MECHANICAL OPERATION

CHEMICAL: GATE & PSUs

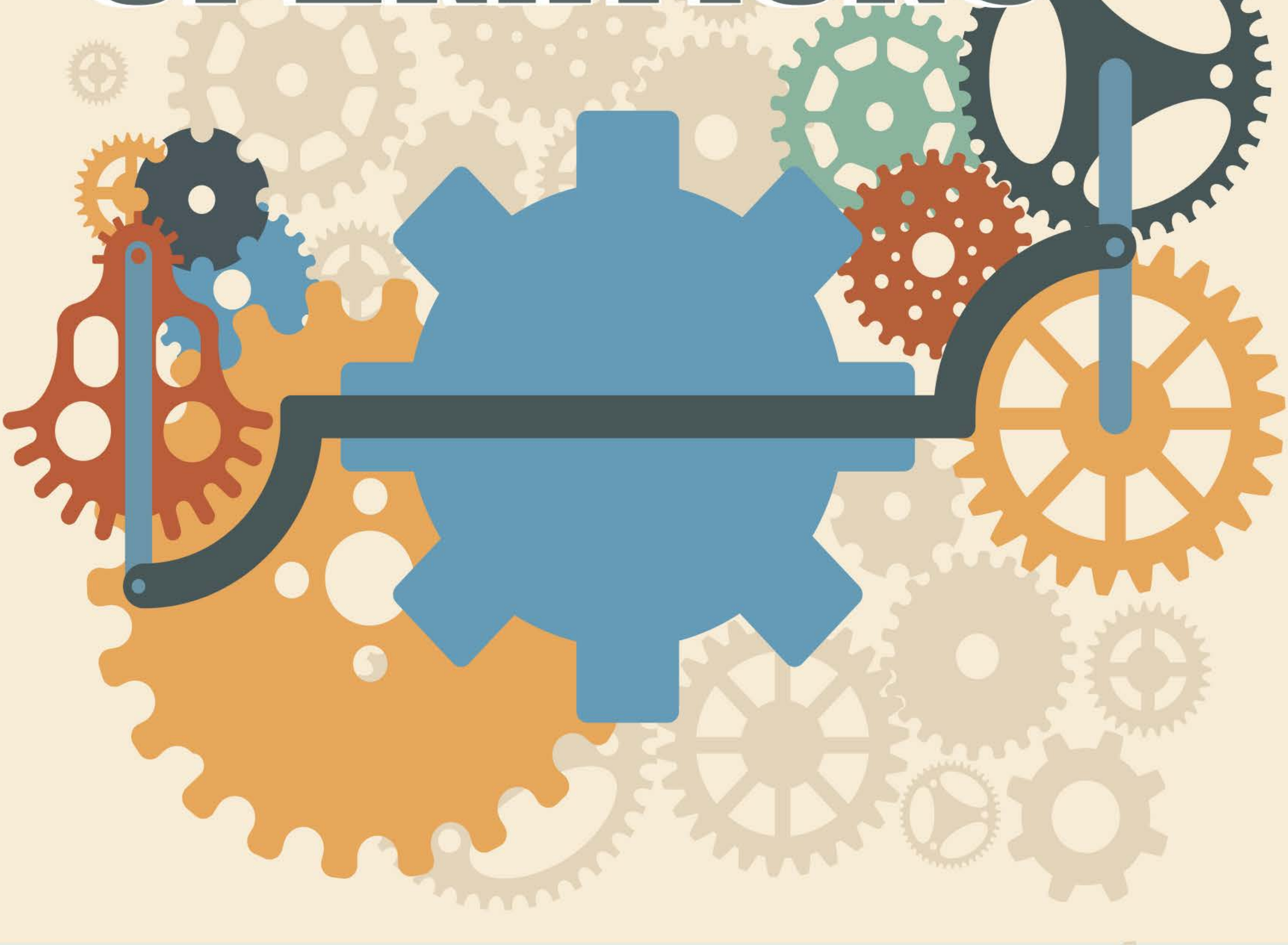
ENGINEERS INSTITUTE OF INDIA

India's Best Institute for CHEMICAL ENGINEERING

CHEMICAL ENGINEERING

REVISED AS PER GATE

MECHANICAL OPERATIONS



ENGINEERS INSTITUTE OF INDIA

India's Best Institute for CHEMICAL ENGINEERING

CHEMICAL ENGINEERING

Revised as Per New GATE Syllabus

STUDY MATERIAL

MECHANICAL OPERATION


ENGINEERS
INSTITUTE OF INDIA
Unparallel Results+UnMatched Quality
GATE-2024 Chemical Engineering
6 Rank in Top 10
3 Rank
KRISH PARADVA
4 Rank
SMIT MAGANLAL VAGADIYA
5 Rank
TUTHIKA MAHESH ANIL
6 Rank
PARAM AGRAHARI
6 Rank
DEBARGHYA CHAKRABARTI
9 Rank
KEVAL VASOYA
11 Rank
PRAVEEN KUMAR YADAV
15 Rank
BRANZIL
16 Rank
NISTHA ROY
39 Rank
MANSUR MUSTAFA
42 Rank
NITIN SINGH
52 Rank
NISHANT PATHAK
and many more ....

Mechanical Operation : Marking Analysis in GATE (2010 to 2023)			
2024	0	1×2	**Total-2 Marks**
2023	1×1	2×2	**Total-5 Marks**

Topic	2022	21	20	19	18	17	16	15	14	13	12	11	10	9	8	7	Gross
Particle size and shape				1													1
Particle size distribution						1		1		1						1	4
Size reduction and classification of solid particles					2	1			1	1			1		1	1	8
Free and Hindered Settling		1	1		1	1	1	1				1	1	1	1		10
Centrifuge and cyclones							1			1		1				1	4
Thickening and classification					1					1							2
Filtration	1		1					1							1	1	5
Agitation and mixing				1		1	1		1		1			1	1		7
Fluidization		1	1					1			1	2	1			2	
Conveying of solids																1	1
Gross	1	2	3	2	4	4	3	4	2	4	2	4	3	2	4	7	

List of Topics in GATE 2024 paper from Mechanical Operation
Terminal settling velocity

Follow these tips to ace the exam:

- Micronotes are a must for multiple revisions.
- Memorize formulae by heart.
- Practice hard.

  Remember this quote –

  “I fear not the man who has practiced 10,000 kicks once, but I fear the man who has practiced one kick 10,000 times.”

Bruce Lee

CONTENTS

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:

Mechanical separation is achieved on the basis of differences in physical properties such as size, shape, density, viscosity.

