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	:	**24–MAY–05**
TIME	:	**10.00**
TIME ALLOWED	:	**3 Hours**

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.

A coal gas is to be freed of its light oil by scrubbing with wash oil as an absorbent in one column (absorber), and the light oil subsequently recovered by stripping the resulting solution with steam in a second column (stripper). The wash oil from the stripper is to be recycled back to the absorber.

Absorber:
The total gas flow rate into the absorber is 3 kmol hr^{-1} and contains 2mol% of light oil vapour. The light oil will be assumed to be entirely benzene. 95% of the light oil must be recovered in the absorber. The wash oil entering the absorber contains 0.5 mol% benzene. The absorber column operation is isothermal.

An oil circulation rate of 1.5 times the minimum is to be used.

The equilibrium relationship for benzene under the absorber column conditions is:
$Y^* = 0.125X$
where Y^* is the equilibrium mole ratio of benzene in the coal gas phase and X is the mole ratio of benzene in the wash oil liquid phase.

Stripper:
The wash oil and light oil solution from the absorber is heated and will enter the second column at 1 atm pressure. The solution is stripped using superheated stripping steam at 1 atm pressure. The debenzolised oil should contain no more than 0.5 mol% benzene and is cooled and returned to the absorber. The stripping column operation is isothermal.

A steam rate of 1.5 times the minimum is to be used.

The equilibrium relationship for benzene under the stripping column conditions is:
$Y^* = 3.16X$
where Y^* is the equilibrium mole ratio of benzene in the steam gas phase and X is the mole ratio of benzene in the oil liquid solution phase.

i) Find the oil circulation flow rate (in kmol s^{-1}) in the absorber and the mole fraction of light oil in the wash oil leaving the absorber. [15]

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ii) Find the steam flow rate (in kmol s^{-1}) in the stripper and the mole fraction of light oil in the steam leaving the stripper. [10]

2.

Two saturated liquid mixtures of n-pentane and n-hexane are to be separated by continuous distillation into a top product that contains 95mol% n-pentane and a bottom product that contains 95mol% n-hexane.
One feed contains 65mol% n-pentane and the other feed contains 40mol% n-pentane. A total of 100 mol hr^{-1} of each feed is to be introduced at the optimum point in the column. The separation is to take place at atmospheric conditions using a total condenser and a kettle reboiler.

i) Determine the distillate and bottoms flow rates. [4]

ii) Determine the minimum reflux ratio. [5]

iii) Determine the internal liquid and vapour flow rates in all the sections of the column if a reflux ratio equal to 1.2 times the minimum is used. If you were not able to find the minimum reflux ratio in question ii), use a value of R = 0.78 (which is not the answer sought in ii)). [6]

iv) Determine the number of stages including the positions of the feeds if a reflux ratio equal to 1.2 times the minimum is used. If you were not able to find the minimum reflux ratio in question ii), use a value of R = 0.78 (which is not the answer sought in ii).) [10]

3.

i) The diffusivity of the gas pair $O_2 - CCl_4$ is being determined by observing the steady-state evaporation of carbon tetrachloride into a tube containing oxygen. The distance between the CCl_4 liquid level and the top of the tube $z_2 - z_1 = 17.1$ cm. The total pressure of the system is 755 mm Hg, and the temperature is 0 °C. The vapour pressure of CCl_4 at that temperature is 33.0 mm Hg. The cross-sectional area of the diffusion tube is 0.82 cm^2. It is found that 0.0208 cm^3 of CCl_4 evaporates in a 10 hour period after steady state has been attained.

What is the diffusivity of the gas pair $O_2 - CCl_4$ (in m^2s^{-1})?

Density of carbon tetrachloride is 1.59 g/cm^3 and its molar mass is 154 g/mol.

1 atm = 760 mmHg. [8]

CONTINUED

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 are provided:

	A	B	C
Ethanol	8.1122	1592.86	226.184
Water	8.07131	1730.63	233.426

Antoine's Equation:

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

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 $A_{BA} = 0.9227$

1 atm = 760 mmHg.

[12]

iii) The capital cost and operating cost of a distillation column are generally a function of the reflux ratio. Explain briefly why and illustrate typical trends of the two costs as a function of the reflux ratio. Indicate clearly any limiting conditions. [5]

PART B

4.

(a) Show that the slurry *washing ratio* for a continuous counter-current series of n equilibrium stages at steady state is given by:

$$\frac{x_{n+1}}{x_1} = \frac{\left(\frac{E}{R}\right)^{n+1} - 1}{\left(\frac{E}{R}\right) - 1}$$

where x_{n+1} is the concentration of solute in the slurry liquor entering stage n and x_1 is the concentration of the solute in the slurry liquor leaving stage 1, E is the mass of the extracting solvent and R is the mass of retained solvent in the suspension. [10]

CONTINUED

(b) A particulate suspension containing 750 kg of inert solids (I) per 1000 kg of solvent (R) and 100 kg of solute is washed counter-currently with 2500 kg of initially pure solvent (E) in three equilibrium stages.

(i) What is the concentration of solute in the discharge suspension? [3]
(ii) What are the compositions of the solvent and slurry streams through the plant? [12]

Assume that E/R = 2.5 and R/I = 1.33 throughout.

