UNIVERSITY COLLEGE LONDON

University of London

EXAMINATION FOR INTERNAL STUDENTS

For The Following Qualification:-

M.Sc.

M11: Fluid Particle Systems

COURSE CODE : **CENG0M11**

DATE : **04-MAY-06**

TIME : **10.00**

TIME ALLOWED : **3 Hours**

06-N0013-3-40

TURN OVER

*Answer **FOUR QUESTIONS** in total with **TWO from each section.***
*ALL questions carry a total of **20 MARKS** each, distributed as shown* [ ]

PART A

1. Geldart (1986) states that "the arrival time of a space probe travelling to Saturn can be predicted more accurately than the behaviour of a fluidized bed chemical reactor!" The reason for this lies in the complexity of defining and measuring fundamental parameters such as: particle shape, particle size and particle density.

(i) Describe why it is important to define such parameters and how they influence the fluidization of powders. [4]

(ii) Describe how particle shape is taken into account in the calculation of fluidization parameters. [3]

(iii) Fluidized beds rarely contain powders with a uniform particle size (monodisperse). In general a distribution of sizes (polydisperse) is present. Then, it is necessary to define the average dimension. If sieving is used as the method for particle size measurements, describe what you determine with such method and write the formula used to calculate the volume-surface mean particle diameter, d_{sv}. [4]

(iv) Define the particle density ρ_p, explaining what the hydrodynamic volume of a particle is. In fluidized beds, the bulk density ρ_b is generally considered. Show how it is related to particle density and bed voidage. [4]

(v) Describe the Geldart classification of powders and the four possible fluidization behaviours that a solid may display according to the classification. [5]

2.
(i) Describe and sketch the mechanism by means of which particles are mixed in a gas fluidized bed and explain how particle size and density affect mixing behaviour. [6]

(ii) Consider a bubbling fluid-bed of FCC catalyst particles which are fluidized using nitrogen at a superficial gas velocity equal to six times u_{mf}. Knowing that the solids flux J(kg m^{-2} s^{-1}) is given by:

$$J(kg / m^2 s) = \rho_p (1-\varepsilon_{mf})(\beta_W \varepsilon_b + 0.38 \beta_d \varepsilon_b) u_B$$

Determine the time required to turn the bed over once. [14]

CONTINUED

Data:
H_{mf} = height at minimum fluidization = 0.48 m
u_{mf} = minimum fluidization velocity = 0.2 cm s^{-1}
β_w = fraction of solids travelling in the bubble wake = 0.43
β_d = fraction of solids travelling in the bubble drift = 1
ε_b = volume fraction occupied by the bubbles in the bed
Consider that the two-phase theory applies, Y = 1

3.

(i) Describe what are the advantages of gas fluidized bed systems and the reason why they are employed in a wide range of applications. Give one example of industrial application related to sustainable development. [5]

(ii) Consider the Orcutt, Davidson and Pigford (1962) model for gas-phase catalytic reaction in a gas fluidized bed. Explain what assumptions the model is based on with regards to:

- The division of gas between the bubble phase and particulate phase
- The degree of mixing in the particulate phase
- The transfer of gas between the phases [5]

(iii) Use the reactor model by Orcutt et al. to determine the conversion of reactant A in a fluidized bed operated at a superficial gas velocity of 0.3 m/s (10 times u_{mf}). Determine also the effect on the conversion found if the bed inventory is increased by one half. [10]

From the overall mass balance on the reactor, the expression for the conversion in the reactor is given by:

$$1-\frac{C_H}{C_o}=(1-\beta e^{-\chi})-\frac{(1-\beta e^{-\chi})^2}{\dfrac{kH_{mf}(1-\varepsilon_p)}{u}+(1-\beta e^{-\chi})}$$

where:

$\beta = (u-u_{mf})/u$; $\chi = k_C H / u_B$

Data:
H_{mf} = height of the bed at minimum fluidization = 1 m
H = operating mean bed height =1.15 m
ε_{mf} = voidage at minimum fluidization = 0.47 (assume $\varepsilon_p = \varepsilon_{mf}$)
k = reaction rate constant (per unit volume of solids) = 75.47
u_B = average bubble rise velocity = 0.111 m/s
k_C = mass transfer coefficient between bubbles and emulsion = 0.1009

