sqrt{2}}{1}$$

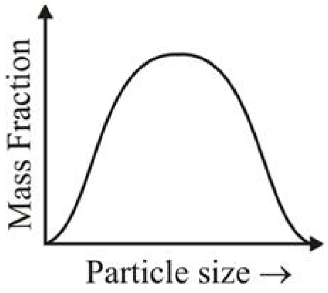
**Screen Analysis**

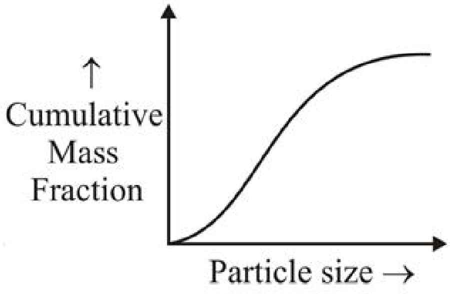
Mixture of particles having various sizes and densities is sorted into fractions, each of constant density and approx constant size. Information from such a particle size analysis is tabulated by two warps:

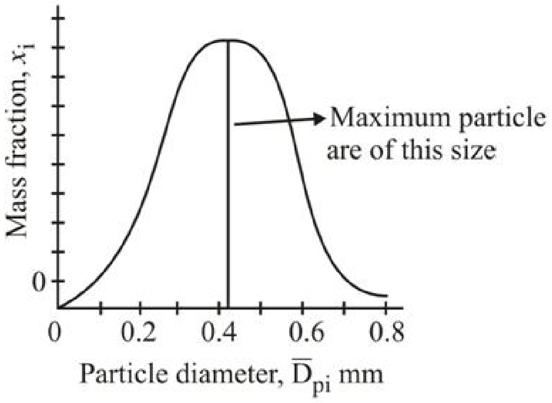
1. **Differential Analysis:**

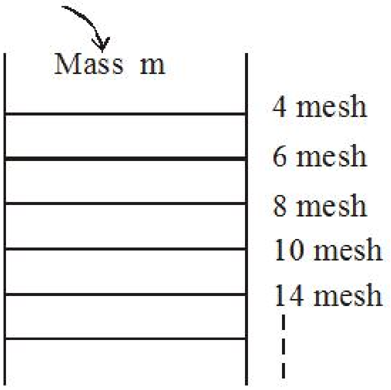
2. **Cumulative Analysis:**

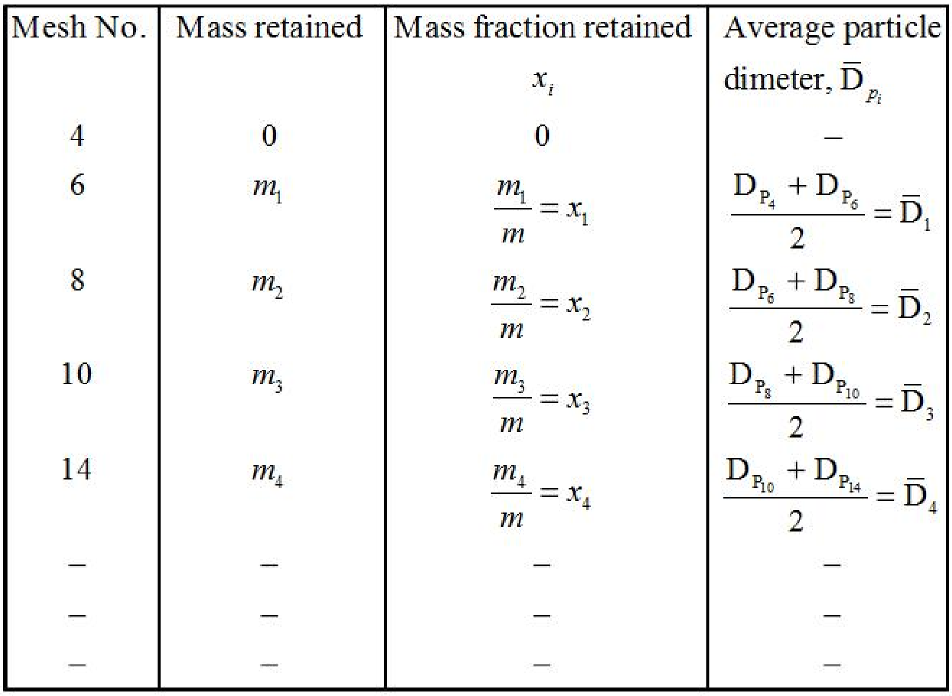
**Differential Analysis:** When particle size analysis is tabulated to show mass fraction in each size increment as a function of the average particle size in the increment. An analysis tabulated in this way is called a differential analysis.





