National Exams December 2015

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 two parts – Part A (Questions 1 to 3): Process Balances

   Part B (Questions 4 and 6): Chemical Thermodynamics

6) Answer **TWO** questions from Part A and **TWO** questions from Part B. **FOUR** questions constitute a complete paper.

7) Each question is of equal value.

PART A: PROCESS MASS and ENERGY BALANCES

1) A fuel oil has the following ultimate chemical analysis on mass basis:

$$C = 85.43\%$$
$$H_2 = 11.31\%$$
$$O_2 = 2.7\%$$
$$N_2 = 0.22\%$$
$$S = 0.34\%$$

This fuel oil is burned in a steam-boiler furnace. Determine the following:

a) Weight of air required for theoretically perfect combustion
b) Weight of gas formed per pound of oil burned
c) Volume of flue gas at the boiler exit temperature of 589 K per pound of oil burned
d) Air required with 20% excess air
e) Volume of gas formed with 20% excess air
f) Percentage CO_2 in the flue gas on a wet and dry basis

2) A particular crude oil is heated to 510 K and charged at 10 L/hr to the flash zone of a laboratory distillation tower. The flash zone is at an absolute pressure of 110 kPa. Assuming that the vapor and liquid are in equilibrium, calculate the following:

a) Percent vaporized
b) Amounts of the overhead and bottom streams

DATA for Crude Oil:
Flash zone temperature = 483 K
Latent heat of vaporization = 291 kJ/kg
Density of vaporized crude = 0.75 kg/L
Specific heat capacity of vaporized crude = 2.89 kJ/kg.K
Density of unvaporized crude = 0.892 kg/L
Specific heat capacity of unvaporized crude = 2.68 kJ/kg.K
Density of feed crude = 0.85 kg/L
Specific heat capacity of feed crude = 2.85 kJ/kg.K

3) In the feed-preparation section of an ammonia plant, hydrogen (H_2) is produced from methane (CH_4) by a combination steam-reforming/partial-oxidation process. Enough air is used in partial oxidation to give a 3:1 hydrogen-nitrogen molar ratio in the feed to the ammonia unit. The hydrogen-nitrogen mixture is heated to reaction temperature and fed into a fixed-bed reactor where 20% conversion of reactants to ammonia (NH_3) is obtained per pass. After leaving the reactor, the mixture is cooled and the ammonia removed by condensation. The unreacted hydrogen-nitrogen mixture is recycled and mixed with fresh feed.

In addition to nitrogen (N_2) and oxygen (O_2), the air used in partial oxidation contains inert gases, particularly argon (Ar), that gradually builds up in the recycle stream until the process is affected adversely. It has been determined that the concentration of argon in the reactor must not exceed 4 moles of argon per 100 moles of hydrogen-nitrogen mixture. The fresh feed contains 0.31 mole of argon per 100 moles of hydrogen-nitrogen mixture. Calculate the following:

a) Amount of recycle stream that must be vented to meet the concentration requirement
b) Amounts of ammonia produced

PART B: CHEMICAL THERMODYNAMICS

4) The dissociation pressure of calcium oxadate (CaC_2O_4) given by the equation

$$CaC_2O_4 \text{ (s)} \leftrightarrow CaCO_3 \text{ (s)} + CO \text{ (g)}$$

at various temperatures is listed below:

T [°C]	Dissociation Pressure [kPa]
375	1.09
388	4.00
403	17.86
410	33.33
416	78.25
418	91.18

Compute the standard Gibbs free energy change, enthalpy change, and entropy change for this reaction for each of the temperature listed above.

5) Estimate the composition of the liquid and vapor phases when n-butane isomerizes at 311 K. The reaction is n-C_4H_{10} ↔ iso-C_4H_{10}. Assume the isomers form an ideal solution in the liquid phase, standard-state fugacity of each component is 1 atmosphere, and reaction occurs in the vapor phase.

DATA:
Equilibrium constant (K) = 2.24
Saturation fugacity coefficient (ϕ^{sat}) for n-butane = 0.91
Saturation fugacity coefficient (ϕ^{sat}) for iso-butane = 0.89
Saturation vapor pressure (P^{sat}) for n-butane = 3.53 atm
Saturation vapor pressure (P^{sat}) for iso-butane = 4.95 atm

6) A cleaning solution is to be manufactured from equal masses of acetone and dichloromethane, both at 298 K. If these components are mixed adiabatically at a pressure of 1 bar, with negligible stirring work, what is the temperature of the cleaning solution formed?

DATA:
Specific heat capacity of acetone at 1 bar and 298 K = 2.173 kJ/kg.K
Specific heat capacity of dichloromethane at 1 bar and 298 K = 1.193 kJ/kg.K
Heat of mixing of equal-mass solution at 1 bar and 293 K = 12.468 kJ/kg
Heat of mixing of equal-mass solution at 1 bar and 298 K = 12.380 kJ/kg
Heat of mixing of equal-mass solution at 1 bar and 303 K = 12.292 kJ/kg

Name: _____ **Date:** _____