# 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 : **23-MAY-06**

TIME : **10.00**

TIME ALLOWED : **3 Hours**

06-C0220-3-70



**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 A hydrocarbon gas stream is to be purified in a packed absorption column by continuous counter-current contact with a liquid organic solvent at 24°C. The inlet gas contains 1.5% by volume of toxic DMSO of which 95% is to be removed. The gas flows at a rate of 0.1 kmol/s on a DMSO-free basis. The organic liquid solvent initially contains 0.001 mole fraction DMSO. The required solvent flow rate is to be 1.5 times the minimum.

The vapour-liquid equilibrium relationship is given by:

$$Y^* = 0.2X$$

where Y* is the mole ratio of DMSO in the gas phase and X is the mole ratio of DMSO in the liquid phase.

a) For both the top and the bottom of the column, find the total gas flow rates (hydrocarbon and DMSO), the flow rates of DMSO gas only and the mole fractions of DMSO in the gas streams. [6]

b) Calculate the required solvent flow rate and the liquid mole fraction of DMSO at the bottom of the column. [5]

c) A pilot plant was run with the same packing as in the proposed absorption column but with another gas X dissolved in the same hydrocarbon stream. The test was carried out with a solvent temperature of 24°C and with 1.5% by volume of component X in the hydrocarbon stream. The following relationship was found:

$$K_{OG}a = 0.07\, L^{0.25}$$

where $K_{OG}$ is the overall mass transfer coefficient [kmol m$^{-2}$ hr$^{-1}$], $a$ is the effective contact area [m$^{2}$ m$^{-3}$] and L is the solvent liquid flow rate [kmol hr$^{-1}$].

Estimate the mass transfer coefficient relationship $K_{OG}a$ for absorption of DMSO instead of component X from the same hydrocarbon stream and with all other conditions unchanged.

**CONTINUED**

Data for the mixtures:

| Mixture | T, K | $P \cdot D_{AB}$, Pa $m^2$ $s^{-1}$ |
|---|---|---|
| Hydrocarbon – Component X | 276.2 | 1.44 |
| Hydrocarbon – Component X | 317.2 | 1.79 |
| Hydrocarbon – DMSO | 297.0 | 1.08 (estimated) |

where T is the temperature [K], P is the total pressure [Pa] and $D_{AB}$ is the diffusivity coefficient [$m^2$ $s^{-1}$].

The following proportionalities can be assumed:

$$K_{OG} \propto D_{AB}^{0.58}$$
$$D_{AB} \propto T^{1.75}$$

[8]

d) Find the required height of the packed column with the mass transfer coefficient found in c) when the diameter of the column is *1.35 m*. If you were not able to find the value, use $K_{OG}a$ = 350 kmol $m^{-3}$ $hr^{-1}$ (which is not the answer sought in c). [6]

**2** A saturated liquid mixture of 40 mol% methanol and 60 mol% water is to be separated in a continuous distillation column into a top product that contains 90 mol% methanol and a bottom product that contains 95 mol% water. The column is also to have a liquid side stream with a composition of 70 mol% methanol. A total of 50 kmol $hr^{-1}$ of feed is to be introduced at the optimum point in the column. The side stream is to be withdrawn at a flow rate of 5 kmol $hr^{-1}$ from an optimal withdrawal point in the column. The separation is to take place at atmospheric conditions using a total condenser and a kettle reboiler.

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

b) Determine the minimum reflux ratio using the x-y diagram attached. [5]

c) 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 b), use a value of R = 0.55 (which does not correspond to the $R_{min}$ value sought in b). [9]

d) Determine the number of stages in the column including the positions of the feed and the liquid side withdrawal 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 b), use a value of R = 0.55 (which does not correspond to the $R_{min}$ value sought in b). [7]

**PLEASE TURN OVER**

**3**

a) A multi-component mixture consists of 40 mol% propane, 20 mol% i-butane and 40 mol% n-butane. The following data are provided:

| | A | B | C |
|---|---|---|---|
| Propane | 15.7260 | 1872.46 | -25.16 |
| i-Butane | 15.5381 | 2032.73 | -33.15 |
| n-Butane | 15.6782 | 2154.90 | -34.42 |

Antoine's Equation:

$$\ln P^{o} = A - \frac{B}{T + C} \qquad [P^{o}] = [\text{mmHg}]; [T] = [K]; \qquad 1 \text{ atm} = 760 \text{ mmHg}$$

Calculate the boiling points of each of the three components as well as the bubble point of the mixture at 5 atm. [8]

Find the average relative volatilities between propane and i-butane and between i-butane and n-butane at 5 atm. [5]

The mixture is to be separated in a sequence of two distillation columns. Suggest a good sequencing for the separation and explain your answer briefly. [2]

b) Concerns have been raised over the release of methanol to the atmosphere from the condenser of a distillation column separating methanol and water. The separation is operated at atmospheric pressure and the condenser has a small vent which is open to the atmosphere as shown in Figure 1. Both the condenser and the cooler below the vent are water cooled. The components can be assumed to be almost completely separated, hence the condenser contains pure methanol.

