UNIVERSITY COLLEGE LONDON

University of London

EXAMINATION FOR INTERNAL STUDENTS

For the following qualifications :-

M.Sc.

Biochem Eng G19: Bioprocess Synthesis and Process Mapping

COURSE CODE	:	**BENGEG19**
DATE	:	**07-MAY-02**
TIME	:	**14.30**
TIME ALLOWED	:	**3 hours**

02-C0110-3-40

TURN OVER

UNIVERSITY OF LONDON

Biochemical Engineering

G19

*Answer **FOUR QUESTIONS** only.*
*ALL questions carry a total of **25 MARKS** each, distributed as shown* [ ]. *Show all workings.*

1. A membrane unit is to be used for cell culture broth clarification and the recovery of a soluble protein. This is prior to the chromatographic purification of the protein. Prepare a flowsheet of this process and describe how the performance of the membrane separation step may affect the performance of the chromatographic stage. [5]

   A 1000L mammalian cell culture broth is concentrated to 200L within 2 hours using a membrane separation unit. Just 40% of an extracellular protein product is recovered in the permeate during this concentration process.

   You are required to predict how much diafiltration buffer may be needed to increase this product recovery from 40% to 90% and how much time this may take using the same membrane separation unit. Detail all assumptions made. [10]

   The subsequent trials using your predictions result in just 70% yield with the diafiltration process taking 3 hours longer than predicted.

   Prepare a report which puts forward analyses of why these differences between predicted and experimental results are occurring and how the next trials should be conducted to confirm which analysis most likely explains the differences. [10]

2. Prepare a flowsheet for the recovery of an extracellular protein from a fermentation broth using centrifugation. Describe all mechanisms where the yield of protein in the supernatant may be decreased compared with a laboratory scale test tube centrifuge. [5]

   A fermentation broth contains 100g wet weight cells per litre of broth. An extracellular product is recovered from the cells by continuous centrifugation with a yield of 80%.

   An improvement in the fermentation process leads to a cell concentration of 160g wet weight cells per litre of broth. Estimate the likely percentage yield of product using the same continuous centrifuge. Detail all assumptions made. [10]

   It is proposed to raise the percentage yield back to that achieved for the original broth by either
   a) prediluting the fermentation broth
   b) resuspending the sedimented cells and recentrifuging.

   Estimate the relative dilutions of the product obtained by these two methods and comment on the advantages and disadvantages of each method. Note that the product is to be subsequently purified by an adsorption/desorption step and is intended for therapeutic use. [10]

   (the cell density may be assumed to be: ~1 g/mL)

TURN OVER

3. Methane and oxygen react in the presence of a catalyst to form methanal. In a parallel reaction, methane is oxidized to carbon dioxide and water:

$$CH_4 + O_2 \rightarrow HCHO + H_2O$$
$$CH_4 + 2\,O_2 \rightarrow CO_2 + 2\,H_2O$$

The feed to the reactor contains equimolar amounts of methane and oxygen. Assume a basis of calculation of 100 mol feed/s.

a) Draw and label a flowchart. Use a degree-of-freedom analysis based on extents of reaction to determine how many process variable values must be specified for the remaining variable values to be calculated. [10]

b) Derive expressions for the product stream component flow rates in terms of the two extents of reaction, $\dot{\xi}_1$ and $\dot{\xi}_2$. [5]

c) The fractional conversion of methane is 0.900 and the fractional yield of methanal is 0.855. Calculate the molar flowrates of the individual components in the output stream and the selectivity of methanal production relative to carbon dioxide production. [10]

4. The oxidation of nitric oxide

$$NO + \tfrac{1}{2}\,O_2 \Leftrightarrow NO_2$$

takes place in an isothermal batch reactor. The reactor is charged with a mixture containing 20.0 volume percent NO and the balance air (78% N_2, 21% O_2) at an initial pressure of 380 kPa.

