National Exams December 2011

04-Chem-A1 Process Balances and Chemical Thermodynamics

Three Hour Duration

NOTES:

1. If doubt exists as to the interpretation of any question, you are urged to submit a clear statement of any assumptions made along with the answer paper.

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. Any non-communicating calculator is permitted.

4. The examination is in three parts – Part A (Questions 1 and 2), Part B (Questions 3 and 4) and Part C (Questions 5-7). Answer **ONE** question from Part A, **ONE** question from Part B and **TWO** questions from Part C. **FOUR** questions constitute a complete paper.

5. Each question is of equal value.

PART A: ANSWER ONE OF QUESTIONS 1-2

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

1) Wet air containing 4.0 mole% water vapour is passed through a column of calcium chloride pellets. The pellets adsorb 97% of the water but none of the other constituents of the entering air. The column packing of pellets was initially dry and had a mass of 3.40 kg. Following five hours of operation, the pellets are reweighed and found to have a mass of 3.54 kg.

Calculate

a) The molar flow rate (mol/h) of the air stream fed to the adsorption column.
b) The mole fraction of water vapour in the air stream leaving the unit.

2) Liquid methanol is fed to a heating unit at a rate of 12 L/h, where it is burned with excess air. The product gas from the heater has the following dry-basis mole percentages:

CH_3OH	0.45%
CO_2	9.03%
CO	1.81%

Determine

a) The conversion of methanol.
b) The percentage excess air fed.
c) The mole fraction of water in the product gas.

PART B: ANSWER ONE OF QUESTIONS 3-4

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

3) Lime (calcium oxide) is widely used in the production of cement, steel, soap, rubber and many other materials. It is usually produced by heating and decomposing limestone (calcium carbonate), a cheap and abundant material, in a process known as calcination which is represented below:

$$CaCO_{3\,(s)} \rightarrow CaO_{(s)} + CO_{2\,(g)}$$

Limestone at 25°C is fed to a continuous calcination reactor. The reactor goes to completion, and the products leave the reactor at 900°C. Using one metric ton (1000 kg) of limestone as a basis, determine how much heat (J) has to be transferred to the reactor.

4) Nitric oxide can be formed by the partial oxidation of ammonia with air according to the following reaction:

$$4NH_{3\,(g)} + 5O_{2\,(g)} \rightarrow 4NO_{(g)} + 6H_2O_{(g)}$$

In a given reactor, the feed consists of ammonia at 25°C and preheated air at 750°C which are reacted at 1.0 atm pressure to produce 90% conversion of the ammonia. If the reactor effluent is not allowed to exceed 920°C, calculate the required rate of heat removal per mole of ammonia fed, assuming a feed of 2.4 moles of oxygen per mole of ammonia.

PART C: ANSWER TWO OF QUESTIONS 5-7

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

5) A well-insulated heat exchanger for cooling a hot hydrocarbon liquid uses 1000 kg/h of cooling water that enters the exchanger at 25°C. The hot hydrocarbon stream enters at 200°C and leaves at 75°C, and has a throughput of 500 kg/h.

$(C_p)_w = 4.19$ kJ/kg·°C $\qquad$ $(C_p)_h = 2.51$ kJ/kg·°C

Calculate:

a) ΔS for the hydrocarbon and water streams.
b) ΔS total. Is the change reversible? Why or why not?
c) The amount of work that would be available if the cooling process had been carried out by using the heat from the hydrocarbon stream to operate a reversible Carnot cycle with a sink temperature of 25°C.

6) You have designed a high-efficiency engine that functions at relatively high temperatures. As a result, the cooling system must run at 220°C. The cooling fluid is made up of two liquids whose properties are shown below:

Saturated Vapour Pressures:

$$\ln P_1^{sat} = 19.75 - \frac{5690}{T}$$

$$\ln P_2^{sat} = 20.90 - \frac{8245}{T}$$

Activity Coefficients:

$$\ln \gamma_1 = 0.53x_2^2 + 0.17x_1$$

$$\ln \gamma_2 = 0.38x_1^2$$

P_1^{sat} and P_2^{sat} are in mm Hg. T is in degrees Kelvin. x_i is the mole fraction in the liquid.

The maximum design pressure of the cooling system (radiator, hoses, etc.) is 2 bar. Calculate the liquid composition of the coolant at this pressure.

7) You are in charge of a reactor that produces hydroxylamine (NH_2OH) via the catalytic gas-phase reaction of ammonia and air. The reaction

$$NH_3 + 0.5\ O_2 \rightarrow NH_2OH$$

occurs at 100°C and 1.0 bar. Data for hydroxylamine are found below:

A/R	ΔH^o_{f298} [kJ/kmol]	ΔG^o_{f298} [kJ/kmol]	T_c [K]	P_c [bar]	ω
3.657	- 62,090	- 23,982	379.0	13.3	0.0

The feed consists of ammonia with air at twice the stoichiometric amount.

a) Calculate the percent conversion of ammonia at equilibrium when T = 100°C and P = 1.0 bar. Use the ideal gas assumption.

You are told to increase the reactor temperature to 125°C in order to improve the kinetics, i.e. speed up the reaction. However, this will affect the equilibrium conversion. There are two ways to change the reaction conditions such that the equilibrium conversion stays the same: you can either increase the oxygen concentration or increase the reactor pressure.

b) Increase the oxygen concentration in the feed by using "oxygen-enriched" air. Calculate the oxygen concentration in the feed. (Oxygen must still be maintained at twice the stoichiometric value.)

c) Increase the reactor pressure. Calculate this pressure.

Use only the A term for C_p as a reasonable approximation. Assume that the gas mixture behaves as an ideal mixture, i.e. $\hat{\phi}_i = \phi_i$.