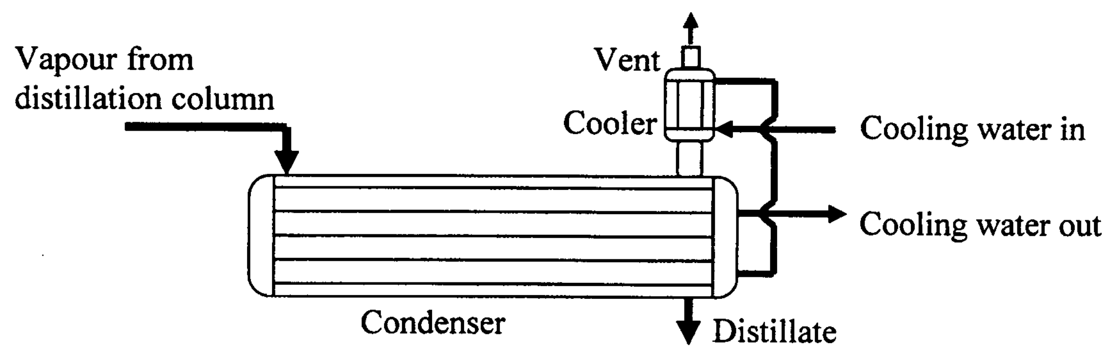


Figure 1. Distillation column condenser with atmospheric vent.

i) Estimate the flux of methanol (mol $m^{-2}$ $hr^{-1}$) due to molecular diffusion through the vent at steady state. [6]

ii) Estimate the yearly release (kg/year) of methanol. [4]

**CONTINUED**

The following data is given:

| | |
|---|---|
| Temperature in the cooler and vent, T: | 21°C |
| Partial pressure of methanol in the vent, $p_{A1}$: | 100 mmHg |
| Inner diameter of the vent, d: | 38 mm |
| Length of the vent, h: | 40cm |
| Vapour volume in the cooler, V: | 0.005 $m^3$ |
| Atmospheric pressure, P: | 1 bar |
| Pressure times diffusivity at 294K, $P \cdot D_{AB}$: | 1.53 Pa $m^2$ $s^{-1}$ |
| Gas constant, R: | 8.314 J $K^{-1}$ $mol^{-1}$ |
| Mole weight of methanol: | 32 kg $kmol^{-1}$ |

1 mmHg = 133.3 Pa, 1 bar = $10^5$ Pa

## PART B

**4**

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) A liquid solution (A) which contains 3 weight % of solute (C) is sent to a recently installed Effluents Treatment Plant (ETP) where C is extracted by using fresh solvent B. C is considered to be harmful to the environment and the treated liquid stream should contain less than 2 weight % C to meet the requirements of the local authorities. Calculate the amount of C extracted from 150 kg of feed solution for three theoretical extractions by using 48.5 kg solvent each. Does the liquid treated by the ETP satisfy the requirements of the local authorities? [15]

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

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| $x' = \frac{\text{kg C}}{\text{kg A}}$ | 0 | 0.0050 | 0.0100 | 0.0150 | 0.0200 | 0.0250 | 0.0300 |
| $y' = \frac{\text{kg C}}{\text{kg A}}$ | 0 | 0.0100 | 0.01750 | 0.0200 | 0.0225 | 0.02375 | 0.0250 |

**PLEASE TURN OVER**

**5**

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 | 175 kg/s |
| Water temperature entering the tower | 47.5°C |
| Water temperature leaving the tower | 22.5°C |
| Wet bulb temperature of inlet air | 12.5°C |
| Temperature of outlet air (nearly saturated) | 32.5°C |

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

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

DATA:

| 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 |

Average 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].

**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]

**CONTINUED**

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

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

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) Seven hours and ten minutes are required under constant drying conditions to reduce the moisture content of a wet solid with a critical moisture content of 6.5% and equilibrium moisture content of 3.4%, from 26.2% to 4.5%. How long will it take to dry a similar material from 32.5% to 5.2%? [12]

(All compositions are given on a dry basis, i.e., kg moisture/kg dry solid.)

**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:......................................................<br><br>Candidate number: .............................................<br><br>Subject: ........................................................... |

**Diagram to be used for Question 2.**