a) Assuming ideal gas behaviour, determine the composition of the mixture (component mole fractions) and the final pressure (kPa) if the conversion of NO is 90%. [12]

b) Suppose the pressure in the reactor eventually equilibriates (levels out) at 360 kPa. What is the equilibrium percent conversion of NO? [10]

c) Calculate the reaction equilibrium constant at the prevailing temperature, K_p [$(\text{atm})^{-0.5}$], defined as

$$K_p = \frac{(p_{NO_2})}{(p_{NO})(p_{O_2})^{0.5}}$$

where p_i (atm) is the partial pressure of species i (NO_2, NO, O_2) at equilibrium. [3]

TURN OVER

5. a) Liquid butan-2-one (or methyl ethyl ketone (MEK)) is introduced into a vessel containing air. The system temperature is increased to 55°C, and the vessel contents reach equilibrium with some MEK remaining in the liquid state. The equilibrium pressure is 1200 mm Hg.
   i) Use the Gibbs phase rule to determine how many degrees of freedom exist for the system at equilibrium. State the meaning of your result in your own words.
   ii) What is the mole fraction amount of MEK in the vapour? [15]

   b) Steam at 260°C and 7.00 bar absolute is expanded through a nozzle to 200°C and 4.00 bar. Negligible heat is transferred from the nozzle to its surroundings. The approach velocity of the steam is negligible. Calculate the exit steam velocity. [10]

Data:
Antoine equation constants for MEK, T in °C, pressure in mm Hg:
A = 7.06356, B = 1261.339, C = 221.969
Specific enthalpy of steam:
2974 kJ/kg at 260°C and 7 bar;
2860 kJ/kg at 200°C and 4 bar.

6. 100 kmol/h of a mixture composed of 55% (mole) carbon disulphide (CS_2) and 45% (mole) carbon tetrachloride (CCl_4) is fed to a fractionating column to produce a distillate containing 95% (mole) carbon disulphide and a residue containing 5% (mole) carbon disulphide. The column is operating at 760 mmHg and is equipped with a total condenser and a partial reboiler. Assume that the feed, the distillate and the residue are all saturated liquids.
Compute the following:

a) flowrates (kmol/h) of the distillate and residue streams; [4]

b) assuming constant molar overflow and with the aid of a graphical construction (McCabe-Thiele method) on the diagram provided, which must be attached to your answer book, determine:
   i) the minimum reflux ratio Rmin; [4]
   ii) the number of theoretical stages for a reflux ratio R = 1.5 Rmin; [12]

c) assuming constant molar overflow, for a reflux ratio R = (L/D) = 1.5 Rmin calculate internal liquid and vapour flowrates (kmol/h) above and below the feed tray. Note that L is the liquid reflux fed back to the column and D is the distillate (top) product withdrawn from the column. [5]

Data
Diagram supplied showing vapour-liquid equilibrium curve for carbon disulphide and carbon tetrachloride.

