

GUJARAT TECHNOLOGICAL UNIVERSITY
BE - SEMESTER-IV (NEW) EXAMINATION – SUMMER 2022

Subject Code: 3140507**Date: 08-07-2022****Subject Name: Chemical Engineering Thermodynamics II****Time: 10:30 AM TO 01:00 PM****Total Marks: 70****Instructions:**

1. Attempt all questions.
2. Make suitable assumptions wherever necessary.
3. Figures to the right indicate full marks.
4. Simple and non-programmable scientific calculators are allowed.

| | MARKS |
|-----------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------|-----------|
| Q.1 (a) State and explain Duhem's Theorem. | 03 |
| (b) Evaluate the fugacity coefficient at 5 bar for a gas that follows the equation of state $PV = RT(1 - 0.005 P)$, where P is pressure in bar. | 04 |
| (c) In the laboratory of mass transfer, will it be possible to prepare 0.12 m ³ of alcohol-water solution by mixing 0.04 m ³ alcohol with 0.08 m ³ pure water? If not possible, Assess the volume which should have been mixed in order to prepare a mixture of the same strength and of the required volume? Density of ethanol and water are 789 kg/m ³ and 997 kg/m ³ respectively. Data: The partial molar volumes of ethanol and water at the desired compositions are: Ethanol = 53.6×10^{-6} m ³ /mol; Water = 18×10^{-6} m ³ /mol. | 07 |
| Q.2 (a) Derive the equation for determination of fugacity of pure gases using any two methods. | 03 |
| (b) Prove that for a multi component system, chemical potential of each component is the same in all phases. | 04 |
| (c) Molar volume of binary solution is expressed as: $H = 400x_1 + 600x_2 + (40x_1 + 20x_2)x_1x_2$ (i) Acquire the expression for partial molar enthalpies. (ii) Compute pure component enthalpy (iii) Compute enthalpy at infinite dilution. | 07 |
| OR | |
| (c) Prove that if Henry's law is obeyed by component 1 in a binary solution over certain concentration range, Lewis–Randall rule (Raoult's law) will be obeyed by component 2 over the same concentration range. | 07 |
| Q.3 (a) For a binary solution consider M_1 and M_2 are properties of component 1 and component 2 in a solution. Derive equations to calculate partial properties of component 1 and component 2 in a solution. | 03 |
| (b) The activity coefficients for component 2 in a binary solution can be represented by $\ln \gamma_2 = Ax_1 + Bx_1^2$, where A and B are concentration independent parameters. Derive an expression for $\ln \gamma_1$. | 04 |
| (c) The ethanol-benzene system forms azeotrope with azeotropic composition of 44.8 mol% ethanol with boiling point of 341.4 K at 101.3 kPa. At this temperature the vapor pressure of benzene is 68.9 kPa and the vapor pressure of ethanol is 67.4 kPa. Compute the activity coefficient in a solution of Ethanol-Benzene containing 20 mol% ethanol using Van Laar equation. | 07 |
| OR | |
| Q.3 (a) State applications and limitations of Wilson and NRTL equation. | 03 |

- (b) Write steps to determine Bubble point temperature using Raoult's Law. **04**
- (c) A certain experiment was carried out in the laboratory. The results of the data are as shown below. Verify whether the following data are thermodynamically consistent or not? **07**

| | | | | | | |
|------------|-------|-------|-------|-------|-------|-------|
| x_1 | 0 | 0.2 | 0.4 | 0.6 | 0.8 | 1.0 |
| γ_1 | 0.576 | 0.655 | 0.748 | 0.856 | 0.950 | 1.0 |
| γ_2 | 1.0 | 0.985 | 0.930 | 0.814 | 0.626 | 0.379 |

- Q.4** (a) Explain Liquid-Liquid Equilibrium with suitable example. **03**
- (b) Define azeotrope and explain maximum and minimum boiling azeotrope with a neat diagram. **04**
- (c) Assuming Raoult's law to be valid for the system benzene (1)–ethyl benzene (2) and the vapour pressures are given by the Antoine equation: **07**

$$\ln P_i^{\text{sat}} = \left[A - \left(\frac{B}{T+C} \right) \right], \text{ where } P \text{ is in kPa and } T \text{ is in K.}$$

| Species, i | A | B | C |
|------------|---------|---------|--------|
| 1 | 13.8858 | 2788.51 | -52.41 |
| 2 | 14.0045 | 3279.47 | -60.00 |

Construct the P-x-y diagram at 100°C.

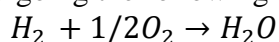
OR

- Q.4** (a) What is retrograde condensation and write its application in chemical industry. **03**
- (b) Two suffix Margules equation is the simplest expression for excess Gibbs free energy. $G^E = \beta x_1 x_2$ where β is an empirical constant. Derive the expression for the activity coefficient of component 1 that results from this equation. **04**
- (c) Assuming the validity of Raoult's law, Evaluate for the system of Acetone (1), Acetonitrile (2) and Nitromethane (3), given the mole fraction of component $x_1 = 0.30$ and $x_2 = 0.40$ and temperature $T = 75^\circ\text{C}$, Compute y_1 and P. **07**

$$\ln P_i^{\text{sat}} = \left[A - \left(\frac{B}{T+C} \right) \right], \text{ where } P \text{ is in kPa and } T \text{ is in K.}$$

| Component | A | B | C |
|------------------|---------|---------|-------|
| Acetone(1) | 14.3916 | 2795.82 | 230.0 |
| Acetonitrile (2) | 14.2724 | 2945.47 | 224.0 |
| Nitromethane (3) | 14.2043 | 2972.64 | 209.0 |

- Q.5** (a) Describe phase rule for reacting systems **03**
- (b) The water–gas shift reaction takes place at 373K, $\text{CO} + \text{H}_2\text{O} \rightarrow \text{CO}_2 + \text{H}_2$ **04**
The equilibrium constant K_P for this reaction at 537K = 9.8×10^{-4} . The heats of formation at 298K are: $\text{CO} = -110,525\text{J/mol}$, $\text{CO}_2 = -393,509\text{ J/mol}$, $\text{H}_2\text{O} = -241,818\text{ J/mol}$. Calculate the equilibrium constant at 1000 K.
- (c) A gas mixture containing 1.25 moles hydrogen, 0.75 moles oxygen and 0.25 mole water initially, is undergoing the following reaction: **07**



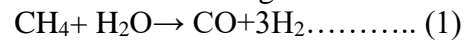
- (i) Derive expressions for the mole fractions of various components in the reaction mixture in terms of the extent of reaction.
- (ii) Explain how the conversion of limiting reactant is related to the extent of reaction.

OR

- Q.5** (a) How would you predict the feasibility of a chemical reaction from the value of standard free energy change? **03**
- (b) What is the effect of temperature on equilibrium constant? Using Van't Hoff equation predict the effect of increasing temperature on endothermic and exothermic reactions. **04**

(c) Consider a system in which the following reactions occur:

07



If 3mol CH_4 and 4mol H_2O are initially present, Compute the mole fraction of the product gases for $\varepsilon_1 = 0.25$ and $\varepsilon_2 = 0.5$