National Exams - December 2003

98-Chem-A3
Mass Transfer Operations
3 hours duration

NOTES

1. If doubt exists as to the interpretation of any question the candidate is urged to submit, as part of the answer, a clear statement of any assumptions made.

2. Calculations must be shown in sufficient detail to enable the examiner to follow all steps in the answers, including the sources of any numerical values used.

3. This is an open book exam: books and notes are permitted.

4. Any non-communicating calculator will be permitted. Candidates will identify the calculator used on the inside left hand sheet of the exam work book, i.e. name and model designation. The calculator must be capable of raising numbers to an exponent.

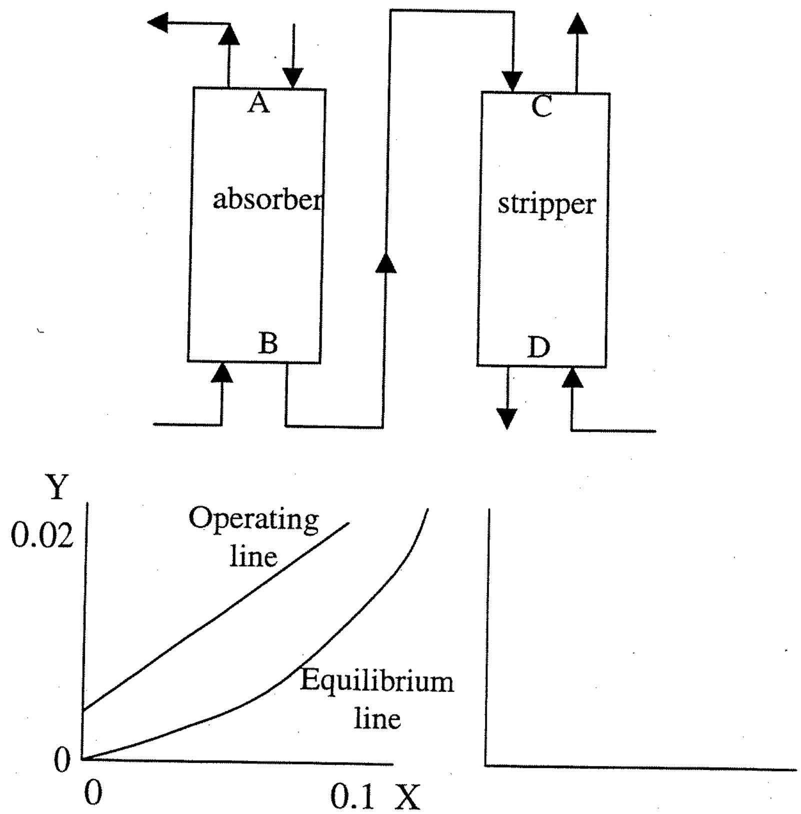
5. Any five questions constitute a complete paper. Only the first five questions as they appear in your answer book will be marked. Clearly stroke out any work that is not to be considered in the marking.

6. All questions are of equal value. Marks will be given for those parts of a question that are answered. Possible mark for each part is shown in the left-hand margin. Part marks will be given for incomplete answers.

7. A psychrometric chart for the system air-water at atmospheric pressure is provided.

8. 3 or 4 sheets of rectilinear graph paper are provided.

1. Benzene is being absorbed out of a gas stream by an absorbing oil, then being stripped out of the oil by a second gas. The operation of the absorber is described by the concentration diagram, where **Y** is the concentration of benzene in vapour in units of moles per mole of dry gas and **X** is concentration of benzene in liquid in units of moles per mole of oil.



(5) Show a similar diagram for the stripper (no numbers required).

(5) In the absorber, what is the ratio of flow rates of oil to benzene-free gas?

(5) Assuming the absorber to be constructed of individual plates and assuming the plates each to be 33% efficient, how many plates are required?

(5) For a packed column a quantity called the *height of a transfer unit* is defined as

$$\mathbf{G} / (\mathbf{F_G} \cdot \mathbf{a})$$

Where **G** is the superficial molar mass velocity, $\mathbf{F_G}$ is the gas-phase mass transfer coefficient, and **a** is the specific interface surface area of the packing. Write units for these quantities and show that the ratio has units of distance, i.e., height.

