Name : .....

Roll No. : .....

Invigilator's Signature : .....

CS/B.TECH (CHE-OLD)/SEM-4/CHE-401/2013

2013

CHEMICAL ENGINEERING THERMODYNAMICS

Time Allotted : 3 Hours Full Marks : 70

The figures in the margin indicate full marks.

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

GROUP – A

(Multiple Choice Type Questions)

1. Choose the correct alternatives for any *ten* of the following : $10 \times 1 = 10$

i) The ratio of high temperature to low temperature for reversed Carnot engine is 1·25. The COP will be

a) 2 b) 3

c) 4 d) 5.

ii) Fugacity of a species in solution is a measure of

a) non-ideal partial pressure of the component

b) escaping tendency of the species in different phases of a system

c) relative volatility of the species

d) both (a) and (b).

iii) Throttling process is a / an

a) irreversible isothermal process

b) irreversible adiabatic process

c) reversible constant enthalpy process

d) irreversible constant enthalpy process.

iv) The degree of freedom for a system of two miscible non-reacting species in VLE forming an azeotrope is

a) 0 b) 1

c) 2 d) 3.

v) The ratio of adiabatic compressibility to isothermal compressibility is

a) 1 b) > 1

c) >> 1 d) < 1.

vi) Which of the following is not a refrigerant ?

a) SO_2 b) NH_3

c) CCl_2F_2 d) $C_2H_4Cl_2$.

vii) The free energy change for a chemical reaction is given

a) $-RT\ lnK$ b) $RT\ lnK$

c) $-R\ lnK$ d) $R\ lnK$

where K is the equilibrium constant.

viii) Chemical potential is

a) an extensive property

b) an intensive property

c) a path property

d) a reference property.

ix) The phase rule for a system can be written as

a) $F = C - P - 1$ b) $F = C - P + 1$

c) $F = C + P + 2$ d) $F = C - P + 2$.

x) Efficiency of a Carnot engine between temperatures T_1 and T_2 $(T_1 < T_2)$ is

a) $\frac{T_2 - T_1}{T_1}$ b) $\frac{T_2 - T_1}{T_2}$

c) $\frac{T_1 - T_2}{T_2}$ d) $\frac{T_1 - T_2}{T_1}$.

xi) One ton of refrigeration capacity is equivalent to the heat removal rate of

a) 50 k.cal/hr b) 200 BTU/hr

c) 200 BTU/minute d) 200 BTU/day.

GROUP – B

(Short Answer Type Questions)

Answer any *three* of the following. $3 \times 5 = 15$

2. How the concept of entropy can be derived from Carnot cycle ? Represent the ideal Carnot cycle in a Temperature (T) Entropy (S) diagram. 3 + 2

3. What is meant by residual and excess property of system ? The excess enthalpy for a liquid mixture of species A and B at fixed temperature and pressure is represented by the equation :

$$H^E = x_A x_B \left(40x_A + 20x_B \right) \text{ J/mol}$$

where, x_A and x_B are the mole fractions of A and B respectively. Determine the expression of partial molar excess enthalp of species A and B in terms of x_A. 2 + 3

4. State the necessary criteria for chemical reaction equilibria. Derive the relation to estimate the equilibrium constant from a knowledge of standard Gibbs free energy change of a chemical reaction. 1 + 4

5. Prove that, Joule-Thompson coefficient is given by

$$\mu_{JT} = \frac{\nu}{C_p} (\beta T - 1).$$

where, β is thermal expansion coefficient. Other symbols bear the usual significance.