TURN OVER

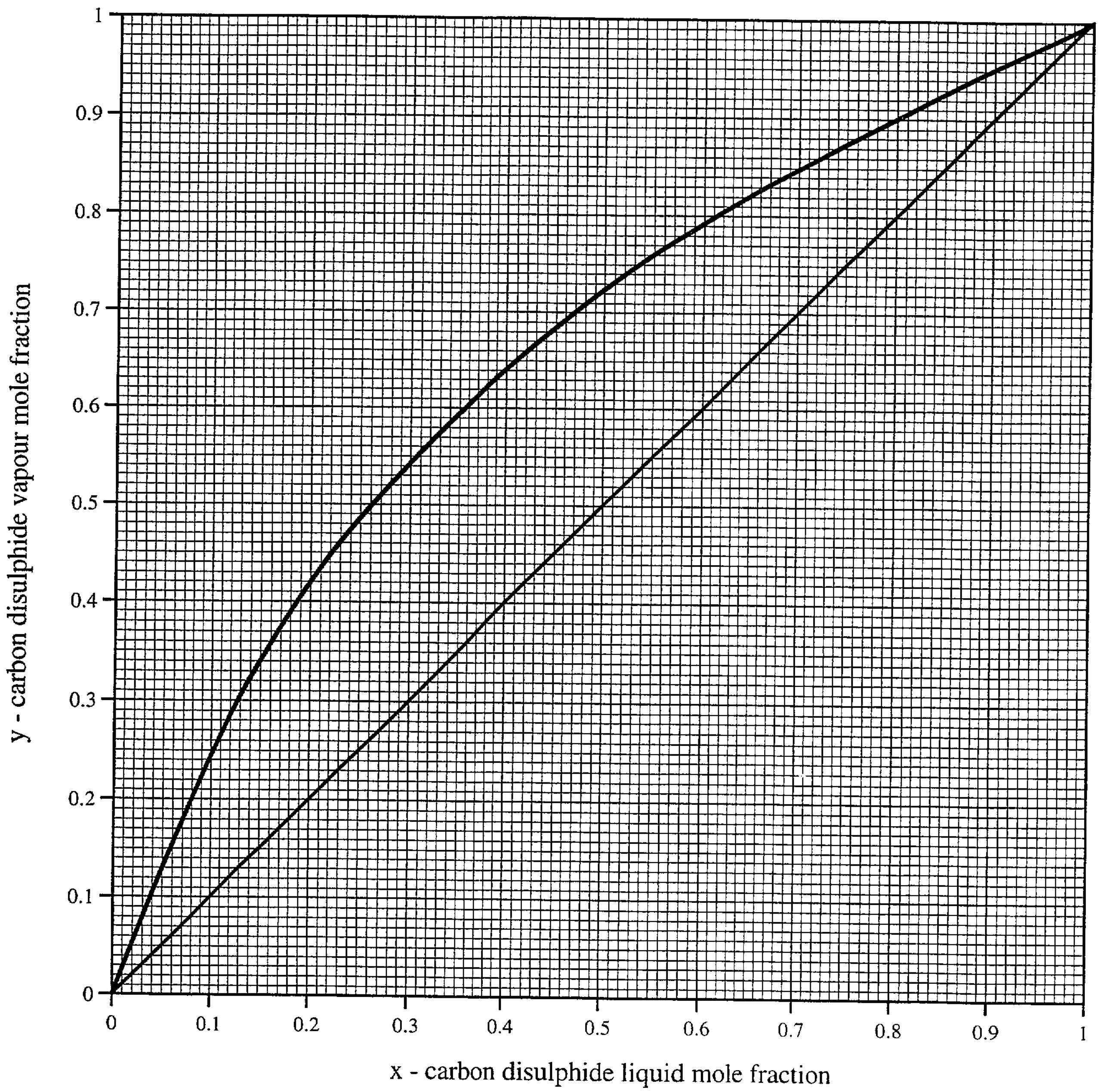
7. a) A flat wall of uniform, homogeneous material having constant thermal conductivity "k", thickness "x" and surface area "A" is exposed to a hot fluid at temperature "T_h" on one side and to a cold fluid at temperature "T_c" on the other side. Derive an expression for the overall heat transfer coefficient "U". Use "h_h" and "h_c" to denote the heat transfer coefficients of the hot and cold fluid respectively. [10]

b) In a one-shell-pass one-tube-pass heat exchanger a hot process fluid is cooled by water. The process fluid flows at 18 kg s^{-1} and is cooled from 105°C to 45°C. The water flows counter-currently to the process fluid, entering at 25°C and leaving at 50°C. Assuming no heat losses, calculate the required flow-rate for the cooling water. The specific heat for water is 4.2 kJ kg^{-1} K^{-1} and that of the process fluid is 3.4 kJ kg^{-1} K^{-1}. [8]

c) Under these conditions, the heat transfer coefficient in the process fluid side film is: 2500 W m^{-2} K^{-1}, the cooling water side heat transfer coefficient is 1200 W m^{-2} K^{-1}. The tube wall thickness is 3mm and the thermal conductivity is 220 W m^{-1} K^{-1}. Neglecting both the thermal resistance due to fouling and the tube wall curvature, calculate the required area for heat exchange. [7]

TURN OVER

G-19 Exam paper 2002: Question number 6



END OF PAPER