2. One hundred kilograms of a gaseous mixture of air and benzene are brought into intimate contact with 122.5 kilograms of activated carbon at 100C. The gaseous mixture starts out with a molar ratio of air to benzene of 7 to 1. Initial pressure is 800 mm Hg abs. Molecular weights are 29 for air and 78 for benzene.
Some existing data on benzene adsorption by carbon are given as follows:

Partial pressure Benzene, mm Hg abs	Adsorption, kg benzene/kg carbon
0	0
8	0.1
15	0.15
45	0.2
75	0.225
120	0.26

(10) Assuming no adsorption of air, what final pressure will this system reach?

(6) In general terms, explain how you would deal with a system in which two adsorbing components are present.

(4) Explain the difference between adsorption and ion exchange

3. Air leaving a solids-drying unit is at 130C and an absolute humidity of 0.3. It is passed through a de-humidifier where it is cooled and water is condensed. The exit temperature is 50C. How much water is removed in this operation? Approximately, how much cooling is required to bring about this change?

(8)

After dehumidification the air is re-heated and recycled to the drier.

The drier consists of a moving belt, 20 metres long and 2 metres wide. The solids, in the form of pellets, are carried along on this belt. Solids rate is 3000 kilograms per hour of moist pellets..

The pellets enter with a moisture content of 10% by weight. For this material, drying is at constant rate of 0.003 kilograms moisture removed per second per square metre of belt surface, down to a pellet moisture content of 2% by weight. Below this value the rate falls off linearly to zero with pellet moisture content.

(12) Calculate the expected moisture content of the pellets leaving the drier.

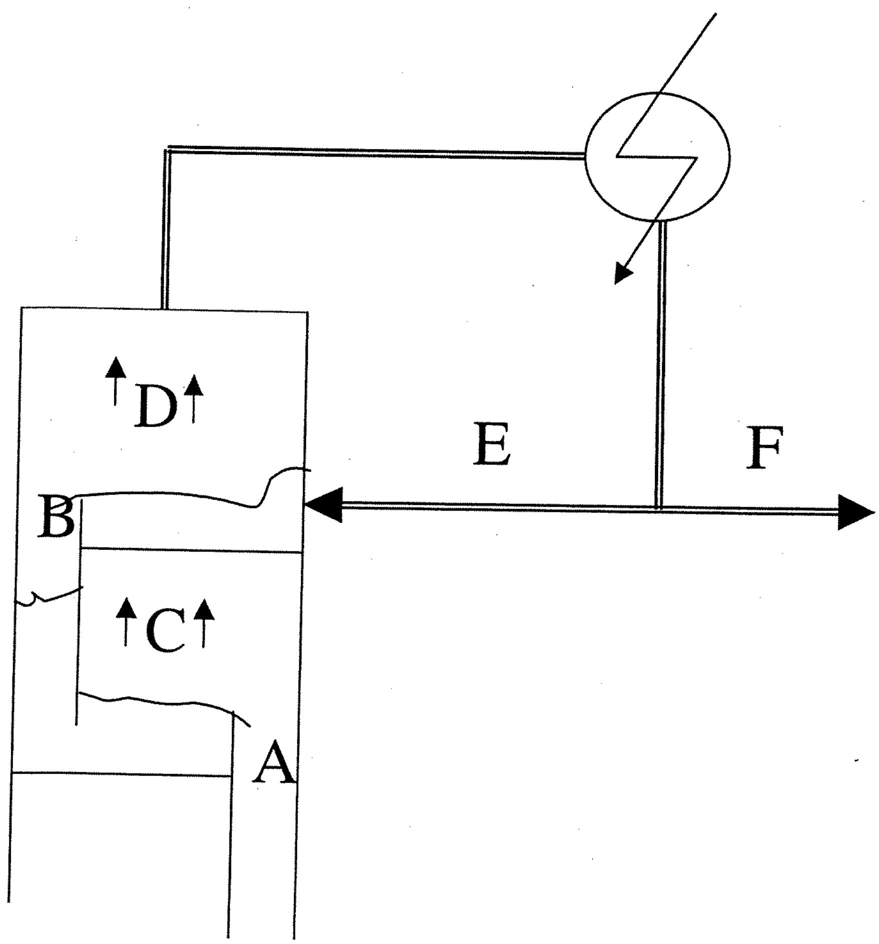
4. You are presented with a pair of liquids which, it is suspected, form an azeotrope. Propose a simple initial test to explore this possibility.

