National Exams May 2010

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 unit operation is being used to separate magnesium oxide from silica so the magnesium oxide can be used to manufacture refractory brick. The unit separates the lighter MgO particles from the heavier SiO_2, yielding a magnesium oxide-rich concentrate and a silica-rich tailings. The feed to the unit has the following composition: 91.8 mass % MgO and 4.8 mass % SiO_2. The concentrate leaving the unit is composed of 94.2 mass % MgO and 2.9 mass % SiO_2, and the tailings leaving the unit are 85.0 mass % MgO and 10.0 mass % SiO_2.

(a) Perform a degree-of-freedom analysis for the process as described above.
(b) Calculate the mass yields of concentrate and tailings per unit mass of feed.
(c) Of the MgO in the feed, what percentage is recovered in the concentrate?
(d) Of the MgO in the feed, what percentage is lost in the tailings?

2. The following reaction is carried out in a continuous reactor operating at steady state:

$$A + B \rightarrow C$$

An undesired secondary reaction also occurs:

$$C \rightarrow D$$

Because the single-pass conversion of reactant A is only 80 %, the reactor product is sent to a separator where unconsumed reactants A and B are recycled back to the reactor. Desired product C and undesired product D also leave the separator in separate streams. The feed to the reactor consists of 40 mole % A and 60 mole % B. The mole ratio of products C and D leaving the reactor is 10 to 1 (i.e., 10 moles of C for every one mole of D).

If the feed rate to the reactor is 100 mol/hr, calculate the
(a) total molar flow rate of the fresh feed to the process,
(b) production rate of C and D, and
(c) overall conversion of A.

3. A fuel (ethane) is burned with its theoretical air in a furnace. All of the ethane is consumed, but 20 % of the ethane fed forms carbon monoxide with the remainder burning to carbon dioxide. The ethane and air streams enter the furnace at 25 °C and the combustion products leave at 400 °C.

Calculate the required heat removal rate from the furnace per mol of fuel fed.

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. You are designing a distillation column to separate two components (1) and (2). As an initial estimate of the feasibility of this separation, you are to calculate the relative volatility, α, at a liquid mixture concentration $X_1 = 0.75$ mole fraction and at 350 K using both ideal and non-ideal solution methods. The following data are needed:

Relative volatility is defined as $(Y_1/X_1)/(Y_2/X_2)$; Y = mole fraction in the vapour.

The vapour pressures (mm Hg) of pure components (1) and (2) are given by the Clausius-Clapeyron equations (T in K):

Component (1): $\ln P_{sat} = -4903/T + 21.5$

Component (2): $\ln P_{sat} = -4865/T + 21.2$

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

$$\ln \gamma_1 = -0.487\,(X_2)^2$$

$$\ln \gamma_2 = 0.178\,(X_1)^2$$

Calculate the relative volatilities for the ideal and non-ideal cases, and the % error when using the ideal case over the non-ideal one.

5. In order to make use of so-called "stranded" natural gas, it is proposed to convert the CH_4 content to a more useable transportation fuel (octane) by using a two-step reaction scheme known as Fischer-Tropsch synthesis:

$$CH_4 + H_2O \rightarrow CO + H_2 \qquad (1)$$

$$8\,CO + 17\,H_2 \rightarrow C_8H_{18} + 8\,H_2O \qquad (2)$$

(a) Calculate the energy efficiency of this conversion, defined as the amount of heat of combustion available per mole of octane divided by that of CH_4 at 1 atmosphere pressure and 298 K.

(b) Reaction (1) normally takes place at 900 K. You are to calculate the equilibrium composition of the reactor outlet for a stoichiometric feed of CH_4 and H_2O. You may assume that C_P values are constant and equal to:

CH_4: $C_P/R = 4.217$	H_2O: $C_P/R = 4.083$
CO: $C_P/R = 3.507$	H_2: $C_P/R = 3.468$

6. You are part of the design team to make a car to compete in a gas-mileage contest. It is well known that the use of ultra-high pressure tires will decrease the rolling resistance of the car; you have developed a special carbon fibre/rubber composite for this purpose. The maximum pressure possible in the tire is 50.2 bar absolute; ethylene gas is to be used for inflation. The morning of the trial, the tire is to be inflated. However, the morning temperature is 20 °C, and it is known that during the race, under hot, desert conditions, the temperature can get up to 52 °C on the track.

Calculate the pressure to which the tire is to be inflated in the morning such that the tire pressure stays within the design limit. You may assume that the volume of the tires remains constant.