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National Institute of Technology Hamirpur
Department of Chemical Engineering
Subject: CH 213 – Chemical Process Calculations
End Semester Examination, November 2023
Branch: Chemical Engineering
Class: B. Tech. | **Semester:** III | **Full Marks:** 50 | **Time:** 3 hours

Instructions:
- Answer all the questions. All parts (a, b, c) of any question must be answered in continuation.
- Calculator is allowed but exchange the same with others is not allowed.
- **Psychrometric chart provided with the question paper is to be submitted with answer sheet.**
- Missing data may suitably be assumed, if any.

1. a) The diffusivity of a gas pair A-B is given by the following equation. What is the unit and dimension of C? (2)

$$D_{AB} = \frac{CT^{3/2}\left(\frac{1}{M_A}+\frac{1}{M_B}\right)^{1/2}}{P\sigma^2\Omega}$$

Where, M_A and M_B are the molecular weights of A and B in g/gmol, respectively, D_{AB} is in m^2/s, T in K, P in Pa, σ in nanometer, and Ω is dimensionless.

b) 1000 kg of mixed acid having composition 40% H_2SO_4, 45% HNO_3, and 15% H_2O is to be produced by strengthening waste acid of composition 30% H_2SO_4, 36% HNO_3 and 34% H_2O. Concentrated H_2SO_4 (containing 95% H_2SO_4 in water) and Concentrated HNO_3 (containing 80% HNO_3 in water) are available for this purpose. Calculate the amount of waste acid, concentrated H_2SO_4, and concentrated HNO_3 are to be mixed. All the compositions are in mass fractions. (6)

2. Ethylene oxide is produced by partial oxidation of ethylene with excess air over silver catalyst via following reaction. (10)

$$2C_2H_4 + O_2 \rightarrow 2C_2H_4O$$

Some of the ethylene also undergoes complete oxidation as follows.

$$C_2H_4 + 3O_2 \rightarrow 2CO_2 + 2H_2O$$

Feed containing 20% (mol%) ethylene in air is fed to the reactor and 25% conversion of ethylene is achieved. The product stream contains 2.02% of C_2H_4O.

a) Perform degree of freedom analysis.
b) Calculate the reactor outlet composition using species balance method.

3. a) Humid air at dry bulb temperature of 28°C has a dew point of 8°C. Using the psychrometric chart determine the (5)
   i) relative humidity
   ii) wet-bulb temperature
   iii) specific enthalpy
   iv) mass of air that contains 2 kg of water.

b) The analysis of the gas sample is given below (volume basis): CH_4 = 66%, CO_2 = 30%, NH_3 = 4%. (4)
   Calculate:
   i) the average molecular weight of the gas.
   ii) the density of the gas at 2 atm. and 303 K.

4. a) A natural gas having 89.4% CH_4, 5% C_2H_6, 1.9% C_3H_8, 1% C_4H_{10}, 0.7% CO_2 and 2% N_2 (all in mol%) is burnt with 10% excess air. (8)
   i) Calculate the flue gas composition on dry basis.
   ii) Calculate gross calorific value of the natural gas if the net calorific value is 854 kJ/gmol at 25°C.

   Given: latent heat of vaporization of water is 40.8 kJ/gmol.

5. Nitric oxide can be formed by partial oxidation of NH_3 with oxygen present in air as per following reaction. (10)

$$4NH_3(g) + 5O_2(g) \rightarrow 4NO(g) + 6H_2O(g)$$

In a given reactor, NH_3 fed at 25°C and preheated air at 750°C is reacted at 1 atm. pressure with 90% conversion of NH_3. The temperature of the reactor effluent should not exceed 920°C. A feed of 2.4 mol O_2 per 1 mol NH_3 is introduced.

a) From the degree of freedom analysis, identify the nature of the problem.
b) Calculate the required rate of heat removal per 1 mol NH_3 fed to the reactor.
c) Calculate the outlet composition.

Data:

Average C_p values:

O_2 = 12.0 cal/gmol.°C
N_2 = 7.0 cal/gmol.°C
NH_3 = 11.7 cal/gmol.°C
NO = 7.8 cal/gmol.°C
H_2O = 9.15 cal/gmole.°C

Standard heat of formation:

$\Delta H_f^o(NH_3, 25°C, 1\ atm) = -10.92$ kcal/gmol
$\Delta H_f^o(NO, 25°C, 1\ atm) = 21.6$ kcal/gmol
$\Delta H_f^o(H_2O, 25°C, 1\ atm) = -57.8$ kcal/gmol

6. Calculate standard heat of reaction of the following reaction at 25°C. (5)

$$C_5H_{12}(g) + 8O_2(g) \rightarrow 5CO_2(g) + 6H_2O(l)$$

Standard heats of formation of $CO_2(g)$, $H_2O(g)$, and $C_5H_{12}(g)$ are – 393.5, – 241.8, and –146.4 kJ/gmol, respectively and latent heat of vaporization of water at 25°C is 43.9 kJ/gmol.

---------- *All the best* ----------