UNIVERSITY COLLEGE LONDON

University of London

EXAMINATION FOR INTERNAL STUDENTS

For The Following Qualifications:-

B.Eng. *M.Eng.*

Chemical Eng E849: Mass Transfer Operations

COURSE CODE	:	**CENGE849**
UNIT VALUE	:	**0.50**
DATE	:	**28-APR-04**
TIME	:	**10.00**
TIME ALLOWED	:	**3 Hours**

04-C0187-3-70

TURN OVER

Answer FOUR questions, **TWO** *from* **Part A** *and* **TWO** *from* **Part B**. **Only the first TWO answers from each part will be marked**. **ALL** questions carry a total of **25 MARKS** *each, distributed as shown* [ ]

Additional stationery provided: graph paper

PART A

1.

Benzene is to be stripped from wash oil using superheated steam as the stripping agent. The mole fraction of benzene is to be reduced from an entering value of 0.15 to 0.001. On a solute free basis the flowrate of wash oil per unit cross-sectional area will be 200 kmol m^{-2} h^{-1}. The superheated steam is to be supplied at a flowrate that is at least 1.4 times the minimum required. The gas flow rate, however, must be sufficiently large to keep the gas outlet concentration of benzene in the outlet stream below a mole fraction of 0.25. The steam entering the column will be benzene free and will contact the wash oil counter-currently in a packed column. The column to be used has a cross-sectional area of 1.2 m^2.

The equilibrium relationship for benzene under the column conditions is:

$$Y^* = 3.16X$$

where Y^* is the equilibrium mole ratio of benzene in the gas-phase and X is the mole ratio of benzene in the liquid phase.

The overall volumetric gas-phase mass transfer coefficient based on gas-phase mole ratio of benzene driving force is expected to be 0.05 kmol m^{-3} s^{-1}.

i) Find the required steam flow rate (in kmol m^{-2} h^{-1}). [16]

ii) Find the number of overall gas-phase mass transfer units. [6]

iii) Find the height of packing required. [3]

2.

i) Tests are being made on the absorption of carbon dioxide from a carbon dioxide-air mixture in a solution containing 100 kg m^{-3} of caustic soda, using a 250 mm diameter tower packed to a height of 3 m with 19 mm Raschig rings. The results obtained at atmospheric pressure were: Gas rate = 0.34 kg m^{-2} s^{-1} and Liquid rate = 3.94 kg m^{-2} s^{-1}. The carbon dioxide in the inlet gas was 315 ppm and the carbon dioxide in the exit gas was 31 ppm, in terms of mass.

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2. continued

Data:

MW_{air}	29 kmol kg^{-1}
MW_{NaOH}	40 kmol kg^{-1}
MW_{water}	18 kmol kg^{-1}

What is the value of the overall gas transfer coefficient $K_G a$? [10]

ii) A mixture of 40 mol% ethanol (A) and 60 mol% water (B) is to be fractionally distilled at atmospheric pressure.

Calculate the vapour liquid equilibrium data ($x - y$) for the ethanol–water system at 1 atm for $x_A = 0.4$.

The following data is provided:

	A	*B*	*C*
Ethanol	8.1122	1592.86	226.184
Water	8.07131	1730.63	233.426

1 atm = 760 mm Hg

Antoine's Equation:

$$\log_{10} P^{\circ} = A - \frac{B}{T+C} \qquad [P^{\circ}] = [\text{mm Hg}]; \quad [T] = [\text{Centigrade}]$$

Van Laar Equations:

$$\ln \gamma_A = A_{AB}\left(\frac{A_{BA}x_B}{A_{AB}x_A + A_{BA}x_B}\right)^2 \qquad \ln \gamma_B = A_{BA}\left(\frac{A_{AB}x_A}{A_{AB}x_A + A_{BA}x_B}\right)^2$$

where for this system, $A_{AB} = 1.6798$ and $A_{BA} = 0.9227$. [10]

iii) A mixture of propane, i-butane, n-butane, i-pentane and n-pentane is to be separated in a train of distillation columns, each to a purity of 98 mol%. The feed compositions and the approximate relative volatilities for all adjacent pairs are given in the following tables.

Suggest a good sequencing of ordinary distillation columns for this separation in terms of heuristics and explain your answer.

