

National Exams - December 2002

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. One hundred grams of acetone (molecular weight 58) are brought together with 200 grams of acetone-free carbon adsorbent and held in a sealed container at 30C. The system is initially at 760 mm Hg abs pressure (101.325 kilopascals). The adsorption isotherm at 30C, over the range 0.1 to 0.4 grams acetone adsorbed per gram of carbon, is described by the equation

Partial pressure acetone in vapour (mm Hg abs) =

$$e^{-1.05 + 16.8 \times \text{g. acetone adsorbed per g. carbon}}$$

- (6) If the system is allowed time to equilibrate, show the calculational procedure by which you determine the final pressure in the system and the amount of acetone adsorbed. Use the perfect gas law for pressure-volume-temperature calculations.
- (4) What is the final pressure and the amount of acetone adsorbed?
- (3) If the temperature is raised to 100C, what will happen (qualitatively)?
- (5) If the starting pressure had been 2 atmospheres absolute but the gas had consisted of an equi-molar mixture of acetone and a negligibly-adsorbing gas like nitrogen, how much acetone would have been adsorbed and what would have been the final pressure?
- (2) What is the Freundlich equation?

2. Wood chips are to be dried. Initially they contain 0.25 grams moisture per gram of dry wood. They are to be dried to 0.10 grams per gram. The chips are in the shape of cubes, measuring 5 millimeters along each edge. Experiments with drying using hot air at 80C have shown the drying rate to be

Constant at moisture levels above 0.20 grams per gram

Proportional to chip moisture at levels below 0.20.

The constant rate is 0.3 grams vaporized per second per square meter of chip surface.

- (10) In a batch process, how long will it take to dry the chips from 0.25 grams per gram down to 0.10. Assume that the air is flowing fast enough to stay close to 80C and to remain at negligible moisture content. Chip density may be assumed constant at 650 kilograms per cubic meter of dry wood.

- (5) Give an explanation of why there are constant-rate and falling-rate regimes in drying.
- (5) In a continuous process, if dry air is entering at 3.0 grams per gram of dry wood, what will be its moisture content leaving the drier? Express as grams moisture per gram of dry air. If the temperature stays at 80C, what is the relative humidity of the exit air?
3. In the type of filtration known as *cake filtration*, a cake of solid particles builds up on the surface of the *filter medium* and imposes a gradually increasing pressure drop through the filter. The passage of liquid, the *filtrate*, through the filter is commonly described by the Hagen-Poiseuille equation:

$$(1/A) * d(V)/d(\text{time}) = P / \{ \mu * (\alpha * w * V/A + \gamma) \}$$

where

A is the surface area of the filter medium (area facing the oncoming stream)

V is the cumulative volume of filtrate

P is pressure drop across filter

μ is liquid viscosity

α is a coefficient to be evaluated (depends on the nature of the solids)

w is weight of filter cake per unit volume of filtrate

γ is a term that accounts for the cake-free pressure drop of the filter

* denotes multiplication

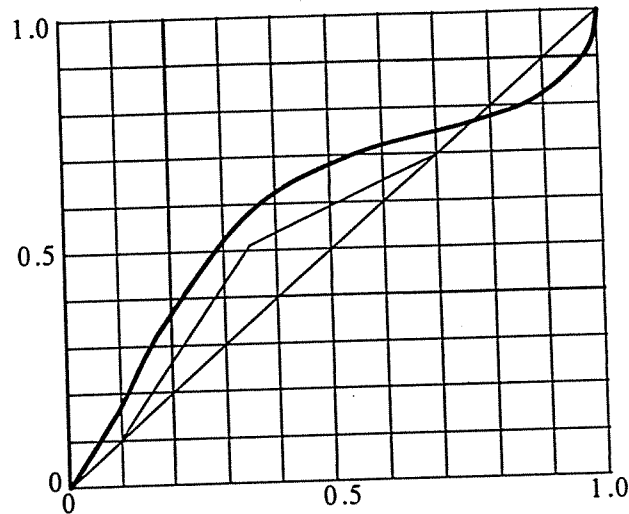
- (4) Comment briefly on this equation. What type of flow (laminar, turbulent) does the equation imply takes place in the filter cake?
- (6) Integrate the H-P equation assuming constant pressure to obtain the relationship

$$\text{Time} / (V/A) = \mu \alpha w V / (2 P A) + \mu \gamma / P$$

And show how this equation could be used to set up a test to evaluate α and γ for a particular filter and liquid-particle system.

