National Exams May 2011

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 all **THREE** questions from Part A and any **TWO** questions from Part B. **FIVE** questions constitute a complete paper.
6. Questions have the values shown.

PART A: ANSWER ALL THREE OF QUESTIONS 1 – 3

Note: Five questions constitute a complete paper

(with all three from Part A and any two from Part B).

1. Value = 10 marks

A mixer is designed to produce 300 kg/day of battery acid composed of 18.6 mass % H_2SO_4 and the remainder water. Three raw material streams are fed to the mixer: pure water, a dilute sulfuric acid solution (10.8 mass % H_2SO_4 in water), and a concentrated sulfuric acid solution (77.0 mass % H_2SO_4 in water).

(a) Perform a degree-of freedom-analysis to demonstrate that this system is underspecified.

(b) Because water is the least expensive of the raw materials, it is desired to use as high an inlet flow of the pure water stream as possible. Determine whether a pure water inlet flow of 250 kg/day is feasible for the mixer as designed.

2. Value = 20 marks

A natural gas is to be burned with 10 % excess air. Two supplies of natural gas are available as shown in the table below:

Natural Gas	Mole % CH_4	Mole % C_2H_6	Mole % C_3H_8	Mole % C_4H_{10}	Mole % N_2
Birmingham, Alabama	90.0	5.0	0	0	5.0
Libyan LNG	70.6	15.0	10.0	3.5	0.9

(a) Which natural gas should be selected if the primary design criterion is to feed the least amount of dry air to the combustion chamber per mole of fuel fed? You need to show supporting calculations for the actual air supply required for each natural gas.

(b) What is the composition of the combustion product stream arising from the selected natural gas if only 80 % of the natural gas is consumed with no production of carbon monoxide?

3. Value = 20 marks

Methanol at a pressure of 1 bar and temperature of 675 °C is fed to a single-pass, well-insulated reactor to produce formaldehyde according to the following reaction:

$$CH_3OH\ (g) \rightarrow HCHO\ (g) + H_2\ (g)$$

A once-through conversion of 25% of the methanol fed is achieved in the reactor. Calculate the temperature of the gaseous product stream using mean molal heat capacities of 17, 12 and 7 cal/(mol)(°C) for CH_3OH, HCHO and H_2, respectively. Comment briefly on the impact this assumption of constant gaseous heat capacities has on your solution.

PART B: ANSWER ANY TWO OF QUESTIONS 4 – 6

Note: Five questions constitute a complete paper

(with all three from Part A and any two from Part B).

4. Value = 25 marks

You are given the task of designing a device that can indicate temperature by reading gauge pressure. The pressure gauge is to be attached to a cylinder that is partially filled with a mixture of two liquids; the gauge measuring the pressure is in the vapour space. Given the properties of the two liquids below, you are to calculate:

(a) the mole fractions required of the two liquids in the solution so that the gauge reads 60 kPa when the temperature of the mixture is 60 °C, and

(b) the resulting vapour mole fractions.

You may assume that the vapour phase can be treated as an ideal gas.

The vapour pressures (mm Hg) of pure component (1) and (2) are given by the following Antoine equations (P in mm Hg, T in °C):

For (1): $\ln (P_1)_{sat} = 20.58 - 4050.0/(T + 239.0)$

For (2): $\ln (P_2)_{sat} = 18.75 - 3428.9/(T + 237.2)$.

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

$\ln \gamma_1 = -0.702 \ (X_2)^2$

$\ln \gamma_2 = -0.622 \ (X_1)^2$

5. Value = 25 marks

An offshore natural gas field has been found which happens to be in a very remote part of the world. It has been decided to use part of the gas to generate electricity for the plant to be built. The flow rate of gas (100% CH_4) is to be 2400 standard m^3 per hour (scmh) and is available at 3 °C and 150 bar. It is necessary to provide this gas at a temperature of 500 °C to the turbine inlet prior to combustion using a heat exchanger supplied with waste heat from the power generation process. Assuming that the pressure drop in the heat exchanger is negligible, calculate:

(a) the actual flow rate of the gas before and after the heat exchanger, and

(b) the amount of heat (kW) necessary to perform the required heating.

6. Value = 25 marks

A group of chemical engineers has been hired to investigate alternatives to the use of petroleum in the manufacture of n-pentene (C_5H_{10}). It is proposed that the following reaction be used. The reaction normally takes place at 1500 K and 50 bar pressure.

$$CO_2 + 3\,H_2 \rightarrow 1/5\,C_5H_{10} + 2\,H_2O$$

(a) Calculate the value of the equilibrium constant at 1500 K and 1 bar pressure.

(b) Calculate the equilibrium constant if the reaction were run at 50 bar and 1500 K instead of 1 bar.

(c) Obtain an equation for the conversion of CO_2 at 50 bar and 1500 K. It is not necessary to solve the equation for conversion.

You may assume that ideal gas behaviour can be used, and that C_P values are constant and equal to:

CO_2: $C_P/R = 6.20$ C_5H_{10}: $C_P/R = 46.0$

H_2: $C_P/R = 3.59$ H_2O: $C_P/R = 4.60$