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2. continued

Feed compositions:

propane (C3)	45.4 kmol h^{-1}
isobutane (iC4)	136.1 kmol h^{-1}
n-butane (nC4)	226.8 kmol h^{-1}
i-pentane (iC5)	181.4 kmol h^{-1}
n-pentane (nC5)	317.5 kmol h^{-1}
total	907.2 kmol h^{-1}

Volatilities:

C4/iC4	3.6
iC4/nC4	1.5
nC4/iC5	2.8
iC5/nC5	1.35

[5]

3.

A distillation column is to be used to separate a mixture of methanol (A) and water (B) with a feed flow of 60 kmol h^{-1}, a mole fraction of methanol of 0.3 and a temperature of 15 °C into a distillate product containing at least 95 mol% methanol, a bottom product containing at the most 5 mol% methanol and a liquid side stream of 5 kmol per hr containing 75 mol% methanol. The separation is to take place at atmospheric conditions with a reflux ratio of 3 using a total condenser and a kettle reboiler.

Data:

Specific heat of water:	4.2 kJ kg^{-1} K^{-1}
Specific heat of methanol:	2.5 kJ kg^{-1} K^{-1}
Latent heat of water:	2.3 MJ kg^{-1}
Latent heat of methanol:	1.1 MJ kg^{-1}
Molecular weight of water:	18 kmol kg^{-1}
Molecular weight of methanol:	32 kmol kg^{-1}
Boiling point of feed mixture:	84.0°C

Vapour-liquid equilibrium diagram for methanol and water at 1 atm. (On provided graph paper at the end of the paper.)

i) Find the distillate and bottom flowrates. [4]

ii) Find all the internal liquid and vapour flowrates. [6]

iii) Find the required number of stages for the separation including the positioning of the feed and the side stream. [15]

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PART B

4.

a) Show that the *leaching ratio* of n equilibrium stages in a continuous counter current operation at steady state is given by

$$\frac{S}{Rx_1} = \left(\frac{E}{R}\right)^n$$

where S is the mass of solute in the feed, R is the mass of the retained solvent, x_1 is the solute composition leaving the first stage and E is the mass of extracting solvent. [10]

b) 1000 kg of inert solids contain 200 kg solute in a dry feed. This is to be leached counter-currently with 5000 kg of fresh solvent to recover the solute using a leaching ratio of 8:1 (i.e. recovering $^7/_8$ of the solute from the inerts).

i) How many ideal stages are required? [3]
ii) What are the compositions and flows from each stage? [12]

To facilitate pumping between stages, 2.5 parts by mass of retained solvent are required for every one part of the inert.

5.

a) Describe the graphical procedures for calculating the number of stages and compositions in multistage cross-current three component liquid-liquid extraction systems for: (i) partially miscible systems by using equilateral triangular co-ordinates and (ii) immiscible systems by using rectangular co-ordinates. [10]

b) Solute (C) in a liquid (A) solution containing 1% C is to be extracted with a fresh solvent (B). A and B are essentially insoluble. Determine the amount of C extracted from 100 kg of feed solution for three theoretical extractions by using 49.5 kg solvent each. [15]

Equilibrium data expressed as kg C per kg liquid are as follows:

$x' = \frac{\text{kg C}}{\text{kg A}}$	0	0.001011	0.00246	0.00502	0.00751	0.00998	0.0204
$y' = \frac{\text{kg C}}{\text{kg B}}$	0	0.000807	0.001961	0.00456	0.00686	0.00913	0.01870

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6.

a) Sketch how the *moisture content* of a drying solid varies with time. [2]

b) Write describing equations for the *drying rate* in terms of (i) solids and (ii) gas phases. [2]

c) Sketch how the batch drying rate varies with moisture content. [2]

d) Describe briefly, with reference to (a) and (c), the *constant drying rate* and falling *drying rate* periods. [2]

e) Show that the *total drying time* in a batch dryer, θ_T, can be expressed by:

$$\theta_T = \frac{L_S}{SN_{CR}}\left\{(X_1 - X_c) + (X_c - X^*)\ln\left(\frac{(X_c - X^*)}{(X_2 - X^*)}\right)\right\}$$

where X_1 and X_2 are the moisture contents of the wet feed and dried product respectively, X_c and X^* are the critical and equilibrium moisture contents respectively, L_s is the mass of dry solid, S is the drying surface area, and N_{CR} is the constant drying rate. State clearly any assumptions that you make. [5]

f) Five hours are required under constant drying conditions to reduce the moisture content of a wet solid with a critical moisture content of 10% and equilibrium moisture content of 3%, from 25% to 7%. How long will it take to dry a similar material from 22% to 5%?

(All compositions are given on a dry basis.) [12]

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