UNIVERSITY COLLEGE LONDON

University of London

EXAMINATION FOR INTERNAL STUDENTS

For the following qualifications :-

M.Sc.

M11: Fluid Particle Systems

COURSE CODE	:	**CENG0M11**
DATE	:	**23-MAY-02**
TIME	:	**10.00**
TIME ALLOWED	:	**3 hours**

*Answer **FOUR** questions at least **ONE** from each section.*
***ALL** questions carry a total of **20** marks each, distributed as shown* [ ]

SECTION A

1. a) Describe the primary forces that act on a fluidized particle under conditions of equilibrium. [5]

b) Derive an expression relating the drag force acting on a fluidized particle, F_d, to the pressure loss in a bed of particles that is due to energy dissipation, ΔP. [4]

Use this expression to find the drag force on a particle in a fluidized-bed in which ΔP is given by:

$$\Delta P = 18\,\frac{u\mu L}{d^2}(1-\varepsilon)\varepsilon^{-4.8}$$ [1]

c) It is postulated that for viscous flow through a bed of spheres the expression for pressure loss due to frictional dissipation has the following form:

$$\Delta P \propto u\varepsilon^{-5}$$

Use this relation to derive an expression for the expansion characteristics, $u(\varepsilon)$, of a homogeneously fluidized bed. [10]

TURN OVER

2. a) Explain what you understand by the term "stability of the homogeneously expanded state" as applied to a fluidized bed. [6]

b) The following expression may be used to describe a void-fraction perturbation wave in a fluidized bed:

$$\varepsilon = Ae^{\alpha t}.e^{ik(z-vt)}$$

where A, v, k and α are the wave amplitude, velocity, number and growth rate, respectively ($k = 2\pi/\lambda$, where λ is the wavelength); ε is the void fraction perturbation; z and t are the distance and time variables.

Under what conditions does the above expression for ε describe homogeneous fluidization? [3]

c) An early formulation of the equations of change for fluidization leads, on linearisation, to the following partial differential equation for a small void-fraction perturbation, ε:

$$\frac{\partial^2 \varepsilon}{\partial t^2} + B\frac{\partial \varepsilon}{\partial t} + C\frac{\partial \varepsilon}{\partial z} = 0$$

where B and C are positive constants.

Find expressions for α and k for which the above partial differential equation is satisfied by the perturbation wave expression of section b). [7]

Hence show that this formulation cannot describe stable (homogeneous) fluidization. [4]

TURN OVER

SECTION B

3. a) A spherical solid material with the physical characteristics reported below is being investigated for the development of a new gas-fluidized bed process. In order to identify the operative conditions in the fluid-bed, the minimum fluidization velocity, u_{mf}, has to be determined.

The Ergun equation for pressure drop through packed beds of spherical particles may be applied to give u_{mf} as follows:

$$Ar = \frac{150\,(1-\varepsilon_{mf})}{\varepsilon_{mf}^3}\,\mathrm{Re}_{mf} + \frac{1.75}{\varepsilon_{mf}^3}\,\mathrm{Re}_{mf}^2$$

Where:

$$\mathrm{Re}_{mf} = \frac{\rho_f\, u_{mf}\, d_p}{\mu} \quad ; \quad Ar = \frac{d_p^3\, \rho_f(\rho_p - \rho_f)\, g}{\mu^2}$$

Calculate the minimum fluidization velocity with:

d_p = particle diameter = 50 μm
ρ_p = particle density = 1200 kg/m^3
ε_{mf} = voidage at minimum fluidization = 0.4
ρ_g = gas density = 1.22 kg/m^3
μ = gas viscosity = 1.8x10^{-5} kg/m s
acceleration gravity = 9.81 m/s^2 [13]

b) Using the Ergun equation, discuss the effect of increasing gas temperature on the minimum fluidization velocity of both small and large particles. [5]

c) Describe the four possible fluidization behaviours that a solid material may display, when fluidized with air at ambient conditions, according to the Geldart classification of powders. [2]

TURN OVER

4. A catalyst circulates between a cracking reactor in which the catalyst is partly deactivated and a regenerator in which the activity is fully restored. Assuming that the rate of catalyst deactivation is directly proportional to its present activity (ie deactivation is of the first order) and that the reactor is perfectly mixed derive an expression for the mean activity of the catalyst leaving the reactor in terms of the deactivation rate coefficient, k_a, the mass of catalyst in the reactor, W, and the solid circulation rate, F_s. [12]

Use this expression to calculate the circulation rate required to maintain the catalyst activity at not less than 1% of the activity of fresh material given that the catalyst half-life of activity is 1.5 s and the mass of catalyst in the reactor is 75 tonnes. [8]

TURN OVER

SECTION C

5. State the *population balance* concept and show that the crystal size distribution (CSD) from a continuous mixed-suspension, mixed-product-removal (MSMPR) crystallizer at steady-state may be expressed by:

$$n(L) = n^o exp\ (-L/G\tau)$$

where L (μm) 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. [10]

An MSMPR crystallizer is operated at steady-state with growth and nucleation kinetics being described by the equation:

$$B^o = kM_T G^5$$

where B^o is the nucleation rate and M_T is the suspension density and G is the overall linear crystal growth rate.

Estimate the effect of increasing the throughput of the crystallizer by 150% on:

i) the crystal growth rate
ii) the nucleation rate
iii) the dominant crystal size

Assume that the suspension density is controlled to the same value in each case and is given by the equation:

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

where f_v and ρ_c are the volume shape factor and crystal density respectively, n^o is the nuclei population density and τ is the mean residence time within the crystallizer. [10]

TURN OVER

6. The crystal size distribution (CSD) from a continuous mixed-suspension, mixed-product-removal (MSMPR) crystallizer at steady-state may be expressed by:

$$n(L) = n^o exp\,(-L/G\tau)$$

where L (μm) is the crystal size, G is the overall linear crystal growth rate and τ is the mean residence time in the vessel.

Show that the solids hold-up, M_T, in the slurry from a continuous mixed-suspension, mixed-product-removal (MSMPR) crystallizer at steady-state may be related to the crystallization kinetics and crystallizer residence time by:

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

where f_v is the volume shape factor, ρ_c is the crystal density, n^o is the population density of nuclei, 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. [10]

An MSMPR crystallizer with a working volume $V = 10\ m^3$ is operated at steady state with a nuclei population density of $n^o = 10^{10}\ (\mu m)^{-1}\ (m)^{-3}$, an invariant crystal growth rate $G = 10^{-8}\ m/s$, and a mixed product slurry removal rate Q = 20 m^3/h.

Estimate:

i) the solids content in the crystallizer (*kg*),
ii) the crystal production rate (*kg/h*)
iii) the dominant crystal size (μm)
iv) the percentage of crystals removed in the outflow by the time they have grown to $20\mu m$.

Data: The crystal density $\rho_c = 2000\ kg/m^3$ and the volumetric shape factor f_v = 0.5. [10]

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