National Exams - May 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. An equi-molar liquid stream of 2-octanone and n-octanol is continuously fed to a distillation column and is separated into a top stream of 90:10 octanone-to-octanol molar ratio and a bottom stream of 10:90 octanone-to-octanol. The vapour pressures for octanone and octanol in the vicinity of the operating pressure and temperature are given by

$$\text{Pressure, bars} = e^{12.992 - 5776.25 / T \text{ kelvin}}$$

$$\text{Pressure, bars} = e^{14.058 - 6539.15/T \text{ kelvin}}$$

respectively.

The column is operated at a top pressure of 200 mm Hg abs or 0.2666 bars, which for the present purpose may be considered the same throughout the column.

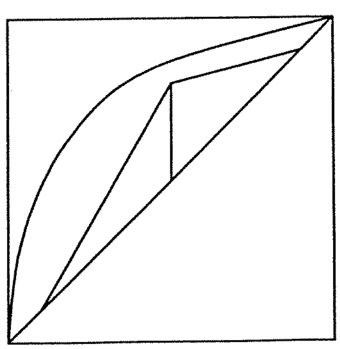
(6) Verify that the top stage temperature is around 133.7 C and that the liquid on the top stage is approximately 0.8 mole fraction 2-octanone.

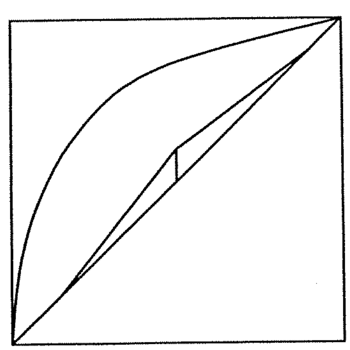
Here are some mole-fraction points along the equilibrium curve at the pressure of operation. The concentrations are in units of mole fraction 2-octanone.

X, liquid	Y, vapour
0.0	0.0
0.2	0.375
0.4	0.600
0.6	0.780
0.8	0.900
1.0	1.0

(8) Draw a sketch of the column and draw the McCabe Thiele diagram. Assume a feed rate of 100 moles per hour. Use 0.5 as the ratio of liquid reflux to top-product-rate.

(6) Here are the McCabe Thiele diagrams for two different design proposals for a separation process (not necessarily the one above). What is the difference in the two proposals and what are the advantages and disadvantages of each.?





2. One cubic meter per second of air (at ambient conditions) is being bubbled through 40 cubic meters of an aqueous solution of ammonia. The solution initially contains 0.1 mole fraction of ammonia. The whole system is at 80F (26.7 C) and one atmosphere absolute pressure. The contents of the vessel, both vapour and liquid, may be assumed to be fully mixed. The vapour-liquid equilibrium for the system ammonia-air-water is described in the range of interest by the following equation

Mole fraction NH_3 in vapour = 6.69 * (mole fraction NH_3 in liquid) $^{1.65}$

(6) **Case 1:** If the mass transfer is so fast that vapour-liquid equilibrium may be assumed, calculate the initial rate of removal of ammonia from the liquid (moles per second).

