

**National Exams December 2013**

**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) 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) Liquid acetone ( $C_3H_6O$ ) is fed at 400 L/min to a heated chamber where it evaporates into a stream of nitrogen. The gas leaving the evaporator is diluted by a second nitrogen stream flowing at  $419 \text{ m}^3$  (STP)/min. The combined gases are then compressed to a total pressure of 7.3 atm at a temperature of  $325^\circ\text{C}$ . The partial pressure of acetone in the final stream is  $p_a = 501 \text{ mm of Hg}$ .

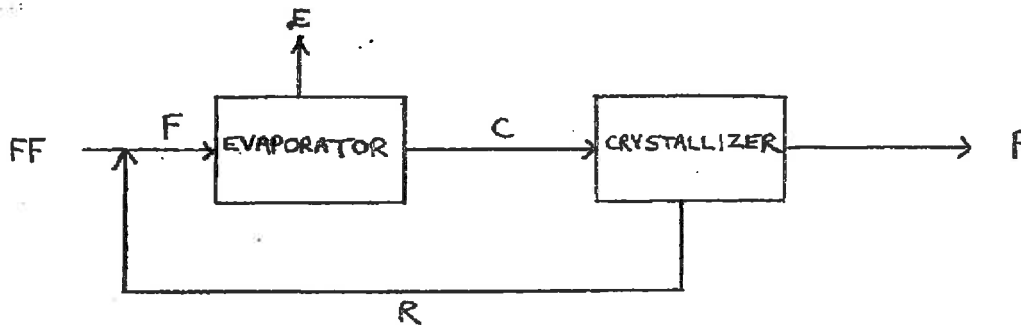
a) What is the composition of the stream leaving the compressor?

b) What is the volumetric flow rate of nitrogen entering the evaporator if  $T = 27^\circ\text{C}$  and  $P_{\text{total}} = 1235 \text{ mm of Hg}$ ?

2) A process involving an evaporator and a crystallizer (Figure 1) is used to obtain solid potassium sulfate from an aqueous solution. The fresh feed is 18.6 wt%  $K_2SO_4$ . The product stream from the crystallizer (P) contains solid  $K_2SO_4$  and a 40 wt%  $K_2SO_4$  solution in the ratio 10 kg solid/1 kg solution. The filtrate from the crystallizer (R) is also a 40 wt% solution and is recycled into the feed. At steady-state, 42.65 wt% of the water entering the evaporator is evaporated.

If the maximum rate of water evaporation is 100 kg/min, determine the following:

- a) the rate of production of solid  $K_2SO_4$
- b) the rate of fresh feed required
- c) the ratio of recycle to fresh feed



FF = Fresh Feed  
C = Feed to Crystallizer

F = Feed to Evaporator  
P = Product Stream

E = Evaporated Water  
R = Recycle Stream

Figure 1

**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) You want to produce superheated steam at 300°C and 1.0 atm to feed a heat exchanger in your plant. Part of the steam may come from a stream of saturated steam that leaves a turbine elsewhere in the plant at the rate of 1000 kg/h and a pressure of 1.0 atm. The steam from the turbine will have to be mixed with a second superheated steam source at 400°C and 1.0 atm. Calculate the volumetric flow rate of 400°C steam required and the rate at which the 300°C steam is produced. (Neglect any heat loss in pipes.)

4) A well-stirred tank with a mass of 5000 kg and an average heat capacity of  $C_v = 500 \text{ J/kg}\cdot\text{K}$  is filled with 1500 kg of a reaction mixture, which is initially at 25°C and has an average heat capacity of  $C_v = 3765 \text{ J/kg}\cdot\text{K}$ . The mixture is heated to 250°C at a heating rate of 300 kW. How long does it take?

There are no chemical reactions and no phase changes. You can neglect the energy of the stirrer.

**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) Consider a mixture of two liquids at 1.0 bar pressure (that is, the mixture is in contact with air at 1.0 bar). The following information is available:

$$P_A^{sat}(298\text{ K}) = 0.8\text{ bar}$$

$$P_B^{sat}(298\text{ K}) = 0.5\text{ bar}$$

Enthalpy of mixing at 298 K = -10 kJ/mole for a 50/50 mixture by mole fraction

Excess entropy of mixing at 298 K = -1 J/mole·K for a 50/50 mixture by mole fraction

The solubility of air in A, B, or in mixtures of A and B is small and can be ignored.

Assume that the excess Gibbs free energy has the following form:

$$G^E = (\text{Constant})x_Ax_B$$

- What is the excess Gibbs free energy for a 50/50 mole % mixture?
  - What is the total entropy change associated with mixing one mole of pure liquid A with one mole of pure liquid B at 298 K?
  - Is the equilibrium vapour pressure higher or lower than that of an ideal solution? Give the reasoning behind the variation in vapour pressure based on these data.
  - Determine the value of the activity coefficients for both A and B for this 50/50 mole % mixture.
  - If this mixture is at 298 K, what is the composition of the air in equilibrium with the liquid mixture that is 50 mole % A and 50 mole % B?
- 6) A gaseous isomerization reaction at 1.0 bar occurs as shown below:



The heat of reaction for this system is small and is 1.0 kJ/mole at 298 K. The entropies of both pure isomers are the same at 298 K.

The following data are also available:

$$S^E = 0\text{ J/mole}\cdot\text{K}$$

$$C_{p1} = 20\text{ J/mole}\cdot\text{K}$$

$$C_{p2} = 25\text{ J/mole}\cdot\text{K}$$

- a) What is the expected heat of reaction for this isomerization at 398 K?
- b) What are the equilibrium mole fractions at 298 K?
- c) What are the equilibrium mole fractions at 398 K?

7) The outlet valve on a pressurized gas cylinder is only partially opened, such that gas flow through this metal valve is slow. Thus, heat transfer can be assumed to be rapid compared to the rate at which gas is leaking through the valve and the temperature of the gas can be assumed to remain constant at 300 K throughout this expansion process. Assume the gas follows the equation

$$Z = 1 + \left(\frac{B}{RT}\right)P$$

with the constant  $B$  independent of temperature and equal to  $10 \text{ cm}^3 \text{ mole}$ . The ideal gas state heat capacity of this gas is  $C_v = 1.5R$  at all temperatures. If the pressure in the tank is 10 bar and the outlet pressure is 1 bar, calculate the following:

- a) the change in enthalpy (J/mole) as the gas flows across the valve
- b) the corresponding change in entropy (J/mole·K)