(5) Does the fact that there is no azeotrope at one pressure mean that there is none at any pressure?

(4) An equi-molar solution of ethanol and 3-hexanol is boiling at 82.9C. Pure-component vapour pressures at this temperature are respectively 101 and 14.1 kilopascals. What is the composition of the vapour and what is the system pressure? Assume Raoult's law.

(4) An equi-molar vapour mixture of ethanol and 3-hexanol is condensing at 82.9C. What is the composition of the condensate and what is the pressure of the system?

(5) The diagram represents the top of a distillation column and total condenser. Draw a McCabe Thiele diagram and indicate on it the lettered streams.



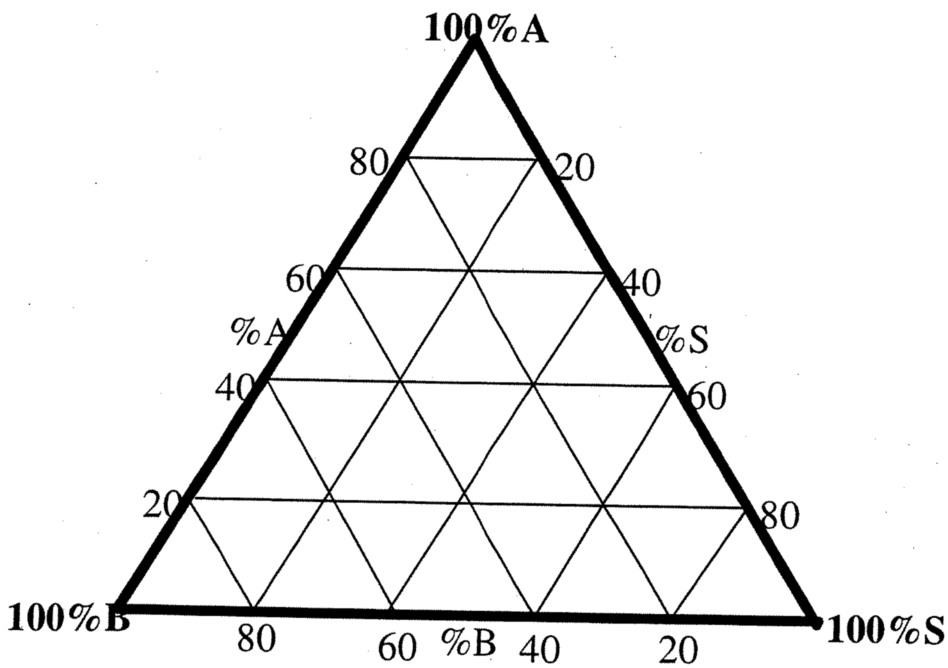
5. Tests have been performed in a lab to generate data for the design of a liquid-liquid extraction system. A solvent '**S**' is going to be used to extract component '**A**' out of liquid '**B**'. One of these tests has generated the following pair of tie-line points:

S: 11%, A: 16% - S: 76%, A: 19%

A second test generated the following pair:

S: 13%, A: 34% - S: 45%, A: 40%

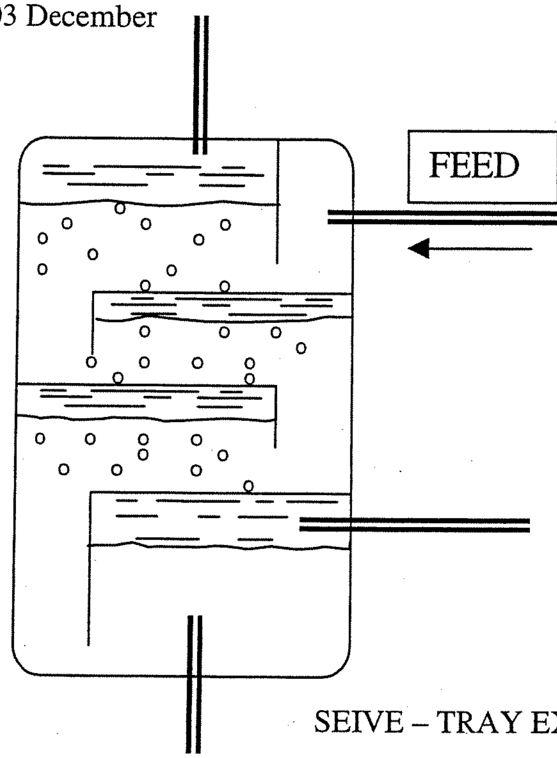
(3) Plot these points on a triangular graph, of the type shown below.