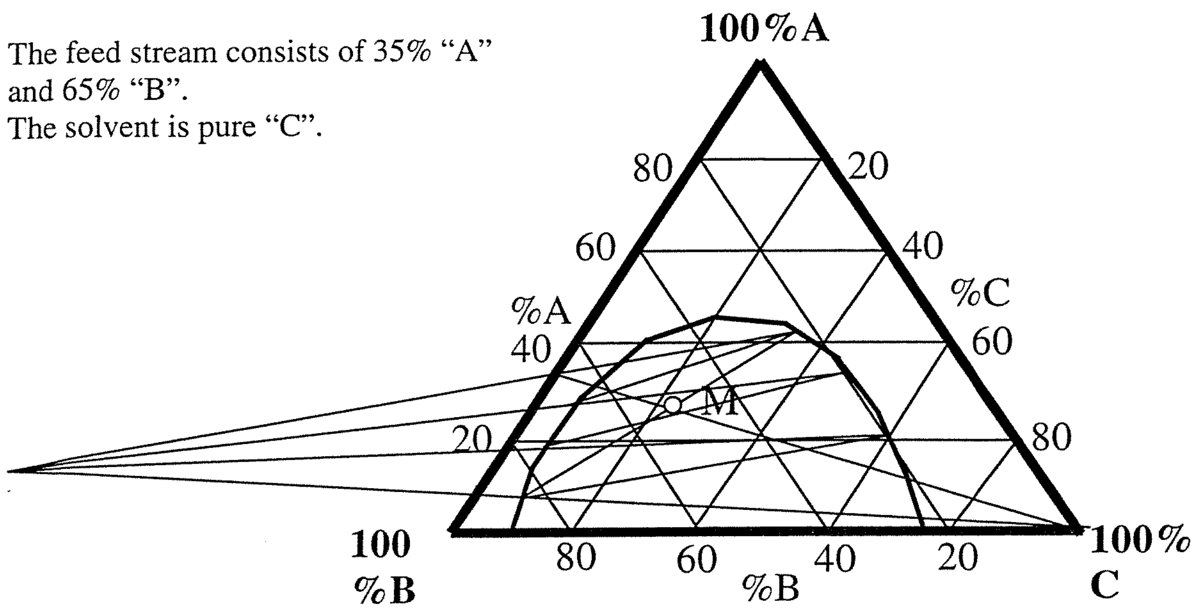
Case 2: Consider next that ammonia removal is limited by mass-transfer resistance such that
Rate of ammonia stripped (moles per cubic meter of liquid per second) =
5 * (mole fraction NH_3 in liquid - equilibrium mole fraction in liquid)

(8) In this case, calculate the initial rate of removal of ammonia from the liquid.

(6) What are the expected effects of temperature in Case 1 and in Case 2? On the rate of ammonia removal ?

3. A solute "**A**" is being extracted from a carrier "**B**" using a solvent "**C**". A three-stage counter-current extraction system is being used. The system is represented by the following diagram:

The feed stream consists of 35% "A" and 65% "B".
The solvent is pure "C".



(6) The air enters at 80 C and 10% relative humidity. What is the water content of this air?

(4) Heat is supplied to keep the air at 80 C. What is the very minimum ratio of air rate to pellet rate if it were possible to operate with the air leaving with 100% relative humidity. Recall that, at 100% relative humidity,

Mole fraction moisture in air = (saturation pressure of water) / (system pressure)

At 80C the saturation pressure of water is 47,550 pascals. System pressure is 101,325 pascals, i.e., one atmosphere.

The dryer is actually operated with a considerably higher air flow, so that the pellets may be considered to be treated with air that is bone dry.

A series of tests have been done on the system, with the following results:

Pellet rate	**Residence time**	**Pellet final moisture**
Kilograms/hour	**Seconds**	**Weight %**
100	450	0.12
150	300	0.74
200	225	1.83
250	180	3.13
500	90	9.23
540	83.3	10.0
1000	45	14.6

(5) Show that these results are consistent with constant-rate drying down to 10% pellet moisture

(5) Show that these results are consistent with falling-rate drying below 10% pellet moisture, with the drying rate being proportional to moisture content.

5. Explain four of the following mass-transfer concepts. (5marks per concept)

1. Benefit of counter-current operation
2. Definition and typical units of mass-transfer coefficients
3. Conceptual design of a stage in a staged device such as a distillation column, gas absorber
4. Operating lines and equilibrium lines
5. Mass-transfer efficiency

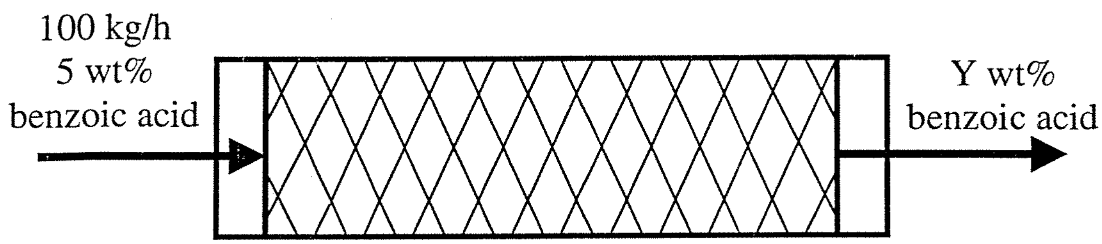
6. A quantity of benzene containing a small amount of benzoic acid is to be treated with silica gel to remove some of the benzoic acid (BA). At low liquid concentrations of BA the following equilibrium relation applies

