UNIVERSITY COLLEGE LONDON

University of London

EXAMINATION FOR INTERNAL STUDENTS

For The Following Qualification:-

M.Eng.

Chemical Eng E864: Fluid-particle Systems

COURSE CODE : **CENGE864**

UNIT VALUE : **0.50**

DATE : **06-MAY-03**

TIME : **10.00**

TIME ALLOWED : **3 Hours**

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Answer ***FOUR QUESTIONS. Answer at least ONE question from each section.***
Only the first FOUR answers will be marked.
ALL questions carry a total of ***20 MARKS*** *each, distributed as shown* [ ]

Section A

1.

(i) Derive an overall, steady-state force balance for a control volume of a fluidised bed and use it to obtain an expression for the fluid pressure drop Δp and the *unrecoverable pressure loss* ΔP across the control volume [4]

Use this to show that the unrecoverable pressure loss *across the whole bed*, ΔP_B, remains independent of the fluid velocity and hence sketch the theoretical relationship between ΔP_B and volumetric flux of the fluid, u, starting at $u = 0$. Describe how this compares with experimental observations giving reasons for any differences. [3]

(ii) Show that the effect of the fluid pressure gradient gives rise to the following expression for the effective weight w_e (weight minus buoyancy force) of a particle immersed in a fluidised bed:

$$w_e = V(\rho_p - \rho_f)g\varepsilon \,,$$

where V is the particle volume, ρ_p and ρ_f are the particle and fluid densities, and ε is the void fraction. [4]

(iii) Derive an expression for the expansion characteristics $\varepsilon(u)$, of a homogeneously fluidised bed on the basis of the following constitutive relation for the pressure drop through a bed of particles:

$$\Delta P = K u^a \varepsilon^b,$$

where K is a constant, u is the fluid flux, ε is the void fraction, and the parameters a and b depend on the particle Reynolds number. [7]

What do experimental measurements reveal about the values of a and b. [2]

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2.

(i) Describe carefully, with the aid of sketches, how a homogeneously fluidised bed responds to both a sudden increase and a sudden decrease in the fluid velocity. Hence confirm that the bed surface velocity, following such a change, may be assumed to travel at velocity $U_2 - U_1$, the difference in fluid fluxes after and before the flow rate change. State any simplifying assumptions that are made, and discuss practical limitations to the simple theory. [10]

(ii) Use the analysis of part (i) to evaluate the kinematic wave speed for a fluidised suspension in terms of the Richardson-Zaki parameter n. [4]

(iii) Discuss briefly the significance of the kinematic wave speed for the stability of the state of homogeneous fluidisation. [6]

Section B

3.

(i) Experiments have to be carried out to study elutriation (or carryover) of small spherical mono-size particles from a gas-fluidized bed. In order to identify the operative conditions in the fluid-bed, the particle terminal fall velocity, u_t, has to be determined.

The force balance on a particle, written as a function of the Reynolds and Archimedes dimensionless numbers, may be applied to give u_t.

$$C_D Re_t^2 = \frac{4}{3} Ar$$

where:

$$Ar = \frac{d_p^3 \rho_f (\rho_p - \rho_f) g}{\mu^2}$$

Assuming creeping flow regime, calculate the particle terminal fall velocity with:

d_p = particle diameter = 40 μm
ρ_p = particle density = 1400 kg m^{-3}
ρ_f = gas density = 1.22 kg m^{-3}
μ = gas viscosity = 1.8x10^{-5} kg m^{-1} s^{-1}
g = acceleration gravity = 9.81 m s^{-2}

[10]

(ii) Discuss the effect of increasing gas temperature and pressure on the calculation of the particle terminal fall velocity. [6]

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(iii) To avoid or reduce elutriation of particles from the fluidized bed, the operative gas velocity has to be kept between the minimum fluidization velocity, u_{mf}, and the particle terminal fall velocity, u_t. If the system of particles under investigation was not mono-size but contained a distribution of different sizes, which particle diameter should you use to calculate u_{mf} for the polydisperse system and which particle diameter should you use to calculate u_t so that elutriation is reduced.

[4]

4.