A solution consisting of equal parts **A** and **B** is to be extracted by solvent **S**. The ratio of solvent to solution will be 1.0. On the basis of the above tie-line data as plotted on your graph, estimate the composition and amounts of the two phases that will result.

(7)

(7) Using the accompanying diagram of a multi-stage vertical extractor, describe the action and provide the names commonly used for the streams entering and leaving the unit.



SEIVE – TRAY EXTRACTOR

(3) Explain why extractors of this type are sometimes equipped, along the centre-line, with a rotating shaft fitted with agitator elements.

6. It is frequently necessary to mechanically agitate a liquid mixture, for a variety of reasons:
to blend miscible components into a uniform composition,
to break up one phase (liquid or gas) of an immiscible mixture in order to promote mass transfer,
to suspend particulate solids in the mixture.

(4) Describe typical agitators for
(a) low-viscosity and high-viscosity liquids
(b) miscible-blending and phase-dispersion.

(4) Sketch typical flow patterns in a mixed vessel

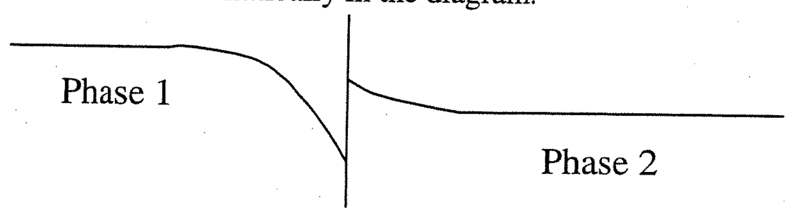
(4) What are some conditions affecting the difficulty of blending two liquids?

(4) What factors affect the power requirement for a rotating mixer? Define the *power number.*

(4) It is desired to produce 200 kg/h of a stream containing 25% of component '**C**' and no more than 40% of component '**A**'. This stream will be produced by blending appropriate amounts of three streams:
#1 containing 30% '**A**' and 70% '**B**'
#2 containing 50% '**A**' and 50% '**B**'
#3 containing 100% '**C**'
Calculate permissible rates of these feed streams.

7. The *two-film theory* is an approximation that is commonly used to describe component transfer from one phase to another. It is based on the assumptions that (a) all of the resistance to transfer is within the phases and is concentrated in a small region in the vicinity of the interface, and
(b)there is no resistance at the interface and consequently the phases are in equilibrium at the interface.

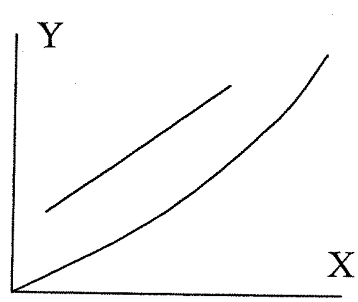
The situation is shown schematically in the diagram.



Concentration of species
being transferred

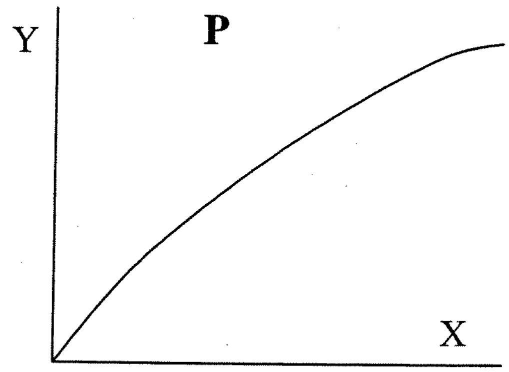
(5) In this diagram, in which direction is the component being transferred? Explain the relative positions of the concentrations at the interface.

A typical pair of operating line and equilibrium line for a countercurrent system are shown in the diagram.



(5) Sketch a similar plot for a cocurrent system.

The following figure shows an equilibrium curve and a single point '**P**' on the operating line.