- (5) What is the purpose of a filter aid?
- (5) List and briefly describe some common types of filter.

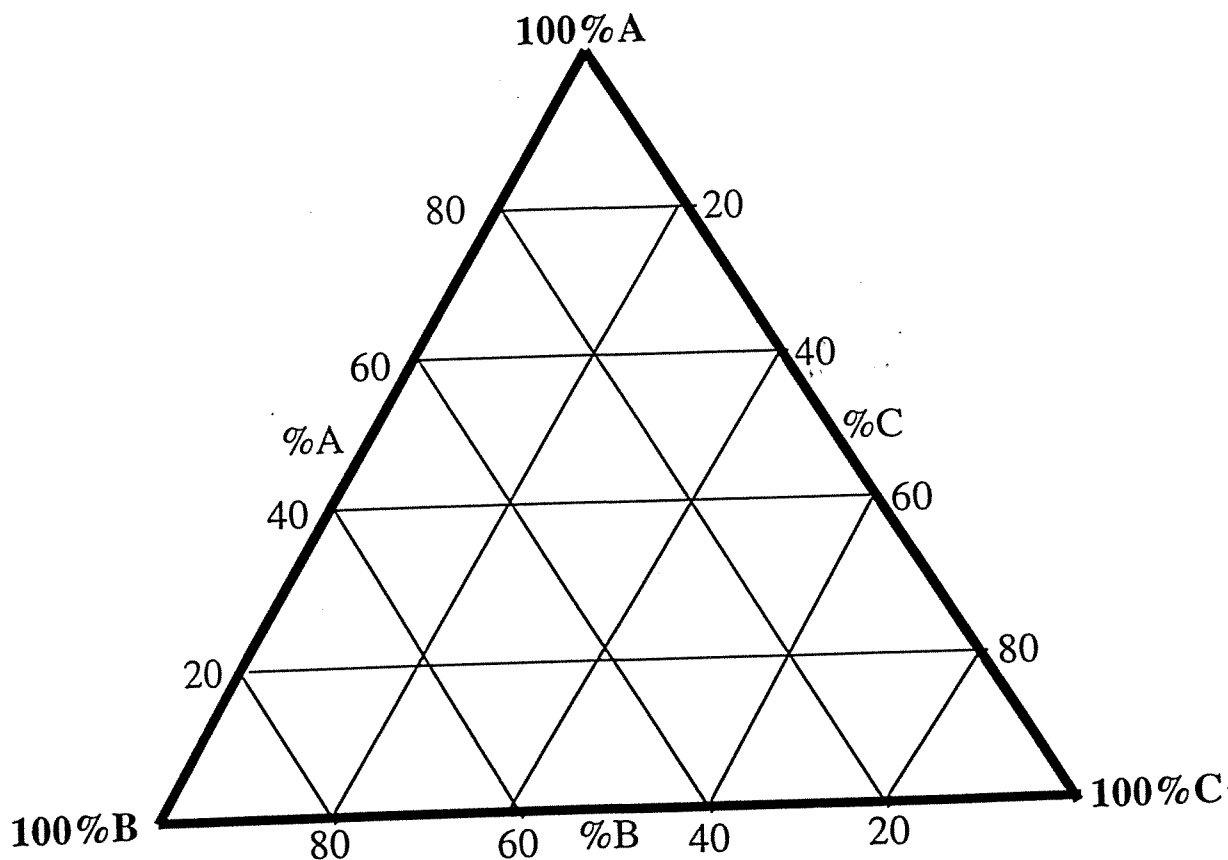
4. The McCabe Thiele diagram for a particular distillation operation is shown below. The concentrations are in units of mole fraction.