6. A horizontal piston-cylinder arrangement contains an ideal gas of volume, 0·03 m^3. An external force holds the frictionless piston in place against an initial gas pressure of 14 bar. The external force on the piston is reduced gradually, and the gas expands isothermally as its volume doubles. What is the work done by the gas in moving the external force ? How much work would be done if the external force were suddenly reduced to half its initial value instead of being gradually reduced ? 3 + 2

GROUP – C

(Long Answer Type Questions)

Answer any *three* of the following. 3 × 15 = 45

7. a) What are the criteria based on which refrigerant is chosen for refrigeration ? Explain the absorption refrigeration with a flow diagram. Determine the expression of performance efficiency of an ideal absorption refrigeration cycle. 2 + 3 + 2

   b) What is the difference between Linde and Claude liquefaction process ? 2

   c) A rigid insulated tank of volume 3 m^3 is divided into two compartments by a removable partition of negligible volume. One compartment of volume 1 m^3 contains oxygen at 500 K and 10 bar while 2nd one contains nitrogen at 800 K and 20 bar. The partition is removed and the gas is allowed to mix. After mixing calculate total change of entropy of the process. Assume both gases to be ideal with $\gamma = 1{\cdot}4$. 6

8. a) What are the conditions when maximum and minimum boiling azeotropes are formed ? Prove that for a closed multi-component system in equilibrium chemical potential of a component in all phases is the same. 3 + 5

   b) The system acetone (i)-acetonitrile (ii)-nitromethane (iii) at 80°C and 110 kPa has the overall composition, $z_1 = 0{\cdot}45$, $z_2 = 0{\cdot}35$, $z_3 = 0{\cdot}2$. Assuming that Raoult's law is appropriate to this system, determine the liquid fraction, vapour fraction and composition at each phase in equilibrium. Given that, the vapour pressure of pure species at solution temperature and pressure are

   $P_1^{Sat} = 195{\cdot}75$ kPa, $P_2^{Sat} = 97{\cdot}84$ kPa

   $P_3^{Sat} = 50{\cdot}32$ kPa. 7

9. a) State the Henry's law and Lewis-Randall rule for ideal solution. Show that, Henry's law applies to a species as it approaches infinite dilution in a binary solution and Lewis-Randall rule for other species as it approaches purity. 3 + 4

b) Establish analytically that the logarithm of activity coefficient is a partial molar property. 3

c) The volume change of mixing (cm^3/mol) for the system ethanol (i) methyl butyl ether (ii) at 25°C is given by the equation

$$\Delta V = x_1 x_2 \left[-1{\cdot}026 + 0{\cdot}22 \left(x_1 - x_2 \right) \right].$$

Given that, $V_1 = 58{\cdot}63$ and $V_2 = 118{\cdot}46$ cm^3/mol. What volume of mixture is formed when 750 cm^3 of pure species (i) and is mixed with 1500 cm^3 of pure species (ii) at 25°C. 5

10. a) What is Van't Hoff equation and what does it predict ? 2 + 2

b) What is reaction co-ordinate ? Discuss the Duhem's theorem for reacting system. 2 + 3

c) The equilibrium constant K for a chemical reaction :

$$CO(g) + H_2O(g) \rightarrow CO_2(g) + H_2(g),$$

$$\Delta H^0_{298} = -41{\cdot}45 \text{ kJ}.$$

at 1 bar and 298 K is $1{\cdot}16 \times 10^5$. Estimate the equilibrium composition of the gas mixture at 1000 K assuming that ΔH^0_{298} remain constant in the temperature range 298 K to 1000 K. 6

11. a) One mole of an ideal gas ($\gamma = 1{\cdot}4$) initially at 1 bar, 300 K is compressed reversibly and adiabatically till the pressure is 2 bar and then it is cooled at constant volume to the initial pressure. Finally the gas is restored to initial state through an isobaric process. Calculate the work done by the gas. 8

b) Water at 90°C is pumped from a storage tank at the rate of 3·15 lit/s. The motor for the pump supplies work at the rate of 1·5 kW. The water passes through a heat exchanger giving up heat at the rate of 170 k.cal/s and is delivered to a second storage tank at an elevation 15 m above the first tank. What is the temperature of water delivered to the second tank ?
Take, C_p of water = 4·18 kJ/kg°C. 7