Mechanical operations are intermediate operations in the industries between two transport processes, like sieving of wheat flour in making of bread, refined flour and semolina; crushing and grinding of metal ores before processing chemical extraction; conveying of wax blocks from bottom of distillation column to storage; filtration of fruit pulp in juice industry; fluidization of urea particles in prilling tower etc.

1. Mechanical Separation

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

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

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.

Mechanical processes include solids transportation, crushing and pulverization, screening and sieving

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

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, ϕ_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, ϕ_S is between 0.6 and 0.8. For particles rounded by abrasion, ϕ_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)

Definition in Particle size analysis:

S.No.	Quantity	Definition	Formula	Index
1.	Sphericity	Ratio of surface area of this sphere having the same volume as the particle to the actual surface area of particle	$\phi_s = \frac{6V_P}{D_P S_P}$ for sphere $\phi_s = 1.0$	V_P = Volume of particle. D_P = Diameter of particle. S_P = Surface area of particle.
2.	Surface shape factor	Reciprocal of Sphericity	$\frac{1}{\phi_s} = \frac{D_P S_P}{6V_P}$	ϕ_s = Sphericity
3.	Volume shape factor	Ratio of volume of particle to that of equivalent spherical volume.	$a = \frac{V_P}{D_{eq}^3}$	D_{eq} = Equivalent diameter
4.	Total surface area of particles in sample	Number of particles × surface area of one particle	$A_T = N \times S_P$ $A_T = \frac{6M}{\rho_P D_{eq} \delta_s}$	
5.	Number of particle in sample	$\frac{\text{Total mass of sample}}{(\text{Density of particle} \times \text{Volume of Particle})}$	$N = \frac{M}{\rho_P V_P}$	
6.	Specific surface area	$\frac{\text{Total surface area}}{\text{Total mass of sample}}$	$A_{ss} = \frac{6}{\rho_P \phi_s} \sum \frac{x_i}{D_{Pi}}$ $A_{ss} = \frac{A_T}{M}$	
7.	Mass mean Diameter	Sum of product of mass fraction and diameter of each particle	$\overline{D}_M = \sum x_i D_{Pi}$	
8.	Volume-surface mean diameter		$\overline{D}_s = \frac{1}{\sum \frac{x_i}{\overline{D}_{Pi}}}$ $\overline{D}_s = \frac{1}{\int \frac{x_i}{D_{Pi}}}$	

