# MANICALAND STATE UNIVERSITY OF APPLIED SCIENCES

## FACULTY OF ENGINEERING

### DEPARTMENT: CHEMICAL AND PROCESSING ENGINEERING

### MODULE: CHEMICAL ENGINEERING THERMODYNAMICS II

### CODE: CHEP212

### SESSIONAL EXAMINATIONS
### DECEMBER 2022

### DURATION: 3 HOURS

### EXAMINER: MR D. NYADENGA

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**INSTRUCTIONS**

1. *Answer **any four** questions.*
2. *Start a new question on a fresh page.*
3. *Total marks 100.*

***Additional material(s):*** *Calculator, Steam Tables, Conversions Table, Antoine Equation Constants Table, Periodic Table*

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## QUESTION 1

a) State the conditions under which a gas mixture is assumed to be ideal. [2]

b) A stream of nitrogen gas flowing at the rate of 14 kg/s and a stream of hydrogen gas flowing at the rate of 6 kg/s are mixed in a steady flow process. The temperature of the whole system is constant at 25 ℃. Assuming the gases to be ideal, calculate:

i. The rate of change in total entropy. [6]

ii. The rate of change in total Gibbs free energy. [4]

c) The molar volume of a binary liquid mixture at $T$ and $P$ is given by:

$$V = 120x_1 + 70x_2 + x_1x_2(15x_1 + 8x_2)$$

i. Find the expressions for the partial molar volumes of species 1 and 2 at $T$ and $P$ as functions of $x_1$. [9]

ii. Find the numerical values of partial molar volumes of species 1 and 2 at infinite dilution. [4]

## QUESTION 2

a) The volume change of mixing ($cm^3$/mol) for the system ethanol (1)/methyl butyl ether (2) at 25 ℃ is given by the equation:

$$\Delta V = x_1x_2[-1.026 + 0.22(x_1 - x_2)]$$

Given that $V_1$ = 58.63 $cm^3$/mol and $V_2$ = 118.46 $cm^3$/mol, calculate the volume of mixture formed when 750 $cm^3$ of pure species 1 is mixed with 1 500 $cm^3$ of pure species 2 at 25 ℃. [8]

b) $LiCl{\cdot}2H_2O(s)$ and $H_2O(l)$ are mixed isothermally at 25 $^0$C to form a solution containing 8 mol of $H_2O$ for each mole of $LiCl$. Determine the heat effect per mole of solution. Data for standard enthalpy changes of formation at 298 K is given in the next page.

| Chemical component | Enthalpy change of formation |
|---|---|
| $LiCl{\cdot}_2H_2O(s)$ | - 1 012 650 J/mol of *LiCl* |
| $H_2O(l)$ | - 285 830 J/mol of $H_2O$ |
| *LiCl* in 8 mol $H_2O$ | - 440 529 J/mol of *LiCl* |

[7]

c) A 100 $lb_m$ batch of 50 wt % *NaOH* solution in water at 80 $^0$F and atmospheric pressure is heated in an insulated tank by injection of live steam drawn through a valve from a line containing saturated steam ($x$ = 1) at 2.4 bar. The process is stopped when the *NaOH* solution reaches a concentration of 45 wt %. Determine the temperature of this final solution in $^0$F. The *H-x* graph for $NaOH/H_2O$ system is attached at the end of the question paper. [10]

## QUESTION 3

a) The phase rule is used to determine the number of intensive variables that must be specified to fix the state of the system.

i. State the phase rule for a non-reacting system. [1]

ii. Determine the number of intensive variables required to fix the state of a mixture of methane, ethane and propane that is in vapour/liquid equilibrium at a specified fixed pressure. [4]

b) State and explain whether the following system obeys Raoult's law:

i. Water/n-decane [3]

ii. Water/ammonia [3]

c) Show that when $x_i$ is unknown Raoult's law can be expressed as:

$$P = \frac{1}{\Sigma_i\left({}^{y_i}/_{P_i{}^{sat}}\right)}$$ [4]

d) A system of n-pentane(1)/n-hexane(2) is at $T$ = 50 °C and $y_1$ = 0.6. Assuming that Raoult's law applies, determine the pressure of the system and $x_1$. The saturation pressures are calculated using the Antoine Equation. [10]

## QUESTION 4

a) Explain the effect of osmotic pressure on reverse osmosis operations. [4]

b) A concentrated binary solution containing mostly species 2 (but $x_2 \neq 1$) is in equilibrium with a vapour phase containing both species 1 and 2. The pressure of this two-phase system is 1 bar; the temperature is 25 $^0$F. Determine good estimates of $x_1$ and $y_1$ given that $H_1$ = 200 bar and $P_2^{sat}$ = 0.1 bar. [8]

c) For the system ethyl ethanoate (1)/n- heptane(2) at 343.15 K,

- $\ln \gamma_1 = 0.95{x_2}^2$ $\quad\quad$ $\ln \gamma_2 = 0.95{x_1}^2$
- $P_1^{sat}$ = 79.8 kPa $\quad\quad$ $P_2^{sat}$ = 40.5 kPa

Assuming that the modified Raoult's law applies,

i. Show that an azeotrope exists for the system. [5]

ii. Determine the azeotropic composition and pressure at 343.15 K. [8]

## QUESTION 5

The following reaction of ideal gases reaches equilibrium at 350 ℃ and 3 bar:

$$CH_3CHO_{(g)} + H_{2(g)} \longrightarrow C_2H_5OH_{(g)} \qquad \Delta H = -ve$$

$K$ at 350 $^0$C is 3.7064. Initially there are 3 moles of $H_2$ and 2 moles of $CH_3CHO$.

a) Calculate the equilibrium composition of the system. [8]

b) If the pressure is reduced to 1 bar and temperature is maintained at 350 ℃, determine the new equilibrium composition. [8]

c) Explain the effect on the equilibrium composition of increasing the temperature to 500 ℃ whilst maintaining pressure at 3 bar. [4]

d) Suppose that *Ar* (g) is added to the system whilst $T$ = 350 ℃ and $P$ = 3 bar.

i. How does this affect $K$. [1]

ii. Explain the effect on equilibrium composition. [4]

**END OF EXAMINATION**

## ***H-x* graph for *$NaOH/H_2O$***