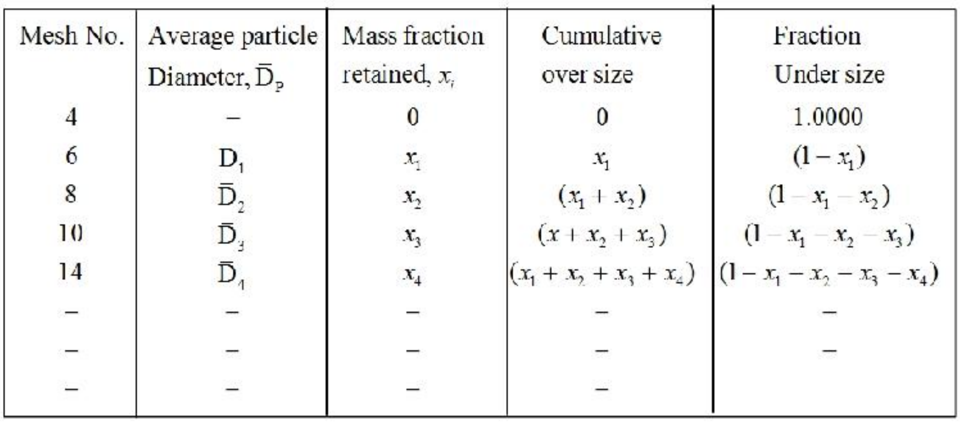






| Mesh No. | Mass retained | Mass fraction retained $x_i$ | Average particle dimeter, $\bar{D}_{p_i}$ |
|---|---|---|---|
| 4 | 0 | 0 | – |
| 6 | $m_1$ | $\frac{m_1}{m} = x_1$ | $\frac{D_{P_4} + D_{P_6}}{2} = \bar{D}_1$ |
| 8 | $m_2$ | $\frac{m_2}{m} = x_2$ | $\frac{D_{P_6} + D_{P_8}}{2} = \bar{D}_2$ |
| 10 | $m_3$ | $\frac{m_3}{m} = x_3$ | $\frac{D_{P_8} + D_{P_{10}}}{2} = \bar{D}_3$ |
| 14 | $m_4$ | $\frac{m_4}{m} = x_4$ | $\frac{D_{P_{10}} + D_{P_{14}}}{2} = \bar{D}_4$ |
| – | – | – | – |
| – | – | – | – |
| – | – | – | – |

**Cumulative Screen Analysis:** It obtained adding consequently the indivisual increments starting with that containing the smallest particle and plotted the cumulative sum aginst the maximum particle dia in the increments.



| Mesh No. | Average particle Diameter, $\bar{D}_P$ | Mass fraction retained, $x_i$ | Cumulative over size | Fraction Under size |
|---|---|---|---|---|
| 4 | – | 0 | 0 | 1.0000 |
| 6 | $D_1$ | $x_1$ | $x_1$ | $(1 - x_1)$ |
| 8 | $\bar{D}_2$ | $x_2$ | $(x_1 + x_2)$ | $(1 - x_1 - x_2)$ |
| 10 | $\bar{D}_3$ | $x_3$ | $(x + x_2 + x_3)$ | $(1 - x_1 - x_2 - x_3)$ |
| 14 | $\bar{D}_4$ | $x_4$ | $(x_1 + x_2 + x_3 + x_4)$ | $(1 - x_1 - x_2 - x_3 - x_4)$ |
| – | – | – | – | – |
| – | – | – | – | – |
| – | – | – | – | |

- Notation (150/200) or (–150 + 200) means that particles pass through the 150 – Mesh screen but are retained on the 200 – Mesh screen.

**Note:** When cumulative analysis is used, the assumption that all particles in a single fraction are equal in size is not needed.

# IMPORTANT KEY TO REMEMBER

**1.** Sphericity $= \boxed{\phi_s = \dfrac{\text{Surface to volume surface to volume ratio of sphere Deq}}{\text{Surface to volume ratio of particle}}}$

$$\boxed{\phi_s = \frac{6/D_p}{S_p/V_p}}$$

**2.** Specific surface of mixture

$$S_m = \frac{\text{Total surface area of all fraction}}{\text{Total mass of mixture}}$$

**3.** Total surface Area of particle

$$\boxed{A = \frac{6m}{\phi_s \rho_p D_p}}$$

**4.** Specific surface Area of mixture:

$$A_w = \frac{6}{\phi_s \rho_p} \sum_{i=1}^{n} \frac{x_i}{D_{pi}}$$

**5.** Volume surface mean Diameter $(\overline{D}_s) = \dfrac{1}{\sum_{i=1}^{n} \left( \dfrac{x_i}{D_{pi}} \right)}$

**6.** Mass mean Diameter $(\overline{D}_w) = \sum_{i=1}^{n} x_i \overline{D}_{pi}$

**7.** Volume mean diameter $\overline{D}_v = \left[ \dfrac{1}{\sum_{i=1}^{n} \left( \dfrac{x_i}{\overline{D}_{pi}} \right)} \right]^{1/3}$

**8.** The ratio of dimensions of the upper screen to the next screen is

$$\frac{D_1}{D_2} = \frac{\sqrt{2}}{1}$$

**9.** The ratio of area of the upper screen to the next screen is:

$$\frac{A_1}{A_2} = \frac{2}{1}$$

## NUMERICAL

**1.** The screen analysis shown below applies to a sample of crushed quartz. The density of the particles is $0.00265\ \text{gm/mm}^3$, and the shape factors are $a = 2$ and $\phi_s = 0.571$. For the material between 4-mesh and 200 mesh in particle size. Calculate.

