

National Exams December 2009

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. Wet air containing 4 mole % water vapour is passed through a column of calcium chloride pellets. The pellets adsorb 97 % of the water and 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.

(a) Calculate the molar flow rate (mol/hr) of the air stream fed to the adsorber and the mole fraction of water vapor in the air stream leaving the unit.

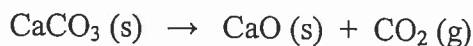
(b) Over time, what will happen to the value of the mole fraction of water vapour in the air stream leaving the adsorber? Explain your reasoning and describe what you would do to ensure continued operation of the unit.

2. Liquid methanol is fed to a heating unit at a rate of 12 L/hr where it is burned with excess air. The product gas from the heater has the following dry-basis mole percentages: CH₃OH = 0.45 %, CO₂ = 9.03 %, and CO = 1.81 %.

(a) Determine the conversion of methanol, the percentage excess air fed, and the mole fraction of water in the product gas.

(b) Suppose the product gas analysis had been conducted on a wet basis and in addition to the mole percentages of CH₃OH, CO₂ and CO, the percentage of water in the product gas was now known. Describe how your calculations in part (a) would be affected.

3. Lime (calcium oxide) is usually produced by heating and decomposing limestone (calcium carbonate), a cheap and abundant mineral, in a process known as calcination:



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

(b) What would happen to the part (a) answer if a preheated stream containing a combustible gas (e.g. carbon monoxide) and oxygen was co-fed to the reactor? Explain your reasoning. Also, what might prevent such a co-feed arrangement in practice?

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. A product is being made by two batch distillations. You have been asked to design a plant to convert an initial liquid to final product. The following data have been obtained by you in laboratory tests:

- The concentration of the liquid from the first distillation is 8 mole % ethanol.
- The vapour product from the first distillation contains 21.5 mole % ethanol, the rest being water.
- The vapour pressures (mm Hg) of pure ethanol and water are given by the Clausius-Clapeyron equations (T in K):

$$\text{For Ethanol: } \ln P_{\text{sat}} = -4721.6/T + 20.08$$

$$\text{For Water: } \ln P_{\text{sat}} = -4892.5/T + 19.75$$

- The equations that describe the relationship of activity coefficients to liquid mole fractions are:

$$\ln \gamma_1 = A (X_1) (X_2)^3$$

$$\ln \gamma_2 = A (X_2) (X_1)^3$$

- Kay's rule, $T_{\text{mix}} = \Sigma (X_i) (T_i)$, can be used to estimate the boiling temperature of ethanol and water liquid mixtures.
- The vapour, being at 1 atmosphere absolute pressure, can be considered to follow the ideal gas relationship.

Calculate the mole percent and weight percent of ethanol in the final (second-distilled) product.

5. The decomposition of N_2O_4 can be represented by the following reaction scheme:



For this reaction, the functional relationship of standard free energy to temperature is given by (T in K):

$$\Delta G^\circ = 64,709 - RT [-1.696 \ln(T) + 0.0665 \times 10^{-3} T + 0.602 \times 10^5/T^2 + 33.08]$$

At a temperature of 350 K, the feed mixture consists of (mole basis):

N_2O_4 20 % NO_2 15 % Inerts 65 %

(a) Calculate the equilibrium conversion of N_2O_4 and the equilibrium composition of the mixture. The reaction is occurring at 1 bar and ideal gas behaviour may be assumed.

(b) If the pressure were lowered to 0.5 bar, what effect would this have on the conversion of N_2O_4 for the same temperature and feed composition as part (a).

6. You are having a cylinder filled with krypton gas. The empty cylinder has a pressure gauge that is calibrated for nitrogen gas. Normally the cylinder is filled to an absolute pressure of 150 bar.

Calculate the ratio of the amount (kmol) of krypton gas in the cylinder to that which would be in the cylinder if it were filled with nitrogen (150 bar absolute pressure and 20 °C in both cases).