National Exams December 2008

04-Chem-A1 Process Balances and Chemical Thermodynamics

Three Hours Duration

NOTES:

1. If doubt exists as to the interpretation of any question, you are urged to submit with the answer paper, a clear statement of any assumptions made.
2. Property data required to solve a given problem are provided in the problem statement or are available in the recommended texts. If you are unable to locate the required data, do not let this prevent you from solving the rest of the problem. Even in the absence of property data, you still have the opportunity to provide a solution methodology.
3. This is an open-book exam.
4. Any non-communicating calculator is permitted.
5. The examination is in two parts – Part A (Questions 1 – 3) and Part B (Questions 4 – 6). Answer **TWO** questions from Part A and **TWO** questions from Part B. **FOUR** questions constitute a complete paper.
6. All questions are of equal value.

PART A: ANSWER TWO OF QUESTIONS 1 – 3

Note: Four questions constitute a complete paper
(with two from Part A and two from Part B).

1. A tannery process involves feeding finely ground wood to an extractor where it is treated with hot water. The wood feed stream consists of 4 mass % moisture, 37 mass % tannin, 23 mass % soluble nontannin material, and the balance insoluble bark. The liquid stream leaving the extractor consists of water enriched with tannin and soluble nontannin material. The residue removed from the extractor consists of 62 mass % moisture, 2.8 mass % tannin, 0.9 mass % soluble nontannin material, and the balance insoluble bark.

   (a) Perform a degree-of-freedom analysis for the extractor.
   (b) What percentage of the tannin in the original wood feed stream remains unextracted in the residue?

2. Ethanol is being produced by a hydration reaction involving ethylene:

$$C_2H_4 + H_2O \rightarrow C_2H_5OH$$

Some of the product ethanol is converted to diethyl ether in a side reaction:

$$2\ C_2H_5OH \rightarrow (C_2H_5)_2O + H_2O$$

The feed to the reactor contains ethylene and steam in a 3:2 molar ratio, as well as 10 mole % inerts. The fractional conversion of ethylene is 5 %, and the selectivity of ethanol production relative to ether production is 18.0 mol/mol. Calculate the molar composition of the reactor output stream.

3. A natural gas containing 87 mole % CH_4 and the balance C_2H_6 is burned with 20 % excess air in a well-insulated furnace. The gas enters the furnace at 298 K and the air is preheated to 423 K. The heat capacities of the stack gas components may be assumed to have the following constant values:

CO_2:	$C_p = 50.0$ J/mol·K
$H_2O(v)$:	$C_p = 38.5$ J/mol·K
O_2:	$C_p = 33.1$ J/mol·K
N_2:	$C_p = 31.3$ J/mol·K

Calculate the temperature of the stack gas at the furnace exit for the case of complete combustion of the fuel.

PART B: ANSWER TWO OF QUESTIONS 4 – 6

Note: Four questions constitute a complete paper (with two from Part A and two from Part B).

4. In several parts of the world (e.g. Newfoundland), although natural gas has been located, there are no markets nearby to use it. One potentially economic method of shipping the gas is to convert it to methanol by high-temperature partial oxidation and then ship the resulting liquid. The reaction involved is:

$$CH_4 + 0.5\,O_2 \rightarrow CH_3OH$$

It has been determined from process and economic considerations, that a conversion of 85 % would be most suitable for this reaction, if equilibrium were assumed. You are to calculate the following:

(a) the relationship of heat of reaction (1 atm absolute) with temperature,
(b) the relationship of Gibbs free energy with temperature, and
(c) approximately what the temperature of the reaction would be in the reactor (assuming isothermal conditions) at the required 85 % conversion.

Data required:

C_p/R (average):	CH_4	12.3
	O_2	4.2
	CH_3OH	10.0
Reactor Feed (mole %):	CH_4	66.7
	O_2	33.3
	CH_3OH	0.0

5. You are picking up your weekly supply of krypton gas from your local supplier, and notice that although the cylinder pressure reads the usual 150 bar (absolute), the cylinder is warm to the touch (40 °C). You mention this to the supplier who realizes that the gas has not cooled down from its recent compression. He agrees to give you a discount because there would be more gas in the same volume at the normal pressure of 150 bar (absolute) and temperature of 20 °C.

   (a) Calculate the percent discount to which you would be entitled.

   (b) After leaving the gas cylinder standing overnight, it has cooled to 20 °C. What would be the resulting absolute pressure in the cylinder?

6. This question concerns the distillation of a 50 mole % mixture of cyclohexanol and benzyl alcohol at 100 °C. The following information is available for this system:

   - A mixture of 28 mole % cyclohexanol and 72 mole % benzyl alcohol boils under normal atmospheric pressure (760 mm Hg) at 189 °C. The vapour contains 35.6 mole % cyclohexanol.
   - Cyclohexanol, at 760 mm Hg, boils at 161 °C and has a heat of vaporization of 45,235.6 J/mol.
   - Benzyl alcohol, at 760 mm Hg, boils at 207 °C and has a heat of vaporization of 50,697.1 J/mol.
   - The vapour can be considered to behave as an ideal gas.

   It has also been determined that the total excess Gibbs free energy is related to the liquid composition by:

$$G^E/RT = A\,X_1\,X_2$$

where: G^E is the excess Gibbs free energy (J/mol), A is a constant, and X_1 and X_2 are the mole fractions of cyclohexanol and benzyl alcohol, respectively.

(a) Calculate the value of the constant A in the above relationship.

(b) It is desired to boil a solution of 50 mole % cyclohexanol at a temperature of 100 °C. Calculate the total pressure under which the solution would boil and the resulting vapour composition. Note that at equal liquid compositions, the activity coefficients are equal, i.e. $\gamma_1 = \gamma_2$.