IMPORTANT KEY TO REMEMBER

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

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

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

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

4. Specific surface Area of mixture:

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

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

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)** $(x_1 + x_2)$	$\frac{x_i}{\bar{D}_{P_i}}$	$\bar{D}_{P_i}^3$	$\frac{x_i}{\bar{D}_{P_i}^3}$
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	0.844	0.1590	1.001	0.8868	0.1588	1.0030	0.158
28	0.578	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

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

CHAPTER-3
STORAGE AND TRANSPORTATION OF SOLIDS

Bulk Storage:

Coarse solids such as S, sand gravel and coal are stored outside in large piles, unprotected from the weather, when hundred or thousand of ton of material involved this is the most economical methods. The solids are removed from the pile by drag line or tractor shovel and delivered to a conveyor or to the process. Outdoor storage can lead to environmental problem such as dusting or leaching of soluble material from pile. Dusting may necessitate a protective cover to some kind for the stored solid. Leaching can be controlled by covering the pile or by locating if in a shallow basin with an impervious floor from which runoff may be safely withdrawn.

Bin Storage:

Solids that are too valuable or soluble to expose in outdoor piles are stored in bins, hopper or silos. These are cylindrical or rectangular vessel of concrete or metal. A silo is tall and relatively small in diameter. A bin is not so tall and usually fairly wide. A hopper is a small vessel with sloping bottom, for temporary storage before feeding solids to a process. All these container are loaded from the top by some kind of elevator, discharging is done from the bottom. Solids are stored indores in storage bins or silos or bunkers. They are usually made of metal, reinforced concrete or wood bins for abrasive materials are linked with replaceable steel plates or special wear resistant glass. Heat insulated or heated bins are employed in cases when the delivered materials are wet or frozen. Every storage bin usually has two sections such as a rectangular, prismatic or cylindrical upper section and a pyramidal or conical lower section (narrowing to discharge opening). Bins are charged through the open top or charging holes in top cover and discharged usually through opening in bottom or bottom portion of side walls. The shape of storage bin should be such that it ensures almost complete loading and unloading without the formation of what are called the dead zones. (These are zones when the material is retained and cannot flow by gravity to discharge opening.) Also the bin shape should be such that it prevents bridging of material inside the bin which otherwise disturb or even block the discharge.

Pressure in Bins and Silos:

When granular solids are placed in a bin or silo the lateral pressure exerted on the walls at any point is less than predicted from the head of material above that point. Further more than usually is friction between the wall and the solid grain and because of the inter locking of the particles the effect of this

61C, Kalu Sarai Hauz Khas, New Delhi-110016. Ph. 9990357855, 9990657855 www.engineersinstitute.com

where, D_P is the particle size.

K_b is a constant which depends on material and equipment.

Work Index: (*i*) Work Index (W_i) is defined as the amount of gross energy in kilowatt hours per ton of feed material required to reduce a very large feed to such a size that 80 percent of product passes through a 100 μm screen.

(*ii*) Mathematically relation between K_b and W_i is given as

$$\boxed{K_b = 0.3162\, W_i}$$

(*iii*) If 80% of the feed passes through a mesh size of D_{Pa} mm and 80 percent of the product passes through a mesh size of D_{Pb}, then

$$\frac{P}{\dot{m}} = 0.3162\, W_i \left(\frac{1}{\sqrt{D_{Pb}}} - \frac{1}{\sqrt{D_{Pa}}} \right)$$

where, D_{Pa} and D_{Pb} are the particle size of feed and product in mm respectively.

Note:

(i) For dry grinding, power calculated from Bond's law is multiplied by 4/3

(ii) K_r,K_k, K_b are constants for same machine and feed material

(iii) General (differential) equation of power required in crushing or grinding.

$$\boxed{d\left(\frac{P}{m}\right) = -K\frac{dD}{D^n}}$$

For kick's law, n = 1

For Rittinger's law n = 2

For Bond's law, n = 1.5

Question: Which of the following statements is/are CORRECT?

(A) Bond number includes surface tension.

(B) Jakob number includes latent heat.

(C) Prandtl number includes liquid-vapor density difference.

(D) Biot number includes gravity. **GATE-2023 (2-Maks)**

Answer : A , B

Bond number is a ratio between gravitional forces and surface tension forces in a system.

Jalcob number is a ratio between sensible heat to latent heat absorbed (or released) during the phase change process.