Weight fraction BA in benzene =
83.5 * (kg BA adsorbed per kg silica gel adsorbent) $^{3.1}$

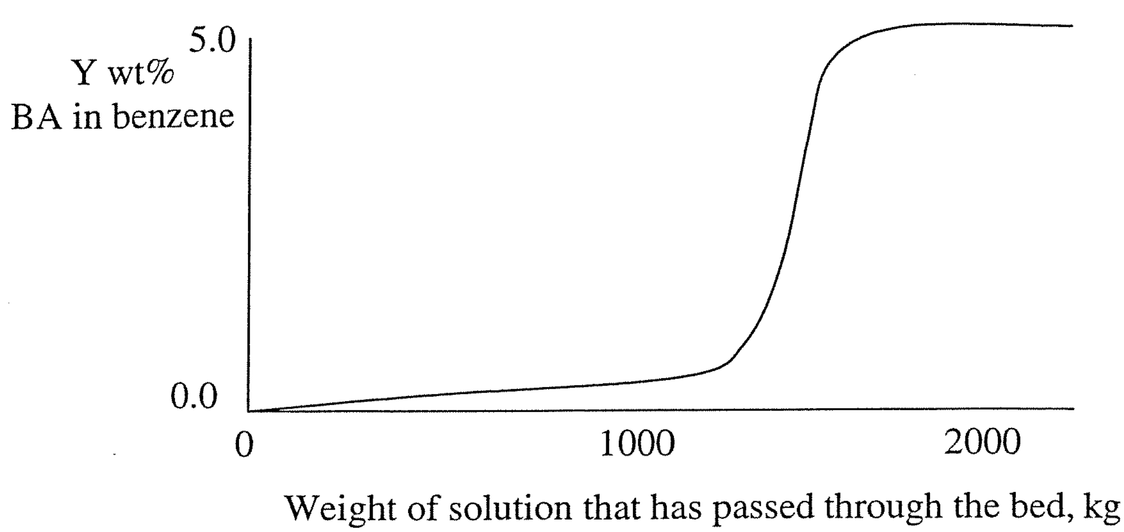
The solution initially contains 5 weight percent BA.

(10) If 100 kilograms of this solution are intimately mixed with 100 kilograms of silica gel and allowed to adsorb until equilibrium is reached, how much BA will adsorb and what is the final concentration of BA in solution?

Instead of a batch adsorption, it is decided to pass the stream of 5% BA-in-benzene continuously through a stationary packed bed of 1000 kg of silica gel, as shown in the sketch.



The concentration of BA in the exit liquid is continuously measured and plotted against the amount of solution that has passed through the bed. The behaviour is shown here.



(10) Explain the shape of this curve. At a time when 500 kg of solution has passed through the bed the amount of BA adsorbed onto the silica gel will vary along the length of the bed. Sketch a graph of

Kg adsorbed BA/kg silica gel -vs- distance along the bed

7. An aqueous solution of an organic salt is being prepared continuously by blending and mixing a stream of acid, base, and water in a vessel.

The acid enters as a stream of pure acid. Acid molecular weight is 146.

