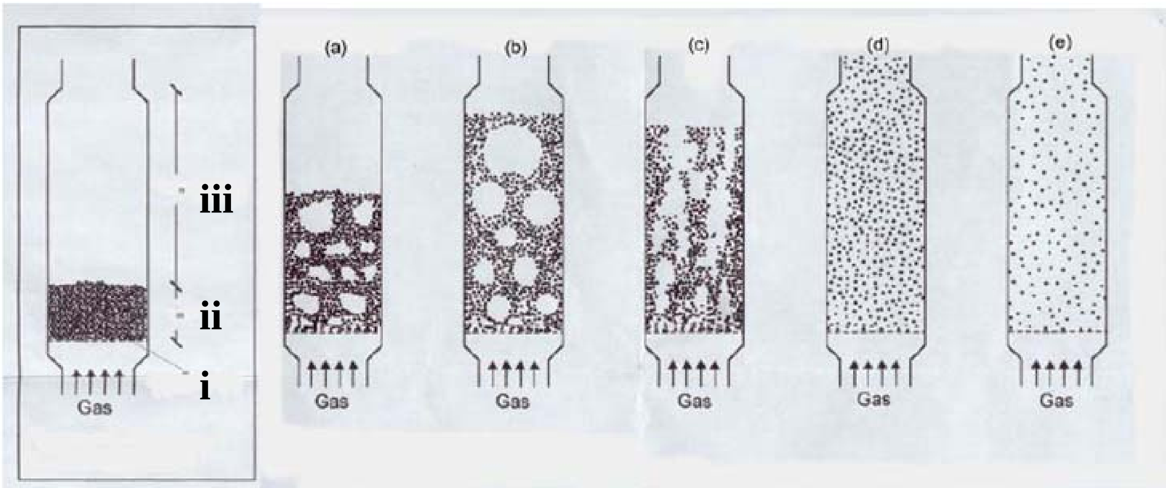
Problem 1.

For each column given below, give its corresponding name that is normally used (i to iii) and classify the hydrodynamic regimes (a through e) from the following choice of words (arbitrarily given):

(1) Fast fluidization	(2) Bed
(3) Slugging	(4) Distributor
(5) Bubbling	(6) Freeboard
(7) Turbulent	(8) Pneumatic Transport



Problem 2.

Several mean particle diameters are commonly used, such as the arithmetic mean, the volume mean and the surface area mean. Different diameters are obtained by weighted averaging, putting emphases on one or more of the particle properties. The most useful and frequently used mean size is the mean surface-to-volume diameter or the Sauter mean diameter, defined as the diameter of the particle having the same surface area-to-volume ratio as that of all particles added together. Assuming that x_i is the weight fraction of particles having a diameter of d_{pi}, show that the Sauter mean can be obtained by:

$$\overline{d_p} = \frac{1}{\sum_{i=1}^{n} \frac{x_i}{d_{pi}}}$$

Elaborate on why this is the most appropriate way to obtain a representative mean particle size for fluidized bed reactors.

Problem 3.

Given the following for a bubbling fluidized bed boiler:

- Flue gas mass flow rate: 15.8 kg/s
- Primary air is 60% of the combustion air and is fed under the distributor
- Molecular mass of flue gas, n: 29.5 kg/kmol
- Bed temperature: 850°C
- Bed pressure is 1.013 bar
- Mean diameter of particles in bed: 1.2 mm
- Minimum fluidization velocity at bed temperature: 0,44 m/s
- Fluidizing velocity in the bed should be 3 to 4 times the minimum fluidization velocity
- Gas constant: 8.314x10-2 m3bar/kmol K

Find the cross-sectional area of bed.

Problem 4.

A fluidized bed column of 0.3 m in diameter and 4 m in height with a perforated distributor plate consisting of 300 holes of 3 mm in diameter is charged with 40 kg of FCC particles. Particle properties are 60 μm in mean size, particle density of 1600 kg/m^3 and bulk density of 850 kg/m^3.

1) If the system is fluidized with air at ambient conditions and at a superficial gas velocity of 0.5 m/s, calculate the overall bed expansion based on ideal two-phase theory. Furthermore, check whether the bed is already in slugging condition. If so, the appropriate equations should be used to calculate the bed expansion.

2) Another way to estimate bed expansion is to calculate the bubbles size at 0.4 times the bed height and use that bubbles size as an average size to calculate bubble rise velocity and bubble holdup. Employ this method to re-calculated the total bed expansion for the same particles given above and comment.

3) At superficial gas velocity of 0.3 m/s, the total bed expansion is 30% and the dense phase expansion is 4%. Assuming that the modified two-phase theory (with a correction factor Y=0.8) applies, calculate the following:

   a. Average bubble fraction, ε_B
   b. Dense phase voidage, ε_D
   c. Superficial gas velocity in the dense phase, U_D
   d. Interstitial gas velocity in the dense phase, u_D

   Note: $u_D = \dfrac{U_D}{\varepsilon_D}$

   For ideal two-phase flow, $U_D = U_{mf}$; $\varepsilon_D = \varepsilon_{mf}$

Problem 5

a. From a one-particle settling-test: Given are the experimentally determined settling velocity $v_s = 0.0024\,\mathrm{m/s}$, the liquid viscosity $\eta = 1.5\cdot 10^{-4}\,\mathrm{kg/sm}$, the fluid density $\rho_f = 1.1\cdot 10^3\,\mathrm{kg/m^3}$, the solid density $\rho_s = 2.4\cdot 10^3\,\mathrm{kg/m^3}$, and g=10m/s^2.
Compute the equivalent settling diameter x, that is the diameter a sphere should have with these material parameters, assuming laminar (Stokes) flow. Is the laminar assumption consistent with the result?

b. Perform the same x-calculation with particles that fall ten times (or 100 times) faster. In which flow regimes are these particle types?

c. Write down force equilibrium (symbols/formulas, no numbers) between gravity, buoyancy, and drag in the case of the terminal settling velocity (no acceleration).
Extract the drag coefficient from this equation. Compute the (constant) dimensionless number that does not contain the size (combine Re and C_D such that the size disappears).
Relate (for the above values 2.a) the drag coefficient to the empirical drag coefficient given by the relation $C_D = \dfrac{24}{\mathrm{Re}} + 0.44$, with the Reynolds number $\mathrm{Re} = \dfrac{\rho_f x v_s}{\eta}$.
Obtain an expression for x in the Stokes limit (analytical) and solve the problem graphical for arbitrary Re.