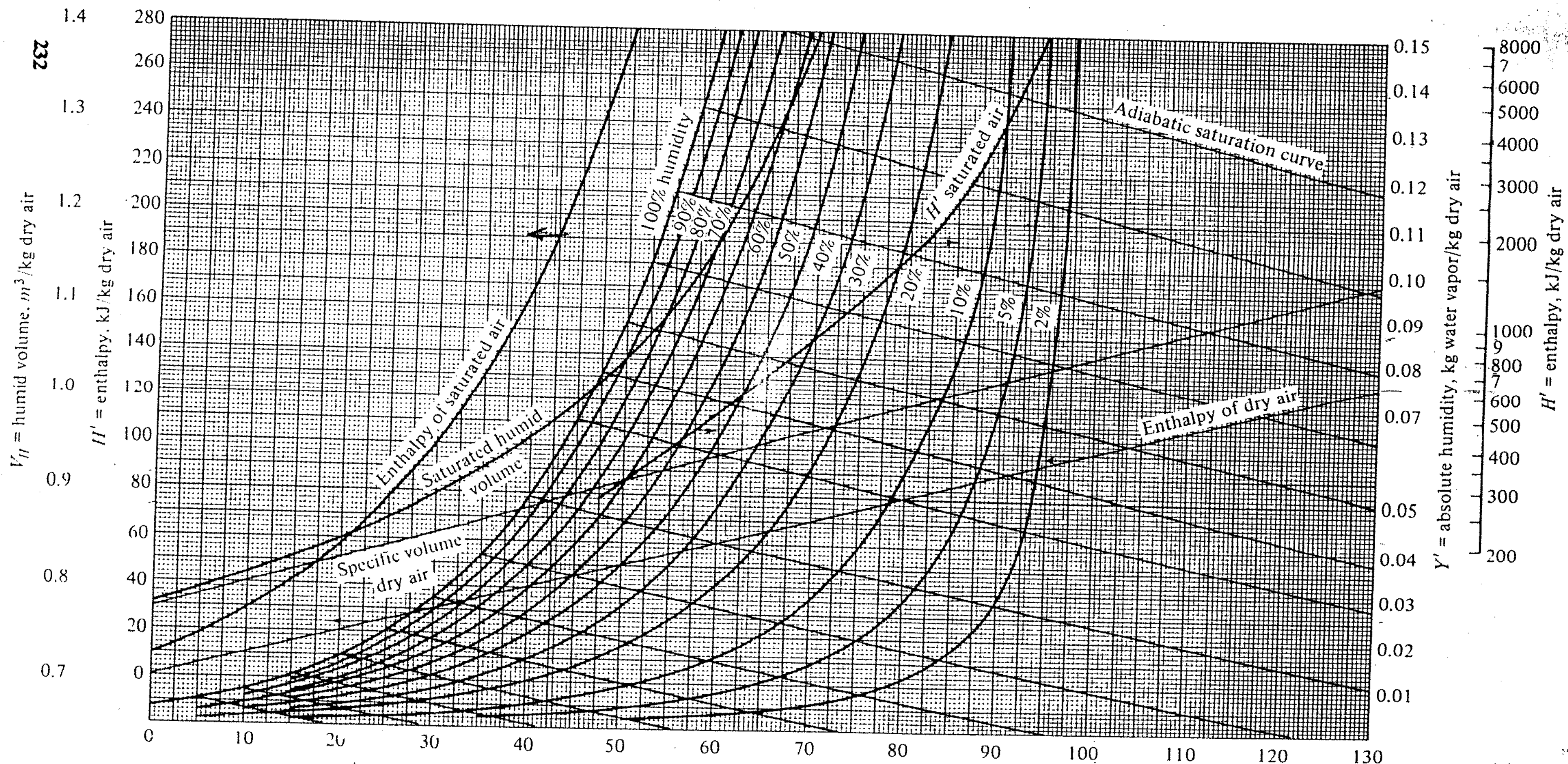
(5) The transfer operation is driven by the impetus of the system at point '**P**' to approach an equilibrium condition. The speed of this approach is dictated by the distance from equilibrium (the driving force) and by the mass transfer rate constant. Using this diagram, explain some possible definitions of driving force and rate constant.

Mass transfer coefficients are often correlated using the dimensionless *Sherwood Number*, defined as

Mass transfer coefficient * characteristic length / component diffusivity

The characteristic length may typically be the diameter of a sphere or the inside diameter of a tube.

(5) Show that this quantity is indeed dimensionless and explain why it is a logical way to correlate mass transfer coefficients, i.e., why the coefficient may depend on dimension and diffusivity.



(a)

Figure 7.5 (*a*) Psychrometric chart for air-water vapor, 1 std atm abs, in SI units.