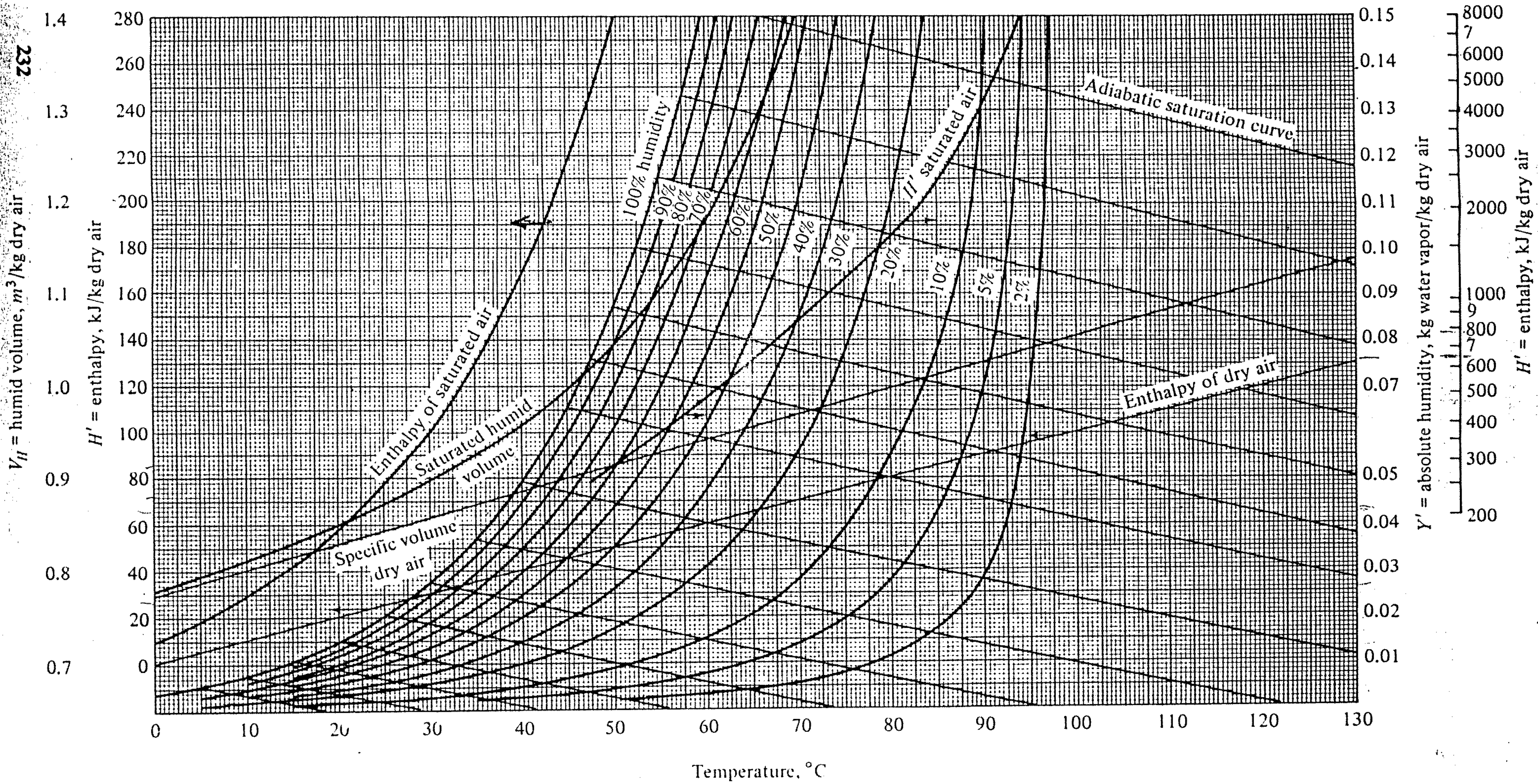
The base enters as an aqueous solution containing 80% by weight of base. The molecular weight of the base is 116.

Extra water, if needed, is supplied as a separate stream.

(7) The blended stream is to contain 40 weight percent water and is to contain acid and base in equi-molar amounts. If the acid feed rate is 1000 kg per hour, calculate the rates of feed of base solution and of extra water.

(5) If the final water content must be within limits of 40 percent plus or minus 1 percent, calculate the allowable variation in the rate of feed of the pure water stream. How would such a system be controlled?

(7) If a rotating mechanical mixer is used, what factors will influence the power requirement? Where will the dissipated mechanical energy appear?



(a)

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