- (4) What are the liquid-to-vapour ratios in the top and bottom of the column?
- (4) The feed is an equi-molar mixture. From the graph, determine if the feed is all liquid, all vapour, or a mixture of liquid and vapour.
- (4) How many perfect stages are required in this column?
- (4) Define single-stage Murphree efficiency and explain why stages are generally imperfect.
- (4) Sketch a typical reboiler (e.g., kettle or thermosiphon) for a distillation column.
5. Water is being used to extract acetic acid from chloroform. Some liquid-liquid equilibrium data are available in the form of tie-lines relating weight fractions in the two immiscible phases that form:

Phase	Acetic Acid Weight %	Chloroform Weight %	Water Weight %
Chloroform-rich	6	92	2
Water-rich	25	3	72
Chloroform-rich	16	81	3
Water-rich	42	7	51

- (5) Fifty kilograms of water are brought into contact with 100 kg of a solution containing 22 weight percent acetic acid and 78% chloroform. The resulting equilibrium phases are approximately described by one of the above tie-lines. Show by mass-balance calculation which tie-line it is.
- (3) How much of each phase is produced?
- (4) Show the extraction on a rough triangular diagram.
- (3) What are the common names for the two starting liquids and the two equilibrium phases?
- (5) Show by a simple sketch, with a mixer and a separator for each stage, a two-stage counter-current system.



6. The diameter of small solid particles is sometimes estimated by measuring the steady (terminal) velocity of settling in a liquid. The technique makes use of Stokes' law, which states that the resistance R of a fluid to the motion of a sphere of diameter D moving at velocity U , is given by

$$R = 3 \pi D U \mu$$

Where μ is liquid viscosity.

- (5) Using this law, write the force balance on a particle falling at steady velocity under gravity and derive the formula for particle diameter:

$$D = \sqrt{\{18 * U * \mu / [(\rho_s - \rho_l) * g_c]\}}$$

Note that the volume of a sphere is $(\pi / 6) \times D^3$. ρ_s and ρ_l are the densities of solid and liquid respectively. * denotes multiplication.

- (5) In size reduction (or comminution) of solids, the danger of fire or explosion may arise as the particles get smaller. Explain.

The energy of size-reduction increases as size gets smaller. A general expression for energy consumption is

$$d(E) = -C d(X) / X^n$$

Where E is work required (typically kilowatt-hours per tonne)

X is particle linear size

C and n are constants to be determined for the particular solid and equipment.

- (5) Show how one particular choice of the index n leads to the commonly used *Bond's Law*:

$$E = 100 E_I * (1 / \sqrt{X_P} - 1 / \sqrt{X_F})$$

Where X_P is the linear dimension of the final particles

X_F is the linear dimension of the feed particles

E_I is the 'Bond index'

- (5) Screening is a technique used to separate particles into different sizes. Using a set of standard screens, into how many groupings can a collection of particles ranging in size from 1 to 4 millimeters be divided? What is the formula that is used to set the hole sizes of successive screens?

