CHEMICAL ENGINEERING THERMODYNAMICS (CHEN 2203)

Time Allotted : 3 hrs **Full Marks : 70**

Figures out of the right margin indicate full marks.

Candidates are required to answer Group A and any 5 (five) from Group B to E, taking at least one from each group.

Candidates are required to give answer in their own words as far as practicable.

Group – A
(Multiple Choice Type Questions)

1. Choose the correct alternative for the following: **10 × 1 = 10**

(i) Which of the following energy property does not change during the change in phase of pure substance?
(a) internal energy (b) enthalpy
(c) Helmholtz free energy (d) Gibbs free energy.

(ii) In an irreversible cyclic process entropy of the system
(a) increases
(b) decreases
(c) does not change
(d) depends on direction of heat transfer between system and surrounding.

(iii) Under which of the following conditions of temperature (T) and pressure (P) cubic equation of state yield three real solutions?
(a) $T>T_c$ and $P>P_c$ (b) $T>T_c$ and $P<P_c$
(c) $T<T_c$ and $P>P_c$ (d) $T<T_c$ and $P<P_c$.
where, T_c and P_c are critical temperature and pressure respectively.

(iv) Which of the following has the minimum value of COP for a given refrigeration effect?
(a) reverse Carnot cycle
(b) ordinary vapour compression cycle
(c) absorption refrigeration cycle
(d) air refrigeration cycle.

(v) Which of the following is an undesirable property for a good refrigerant?
(a) high thermal conductivity (b) low freezing point
(c) high latent heat of vaporization (d) high viscosity.

(vi) The ratio of isobaric thermal expansion coefficient to isothermal compressibility coefficient for ideal gas is
(a) proportional to molar volume
(b) inversely proportion to molar volume
(c) proportional to temperature
(b) inversely proportional to temperature.

(vii) The degrees of freedom of a binary azeotropic mixture under vapour liquid equilibrium is
(a) 0 (b) 1 (c) 2 (d) 3.

(viii) For a highly favorable chemical reaction, the standard Gibbs free energy change is
(a) zero (b) unity
(c) positive (d) negative.

(ix) The theoretical minimum work required to separate one mole of an equimolar mixture of components A and B into pure components at constant temperature (T) and pressure (P) is
(a) 0.5 RT (b) 0.693 RT
(c) 1.386 RT (d) 2RT.

(x) In a binary liquid solution of components A and B, if component A exhibits positive deviation from Raoult's law then component B
(a) exhibits positive deviation from Raoult's law
(b) exhibits negative deviation from Raoult's law
(c) obeys Raoult's law
(d) may exhibit either positive or negative deviation from Raoult's law.

Group – B

2. (a) One mole of an ideal gas initially at P_1 and T_1 is compressed reversibly and adiabatically till the pressure is P_2 and then it is cooled at constant volume to the initial pressure. Finally the gas is restored to their initial state through an isobaric process. Determine an expression of work done by the gas.

(b) A turbine, operating under steady flow conditions, receives 4500 kg of steam per hr. The steam enters the turbine at a velocity of 2800 m/min, an elevation of 5.5 m and a specific enthalpy of 2800 kJ/kg. It leaves the turbine at a velocity of 5600 m/min, an elevation of 1.5 m and a specific enthalpy of 2300 kJ/kg. Heat losses from the turbine to the surroundings amounts to 16000 kJ/h. Determine the power output (in MW) from the turbine.

6 + 6 = 12

3. (a) 0.25 kg gaseous ammonia is contained in a 15 liter closed rigid cylinder at 30°C. Calculate the pressure in the cylinder using (i) Van-der-Waals equation of state and (ii) Virial equation of state. Given, P_c = 111.3 atm, T_c = 405.6 K and ω = 0.25. (Symbols bear usual significance).

(b) Show that, minimum work required to drive an adiabatic compressor operating with an ideal gas is given by $W_c = \frac{\gamma R T_i}{1-\gamma}\left[1-\left(\frac{P_i}{P_o}\right)^{\frac{1-\gamma}{\gamma}}\right]$, where, P_i and T_i are inlet pressure and temperature respectively, P_o is the outlet pressure and γ is the heat capacity ratio of ideal gas.