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 66 kg solvent each. [15]

Equilibrium data expressed as kg C/kg liquid is as follows:

$x' = \frac{\text{kg C}}{\text{kg A}}$	0	0.0010	0.0025	0.0050	0.0075	0.0100	0.0200
$y' = \frac{\text{kg C}}{\text{kg A}}$	0	0.0008	0.0020	0.0045	0.0070	0.0090	0.0190

Standard graph paper to be supplied (A4 size)

6.

A chemical works produces an aqueous effluent at above ambient temperature. The Environmental Agency insists that before the effluent is discharged to the river, it must be cooled.

A forced draught counter current cooling tower is available. When tested it provided the following results:

Flow rate of water into the tower	100 kg/s
Water temperature entering the tower	45°C
Water temperature leaving the tower	20°C
Wet bulb temperature of inlet air	10°C
Temperature of outlet air (nearly saturated)	30°C

CONTINUED

(a) Calculate the air flowrate through the tower. [10]

(b) Determine the approximate number of gas transfer units achieved. [15]

Saturated Air Temperature °C	10	15	20	25	30	35	40	45	50
Enthalpy of saturated air-water vapour mixture kJ/kg	29.5	42.4	57.9	77.0	100.6	130.3	167.8	215.6	277.3

DATA:

Heat capacity of liquid water: 4.19 kJ/kg K.

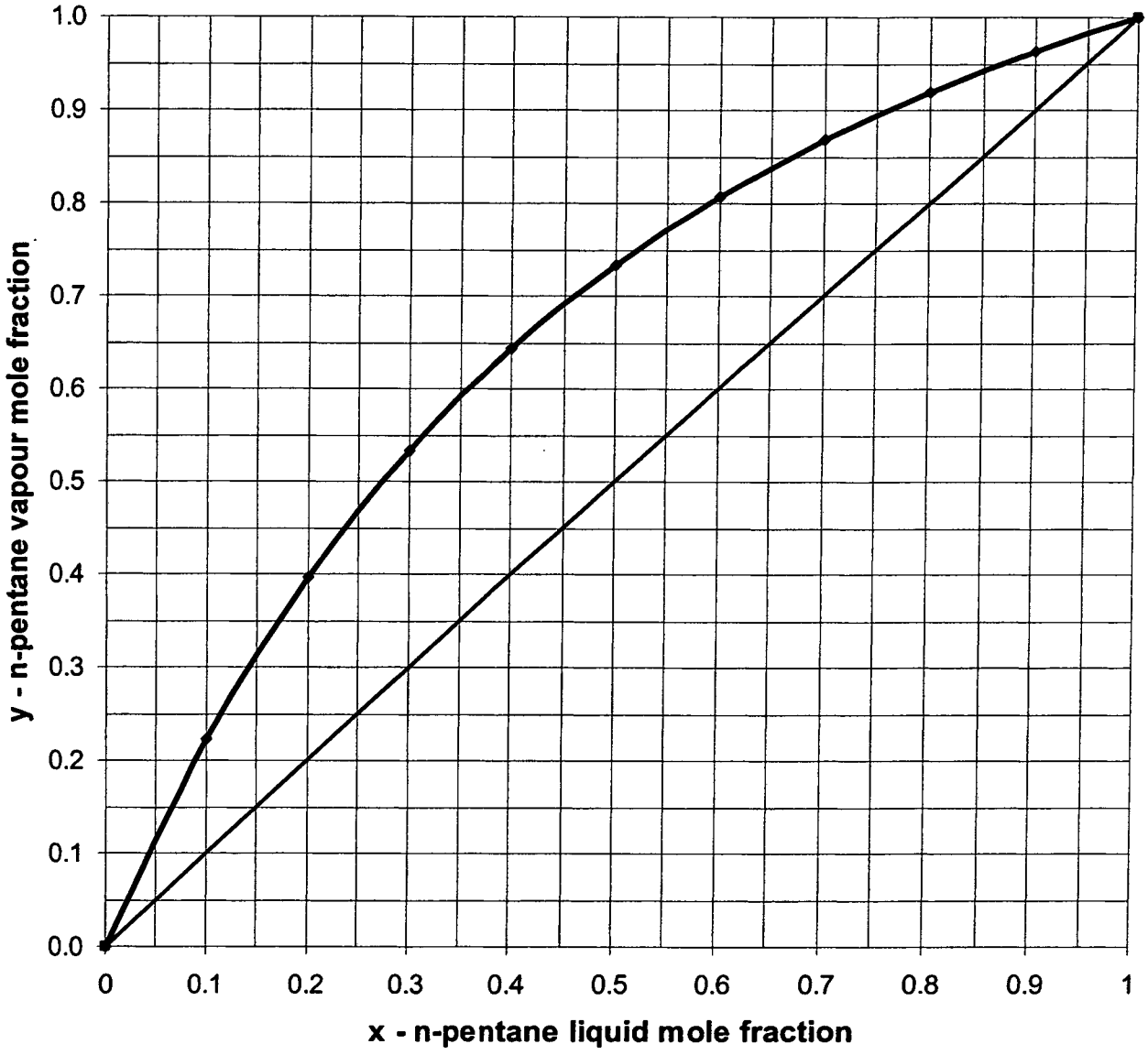
[It may be assumed that the resistance to heat transfer in the liquid phase is negligible].

Standard graph paper to be supplied (A4 size)

END OF PAPER

Candidates using this paper must tie it into their Answer books so as to face the answer to the question to which it relates. They must write their number and the subject of the paper on every sheet used

Seat number:.....
Candidate number: .....
Subject: .....



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