IMPORTANT KEY POINTS TO REMEMBER

1. Combined overall efficiency: $$E = \frac{(x_F - x_B).(x_D - x_F)x_D(1-x_B)}{(x_D - x_B)^2(1-x_F)x_F}$$

2. **Crushing efficiency:** $$\eta_c = \frac{e_s(A_b - A_a)}{W_h}$$

3. **Rittinger's Law:** $$\frac{P}{\dot{m}} = K_r\left[\frac{1}{\overline{D}_{sb}} - \frac{1}{\overline{D}_{sa}}\right]$$

4. **Kick's Law:** $$\frac{P}{\dot{m}} = K_K \ln\frac{D_f}{D_p}$$

5. **Work Index:** $$K_b = 0.3162W_i$$

6. Bond's Law: $$\frac{P}{\dot{m}} = 0.3162W_i\left(\frac{1}{\sqrt{D_{Pb}}} - \frac{1}{\sqrt{D_{Pa}}}\right)$$

CHAPTER-7
SIZE SEPARATION

- Particles heavier than the suspending fluid may be removed from a gas or liquid in a settling tank in which fluid velocity is low and particle have sufficient time to settle out.
- Clarifier is a device which removes all the particle from liquid. Clarifier is settler.
- Classifier is a device which separates the solid into two or more fraction.
- Sorting classifier is a device which separate different density particle.
- Two principal separation methods are: Sink and Float and differential settling.

Sink and Float Methods:

(*i*) This method is also called heavy fluid separation. Sink and float methods based on liquid sorting medium density of which is intermediate between that of light material and that of heavy.

(*ii*) In this method, principle separation depends only on density differences of two substances and is independent of particle size.

Differential Settling Methods:

(*i*) Separation of solid particle into several size fraction based on the difference in terminal velocity in a medium is called differential settling method.

(*ii*) Suppose two different material A and B are present in a solid particulate mixture with A more dense than B.

For the same settling velocity the ratio of diameter of material A and B is given by

$$\boxed{\frac{D_{PA}}{D_{PB}} = \left[\frac{\rho_{PB} - \rho}{\rho_{PA} - \rho}\right]^n}$$

where, n = 0.5 for stoke's law regime

n = 1 for Newton's law regime

(*iii*) Density of medium is less than that either substances.

(*iv*) The disadvantage of differential settling method is that since the mixture of material to be separated cover a range of particle size, light particle settle at the same rate as the smaller, heavy one and mixed fraction is obtained.

Question: A large tank is filled with water $(\text{density} = 1\ \text{g.cm}^{-3})$ upto a height of 5 m. A 100 μm diameter solid spherical particle $(\text{density} = 0.8\ \text{g.cm}^{-3})$ is released at the bottom of the tank. The particle attains its terminal velocity (v_t) after traveling to a certain height in the tank. Use acceleration due to gravity as $10\ \text{m.s}^{-2}$ and water viscosity as 10^{-3} Pa.s. Neglect wall effects on the particle. If Stokes law is applicable, the absolute value of v_t (in mm.s^{-1}) is ____________ (rounded off to two decimal places). **GATE-2023 : (2-Marks)**

Answer: 1.11

Apply stoke's law

$$V_t = \frac{g d_P^2 (\rho_P - \rho)}{18\mu}$$

$$= \frac{9.81 \times (100 \times 10^{-6})^2 (1000 - 800)}{18 \times 10^{-3}} = 1.1\ \text{mm/s}$$

IMPATIENT KEY POINT TO REMEMBER

1. Differential settling method:

$$\frac{D_{PA}}{D_{PB}} = \left[\frac{\rho_{PB} - \rho}{\rho_{PA} - \rho}\right]^n$$

n = 0.5 (For Stoke's law)

n = 1 (For Newton's law)

2. Richardson Zaki correlation:

$$\frac{V}{V_t} = \varepsilon^n$$

3. Free Settling:

(a) Laminar flow: $V_t = K_i D^2$

(b) **Turbulent flow:** $V_t = K_2 D^{0.5}$

4. Cyclone sepration factor:

$$\frac{f_c}{f_g} = \frac{u_{\tan}^2}{r.g}$$

5. Terminal settling velocity

(a) Laminar settling $V_t = \dfrac{D^2(\rho_s - \rho)g}{18\mu}$

(b) Turbulent regime $V_t = \sqrt{\dfrac{4D(\rho_s - \rho)g}{3C_D\rho}}$