(*a*) The specific surface area in $\text{mm}^2/\text{gm}$, $A_w$ :

(*b*) No. of particles/gm, $N_w$;

(*c*) Volume surface mean diameter, $\bar{D}_s$;

(*d*) Mass mean diameter, $\bar{D}_w$;

(*e*) Volume mean diameter, $\bar{D}_v$;

(*f*) Number of particles for the 150/200 – mesh increment, $N_i$;

(*g*) What fraction of the total number of particles are in the 150/200-mesh increment?

| Mesh No. | Screen Opening $D_{P_i}$, mm | Mass fraction retained, $x_i$ (Total mass = 1 gm) | Average particle diameter, $\bar{D}_{P_i}$, mm | Cumulative screen analysis (over size) $(x_1 + x_2)$ | $\frac{x_i}{\bar{D}_{P_i}}$ | $\bar{D}^3_{P_i}$ | $\frac{x_i}{\bar{D}^3_{P_i}}$ |
|---|---|---|---|---|---|---|---|
| 4 | 4.699 | 0.0000 | – | 0.0000 | – | – | – |
| 6 | 3.367 | 0.0251 | 4.013 | 0.0251 | 0.0063 | 64.6260 | 0.00036 |
| 8 | 2.362 | 0.1250 | 2.845 | 0.1501 | 0.0439 | 23.0275 | 0.0054 |
| 10 | 1.651 | 0.3207 | 2.007 | 0.4708 | 0.1598 | 8.0843 | 0.0396 |
| 14 | 1.158 | 0.2570 | 1.409 | 0.7278 | 0.1824 | 2.7973 | 0.0918 |
| 20 | 0.1333 | 0.1590 | 1.001 | 0.8868 | 0.1588 | 1.0030 | 0.158 |
| 28 | 0.289 | 0.0538 | 0.711 | 0.9406 | 0.0757 | 0.3594 | 0.149 |
| 35 | 0.417 | 0.0210 | 0.503 | 0.9616 | 0.0417 | 0.1273 | 0.165 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| 48 | 0.295 | 0.0102 | 0.356 | 0.9718 | 0.0286 | 0.0450 | 0.221 |
| 65 | 0.208 | 0.0077 | 0.252 | 0.9795 | 0.0306 | 0.0160 | 0.48 |
| 100 | 0.147 | 0.0058 | 0.178 | 0.9853 | 0.0326 | 0.005639 | 1.02 |
| 150 | 0.101 | 0.0041 | 0.126 | 0.9894 | 0.0325 | 0.002 | 2.04 |
| 200 | 0.074 | 0.0031 | 0.089 | 0.9925 | 0.0348 | 0.0007 | 4.397 |
| PAN | – | 0.0075 | 0.037 | 1.0000 | 0.2027 | 0.00005 | 148.07 |

$$\Sigma \frac{x_i}{\bar{D}_{P_i}} = 0.8277 \qquad \Sigma \frac{x_i}{D^3_{P_i}} = 8.727$$

(*a*) Specific surface area, $A_w = \dfrac{6}{\phi_s \rho_P} \sum_{i=1}^{n} \dfrac{x_i}{\bar{D}_{P_i}}$

$$= \frac{6}{(0.571)\,(0.00265)} \times \left(\frac{0.8277}{1-0.0075}\right) = 3306.8 \text{ mm}^2/\text{gm}$$

(*b*) Number of particle per gm,

$$N_w = \frac{1}{a\rho_P} \sum_{i=1}^{n} \frac{x_i}{D^3_{P_i}} = \frac{1}{2(0.00265)} \times \frac{(8.7931)}{(1-0.0075)} = 1671.6 \text{ Particles/gm}$$

(*c*) Volume surface mean diameter:

$$\bar{D}_s = \frac{1}{\sum_{i=1}^{n} \frac{x_i}{\bar{D}_{P_i}}} = \frac{1}{0.8277} = 1.208 \text{ mm}$$

(*d*) Mass mean diameter, $\bar{D}_w = \Sigma x_i \,\bar{D}_{P_i} = 1.677$ mm

(*e*) Volume mean diameter, $\bar{D}_v = \left[\dfrac{1}{\sum_{i=1}^{n} \frac{x_i}{D^3_{P_i}}}\right]^{\frac{1}{3}} = \left[\dfrac{1}{8.7931}\right]^{\frac{1}{3}} = 0.4845$ mm

(*f*) The number of particle in the $\dfrac{150}{200}$ mesh increment:

$$N_i = \frac{1}{a\rho_P} \sum_{i=1}^{n} \frac{x_i}{\bar{D}^3_{P_i}}$$

$$= \frac{1}{2(0.00265)} \times 4.397 = 830 \text{ particles/gm}$$

(*g*) Fraction of total number of particles in the $\dfrac{150}{200}$ mesh increment:

$$= \frac{830}{1671.6} = 0.4965 \quad \text{or} \quad 49.65\%$$

# Sample Study Materials