National Exams December 2014

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.

4) Any non-communicating calculator is permitted.

5) 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.

6) The question from Part A is worth 15 marks, the question from Part B is worth 25 marks, and each of the questions in Part C is worth 30 marks, for a total of 100 marks.

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) A seawater purification process has been designed to produce 2000 kg/h of pure water in the form of ice by freezing H_2O out of seawater. The concentration of NaCl in the seawater entering the freezing unit is 2% by mass, and the concentration of NaCl in the liquid brine leaving the freezing unit is 10% by mass. Calculate the mass flow rate of the seawater fed to the freezing unit.

2) Although gasoline is actually a mixture of numerous compounds, for this problem it can be assumed to consist of 11 mol% *i*-butane, 10 mol% *i*-pentane, 12 mol% *n*-hexane, and 7 mol% *n*-heptane, with the remainder being low-volatility compounds, which can be ignored.

Suppose a sealed can of this gasoline is sitting outside on a hot summer day on which the temperature is 38°C. The can has been tested and found to be acceptable up to a gauge pressure of 200 mm Hg.

a) Will the can deform under these conditions?
b) Estimate the temperature at which the "safe" pressure of 200 mm Hg (gauge) would be exceeded.

PART B: ANSWER ONE OF QUESTIONS 3-4

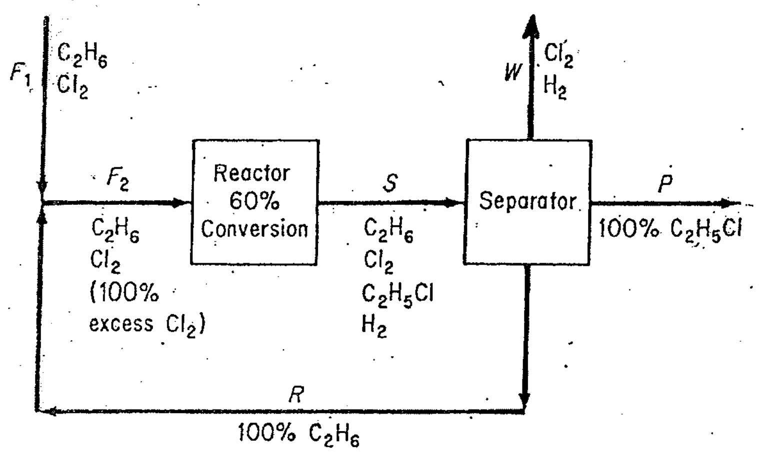
Note: Four questions constitute a complete paper
(with one from Part A, one from Part B and two from Part C)

3) Ethyl chloride can be prepared by the following reaction:

$$2C_2H_6 + Cl_2 \rightarrow 2C_2H_5Cl + H_2$$

In the reaction process in the sketch below, fresh ethane, fresh chlorine and recycled ethane are combined and fed into a reactor. A test shows that if 100% excess chlorine is mixed with ethane in the reactor feed, a single-pass conversion of 60% will be obtained and the ethane that reacts will yield only the desired products, i.e. there will be no undesired side reactions. Calculate the following:

a) the molar composition of the feed
b) the molar ratio of ethyl chloride produced to ethane in the fresh feed
c) the molar composition of stream W leaving the separator
d) the overall conversion of chlorine



4) A fuel gas consisting of 50 mol% CO, 30 mol% CO_2, and 20 mol% N_2 is burned with 205 excess air in an adiabatic combustion chamber. The fuel gas enters the chamber at 100°C and the air enters at 200°C. Only half of the CO in the entering fuel gas undergoes combustion. Calculate the temperature of the gaseous product stream leaving the combustion chamber.

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) In an air-liquefaction process, air is compressed from 1.0 bar and 25°C to 180 bar. To avoid overheating, the compression is carried out in stages so that the exit temperature does not exceed 200°C. The stream exiting a stage is cooled to 25°C before it is fed to the next stage. If the efficiency of the compression in each stage is 80%, determine the number of stages required and the total amount of compression work.

6) At 70°C and 1.0 bar, a system consisting of acrylonitrile (1) and water (2) forms two phases; one is rich in acrylonitrile (A) and the other is rich in water (W). The mole fraction of acrylonitrile in the acrylonitrile-rich phase is $x_{1A} = 0.968$, and the mole fraction of acrylonitrile in the water-rich phase is $x_{1W} = 0.073$. Assume that the Margules equation is appropriate for this system.

a) Calculate the activity coefficients of the two components at the given condition.
b) Calculate the bubble-point pressure of the two-phase system at 70°C and the composition of the vapour.

The saturation pressures of the pure components at 70°C are as follows:

$$P_1^{sat} = 0.791 \text{ bar} \qquad P_2^{sat} = 0.312 \text{ bar}$$

7) Consider the water-gas shift reaction

$$CO_{(g)} + H_2O_{(g)} \leftrightarrow CO_{2(g)} + H_{2(g)}$$

A reactor initially contains one mole of each of the four species. The temperature is 900 K and the pressure is 1.0 bar.

a) What percentage of CO has reacted when the system has reached equilibrium?
b) Estimate the amount of heat per mole of CO that would need to be added or removed from the reactor to keep the temperature constant.
c) At what temperature should you run the reaction in order to react 50% of the initial amount of CO?