7 + 5 = 12

Group – C

4. (a) Establish logically that no heat engine operating between two thermal reservoirs can be more efficient than a reversible heat engine operating between same two thermal reservoirs.

(b) A hydrocarbon oil (c_p = 2512 J/kg K) is cooled from 422 K to 399 K in a heat exchanger at the rate of 2500 kg/h. Cooling water at the rate of 5000 kg/h enters the exchanger at 294 K. Assume there is no heat loss in the heat exchanger.
(i) What is the rate of change of entropy (in W/K) of the system?
(ii) How much maximum power could be obtained if the cooling of hydrocarbon oil is carried out by a heat engine rejecting heat to a sink at 294 K?

6 + 6 = 12

5. (a) Show that Joule-Thompson coefficient for any real gas is given by, $\mu_{JT} = \frac{v}{C_p}(\beta T - 1)$ where, β is isobaric thermal volume expansion coefficient. Other symbols bear usual significance.

(b) The compression ratio of an Otto cycle is 8. The pressure and temperature of air (γ = 1.4) at the beginning of compression stroke are 1 bar and 300 K respectively. The amount of energy added to the air as a result of combustion is 1500 kJ/kg of air. Determine the pressure and temperature of the air at the end of each process of the cycle.

6 + 6 = 12

Group – D

6. (a) For a binary liquid mixture at constant temperature and pressure excess Gibbs energy is given by
$G^E/RT = (0.198\, x_1 + 0.372\, x_2)\, x_1 x_2$
Find the value of $\ln \gamma_1$ at infinite dilution.

(b) The azeotrope of the ethanol-benzene system has a composition of 44.8 mol% ethanol with a boiling point of 341.4K. At this temperature the vapour pressures of benzene and ethanol are respectively 68.9 kPa and 67.4 kPa. Find the vapour composition of benzene in equilibrium with a solution containing 10 mol% ethanol and rest benzene at 341.4K.

7 + 5 = 12

7. (a) Deduce the Lewis Randall rule.

(b) It is required to prepare 3 m^3 of a 60 mole% ethanol – water mixture. Determine the volumes of ethanol and water to be mixed in order to prepare the required solution. Given:

Component	Partial molar volume, m^3/mole	Molar volume of pure component, m^3/mole
Ethanol	57.5×10^{-6}	57.9×10^{-6}
Water	16.0×10^{-6}	18.0×10^{-6}

6 + 6 = 12

Group – E

8. (a) For a binary system prove that $\overline{M_1} = M + x_2 \frac{dM}{dx_1}$, where notations bear their usual meaning.

(b) Estimate the maximum conversion of ethylene to ethanol by the vapour phase hydration at 250°C and 35 bars for an initial steam to ethylene ratio of 5. The system may be assumed to be ideal.
Data; The reaction is: C_2H_4 (g) + H_2O (g) = C_2H_5OH (g)
At 250°C, the equilibrium constant (K_a) = 9.841×10^{-3}

5 + 7 = 12

9. Calculate the equilibrium constant for the vapour phase hydration of ethylene at 320°C from the given data:
The reaction is: $C_2H_4(g) + H_2O(g) = C_2H_5OH(g)$
$\frac{C_P}{R} = A + BT + CT^2 + \frac{D}{T^2}$

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Component	A	$Bx10^3$	$Cx10^6$	$Dx10^{-5}$
$C_2H_5OH(g)$	3.518	20.001	-6.002	0.000
$C_2H_4(g)$	1.424	14.394	-4.392	0.000
$H_2O(g)$	3.470	1.450	0.000	0.121

At 298.15K:

Component	$H_f, J/mol$	G, J/mol
$C_2H_5OH(g)$	-235100	-168490
$C_2H_4(g)$	52510	68430
$H_2O(g)$	-241818	-228572

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