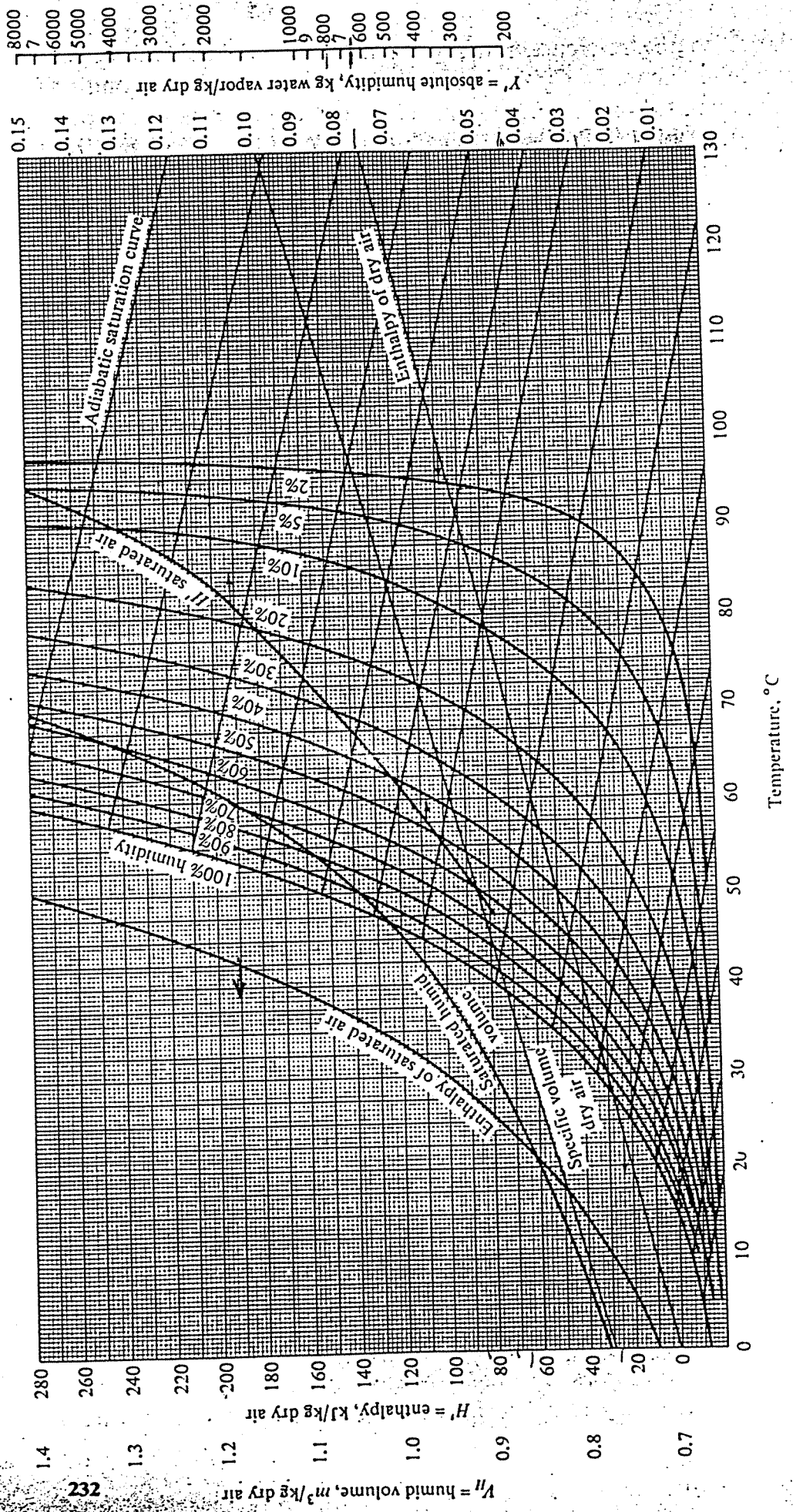
7. A tank contains ammonia (molecular weight 17) at 30C at 2 atmospheres pressure i.e., 1520 mm Hg abs. The tank is designed to withstand internal vacuum down to an absolute pressure of 300 mm Hg abs before collapsing.

A spray of water is accidentally injected into the tank.

At 30C the following absorptivity data are available for the system ammonia-water:

Ammonia dissolved in water	Partial pressure of ammonia in vapour
Mole fraction	Mm Hg abs
0	0
0.15	219
0.20	338
0.25	480

- (12) How many kilograms of water can be added before the tank collapses? Assume the perfect gas law for pressure-volume-temperature calculations.
- (8) Sketch a counter-current absorption column and show the plot of equilibrium line and operating line for the following process: an air stream of 50 kg/h dry air entering with 0.07 kg ammonia per kg dry air and leaving with 0.01 kg per kg, and water at 80 kg/h entering with zero dissolved ammonia. The equilibrium line has a slope of approximately unity.



(a)

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