PLEASE TURN OVER

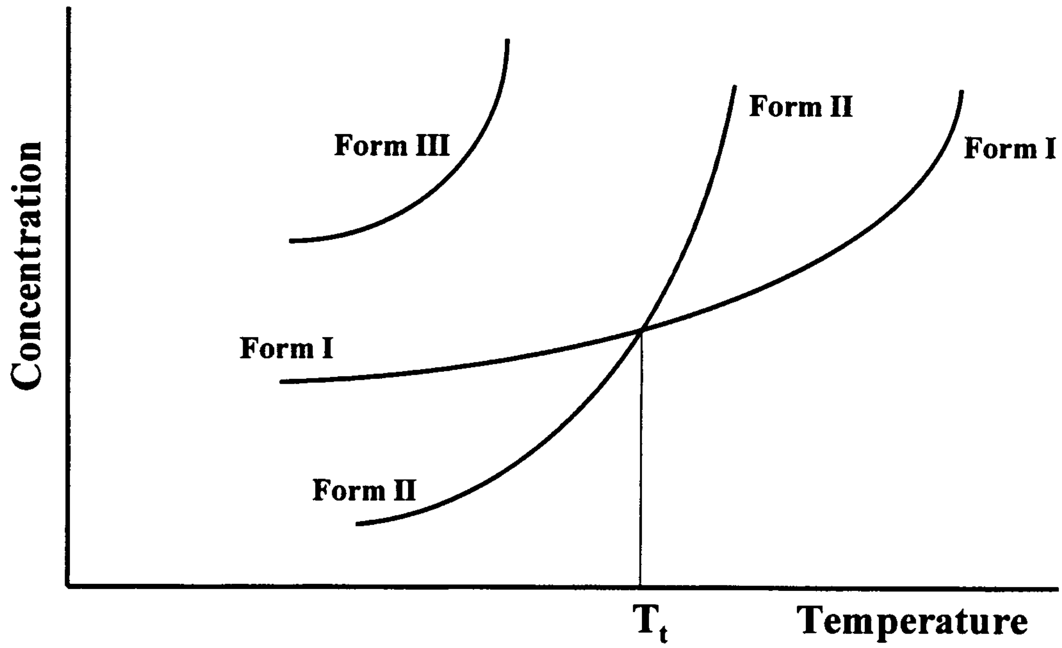
PART B

4.

(i) Explain briefly the concept of polymorphism, in relation to crystal structure and solid phase thermodynamics. [4]

(ii) Solid compounds exhibiting polymorphism may be either monotropic or enantiotropic. Explain briefly what is meant by the terms monotropy and enantiotropy, and how substances exhibiting each will differ in their crystallization behaviour. [5]

(iii) The diagram below shows the solubility curves of three polymorphic forms of a compound X, denoted as Forms I, II and III, in ethanol:



Identify the relationships between the stabilities of the three forms across the temperature range plotted. What is the significance of the temperature T_t? [5]

(iv) You are given a quantity of Form II, and are asked to try to prepare small samples of Forms I and III. From the above diagram, what conditions of temperature and cooling rate would you employ for each of these preparations, and why? What further information would be useful in assisting you to plan your experiments? [6]

PLEASE TURN OVER

5.

(i) Discuss the main factors that determine the crystal size distribution (CSD) from a continuous mixed-suspension, mixed-product-removal (MSMPR) crystallizer and show, with the aid of a simple information flow diagram, how they are interrelated. [5]

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

$$n(L) = n^0 exp\,(-L/G\tau)$$

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. [5]

(iii) 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 doubling the throughput of the crystallizer on:

a) the crystal growth rate
b) the nucleation rate

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

PLEASE TURN OVER

6.

(i) 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 $n(L)$ is the population density at crystal size L, n^o is the population density of nuclei, G is the overall linear crystal growth rate (ms^{-1}) and τ is the mean residence time in the vessel (s).

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:

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

where f_v is the volume shape factor, ρ is the crystal density. State clearly any assumptions that you may make.

[Hint: the Gamma Function $\int_0^\infty e^{-p} p^j dp = j! = \Gamma(j+1)$]. [5]

(ii) Similarly, derive an expression for the dominant crystal size in the vessel. [5]

(iii) An MSMPR crystallizer with a working volume V = 25 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 = 25 m^3h^{-1}. Estimate:

a) the solids content in the crystallizer (kg m^3),
b) the crystal production rate (kg hr^{-1})
c) the dominant crystal size (μm)
d) the percentage of crystals removed in the outflow by the time they have grown to 20μm.

The crystal density ρ = 2000 kg/m^3 and the volumetric shape factor f_v = 0.5.

[10]

END OF PAPER