(i) Consider a fluidized bed of solids operated at constant temperature T_s. Hot fluidizing gas at temperature T_{gi} enters the bed, with $T_{gi}>T_s$. The expression for the distance "L_n" at which the gas-to-particle temperature difference falls by a factor "n" from its initial value is shown in Eq.(1):

$$L_n = -5.5\left[\frac{\ln n\, \mu^{1.3}\, d_p^{0.7}\, C_g}{u_{rel}^{0.3}\, \rho_g^{0.3}\, (1-\varepsilon) k_g}\right] \qquad (1)$$

Write the heat balance equation across an element of fluid-bed of height dL and show the derivation of Eq.(1). [14]

To this end, use the following information:

Assume the following boundary conditions: $T_g=T_{gi}$ at $L=0$; and denote with T_{ge} the temperature of the gas leaving the fluid-bed element, where $T_{ge}<T_{gi}$.

The surface area of solids per unit volume of bed S (m^{-1}) is expressed as:

$$S = \frac{6(1-\varepsilon)}{d_p}$$

The gas-to-particle heat transfer coefficient h_{gp} (W m^{-2} K^{-1}) is expressed as:

$$h_{gp} = \frac{0.03\, d_p^{0.3}\, \rho_g^{1.3}\, u_{rel}^{1.3}\, k_g}{\mu^{1.3}}$$

d_p = particle diameter (μm)
ρ_g = gas density (kg m^{-3})
μ = gas viscosity (N s m^{-2})
k_g = gas conductivity (W m^{-1} K^{-1})
C_g = specific heat capacity of the gas (J kg^{-1} K^{-1})
u_{rel} = gas-particle relative velocity (m s^{-1})
ε = fluid-bed voidage
ΔT_g = change in temperature of the gas flowing through the element of bed (K)
dL = element of bed dL deep and of unit cross section area (m)

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(ii) Using the equation derived for "L_n" (Eq.1) and the data given below, calculate the distance penetrated by the gas into a bed of constant temperature before the difference between its temperature and that of the bed solids is reduced by half. [6]

d_p = 300 μm
ρ_g = 1.2 kg m^{-3}
μ = 1.8×10^{-5} N s m^{-2}
k_g = 0.0262 W m^{-1} K^{-1}
C_g = 1005 J kg^{-1} K^{-1}
ε = 0.45
u_{mf} = minimum fluidization velocity = 0.10 m s^{-1}

Section C

5.

(i) Sketch the product CSD (crystal size distribution) from a continuous MSMPR (mixed-suspension, mixed-product-removal) crystallizer in terms of *population density* and *mass fraction.* [2]

(ii) State the *population balance* concept and show that the CSD from a continuous MSMPR crystallizer at steady-state may be expressed by:

$$n(L) = n^{\circ} \exp(-L / G\tau)$$

where L is the crystal size, G is the overall linear crystal growth rate and τ is the mean residence time in the vessel. State clearly any assumptions that you may make. [6]

(iii) The suspension density M_T in a continuous MSMPR crystallizer operated at steady-state is given by the equation:

$$M_T = 6 f_v \rho_c n^{\circ} (G\tau)^4$$

where f_v and ρ_c are the crystal volume shape factor and density respectively, n^O is the nuclei population density, G is the linear crystal growth rate and τ is the mean residence time within the crystallizer.

The CSD from an MSMPR crystallizer with a working volume of 1 m^3 operated with a magma density of 100kg crystals/m^3 slurry and a production rate of 1000kg crystals/hr has a Sauter mean size of 100 μm. Calculate:

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a) the linear crystal growth rate (m/s)
b) the population density of nuclei (#/m^4) and,
c) the nucleation rate (#/sm^3).

[Take the crystal volume shape factor to be 1.0 and the crystal density to be 2000 kg/m^3] [12]

6.

(i) Define the moments about the origin of the CSD (crystal size distribution) from a continuous MSMPR (mixed-suspension, mixed-product-removal) crystallizer and explain their physical significance. [8]

(ii) An MSMPR crystallizer is operated continuously at steady state. The suspension density M_T is given by:

$$M_T = 6 f_v \rho_c n^o (G\tau)^4$$

where f_v and ρ_c are the volume shape factor and crystal density respectively, n^o is the nuclei population density, B^o is the nucleation rate, G is the linear crystal growth rate and τ is the mean residence time within the crystallizer.

The crystal growth rate and nucleation rate B^o are found to be related by:

$$B^o \propto M_T G^2$$

Estimate the effect of decreasing the throughput of the crystallizer by 50% on:

a) the crystal growth rate (m/s)
b) the nucleation rate (#/sm^3), and
c) the dominant crystal size (μm)

You may assume that the suspension density is controlled to a constant value. [12]

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