BASICS OF MATERIAL & ENERGY BALANCE
(CHEN 2103)

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) The mass of 56 l of ammonia at N.T.P is
(a) 2.5 gm (b) 42.5 gm (c) 56 gm (d) 25 gm.

(ii) The vapour pressure temperature relation given by $\ln\frac{P}{P_0}=\frac{\lambda}{R}(\frac{1}{T_0}-\frac{1}{T_1})$ is known as
(a) Kirchoff's equation (b) Claussius-Clapeyron equation
(c) Berthelot equation (d) Clapeyron equation.

(iii) A gas mixture contains 28 kg N_2, 16 kg O_2 and 17 kg NH_3. The volume fraction of Oxygen in the mixture is
(a) 0.262 (b) 0.20 (c) 0.355 (d) 0.25.

(iv) The SI unit of the ratio of kinematic viscosity to thermal diffusivity of a material is/has
(a) m (b) m^2/s (c) W/m^2K (d) no unit.

(v) Addition of a non-volatile solute to a pure solvent
(a) increases its freezing point (b) increases its boiling point
(c) decreases its boiling point (d) both 'a' & 'c'.

(vi) An equimolar mixture of gas containing CO_2, H_2, O_2 and N_2 has the average molecular weight equal to
(a) 106 (b) 53 (c) 79.5 (d) 26.5.

(vii) The maximum adiabatic flame temperature of fuels in air is _____ the maximum flame temperature in pure oxygen.
(a) lower than (b) higher than (c) same as (d) not related to

(viii) A limiting reactant is the one which decides the _____ in the chemical reaction.
(a) equilibrium constant (b) rate constant (c) selectivity (d) conversion

(ix) A bypass stream in a chemical process is useful, because it
(a) facilitates better control of the process (b) eliminate inert components
(c) increases the yield of product (d) improves the conversion.

(x) In a chemical process, the recycle stream is purged for
(a) increasing the yield (b) enriching the product
(c) limiting the inert (d) increasing the selectivity.

Group - B

2. (a) Using Buckingham's π-theorem, show that the frictional torque T of a disc of diameter D rotating at a speed N in a fluid of viscosity μ and density ρ in a turbulent flow is given by

$$\frac{T}{D^5 N^2 \rho} = f\left[\frac{\mu}{D^2 N \rho}\right]$$ [(CO3)(Analyze/IOCQ)]

(b) Air is supplied to a drying chamber at 60°C temperature, 101 kPa pressure and dew point of 5°C. Air leaves from the dryer at 30°C temperature, 101 kPa pressure and dew point of 24°C. Wet solid material in the dryer loses water at the rate of 25 kg/h. Calculate the volumetric flow rate of inlet air to the dryer. Given, the vapour pressure of water at 5°C and 24°C are 0.87 kPa and 2.98 kPa, respectively.
[(CO1,2)(Analyze/HOCQ)]
6 + 6 = 12

3. (a) An aqueous solution of Na_2CO_3 contains 15% carbonate by weight. 80% of the carbonate is recovered as Na_2CO_3, $10H_2O$ by evaporation of water and subsequent cooling to 278K. The solubility of Na_2CO_3 at 278 K is 9% (by weight). On the basis of 100 kg of solution treated determine the quantity of crystals formed and the amount of water evaporated. Given, atomic weight of Na is 23. [(CO2)(Apply/IOCQ)]

(b) Isopropyl alcohol and water can be separated by extraction with ethylene tetrachloride. 100 kg of a solution containing 30% (weight) isopropyl alcohol and the rest water is mixed with the solvent ethylene tetrachloride. After extraction, the raffinate phase analyzed 71% water, 28.1% isopropyl alcohol and 0.9% ethylene tetrachloride. The extract phase analyzed 94% ethylene tetrachloride, 5.2% isopropyl alcohol and the rest water. Calculate the quantities of raffinate and extract phase generated and the percentage extraction of isopropyl alcohol.
[(CO1,2)(Understand/LOCQ)]
6 + 6 = 12

Group - C

4. (a) What is a purge stream? Why it is required for some chemical process flow system?
[(CO1)(Remember/LOCQ)]

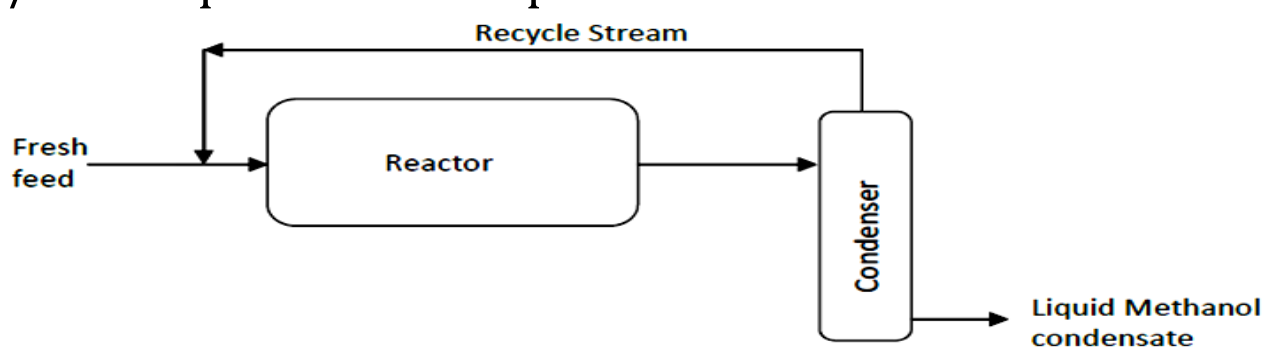
(b) The fresh feed to an ammonia production process contains 24.75 mole% nitrogen, 74.25 mole% hydrogen, and the balance inert (I). The feed is combined with a recycle stream containing the same species, and the combined stream is fed to a reactor in which a 25% single-pass conversion of nitrogen is achieved. The products pass through a condenser in which essentially all of the ammonia is removed, and the remaining gases are recycled. However, to prevent build-up of the inert in the system, a purge stream must be taken off. The recycle stream contains 12.5 mole% inerts. Calculate the overall conversion of nitrogen, the ratio (moles purge gas/mole

of gas leaving the condenser), and the ratio (moles fresh feed/mole fed to the reactor). [(CO1, 4) Evaluate/HOCQ]

(2 + 2) + 8 = 12

5. (a) What is yield and selectivity of a chemical reaction? [(CO4)(Understand/LOCQ)]

(b) Methanol is produced from synthesis gas by the reaction $CO + 2H_2 = CH_3OH$ as per the scheme shown below. Carbon mono-oxide single conversion in the reactor is 20 mole%. The ratio of hydrogen to carbon mono-oxide in fresh feed gas stream is 2:1. Calculate the molar flow rate of feed stream and recycle stream required for 1500 l/hr of liquid methanol production.



[(CO4)(Analyze/HOCQ)]

3 + 9 = 12

Group - D

6. (a) An aqueous solution of acetaldehyde contains 2% acetaldehyde by weight. The partial pressure of acetaldehyde over the solution is found to be 41.4 kPa at 367 K. What will be the patial pressure over 0.1 molal solution at the same temperature? [(CO5)(Understand/LOCQ)]

(b) The vapour pressure of substance A and B can be evaluated by the following Antoine equation: $\ln P_A^S = 14.5 - \frac{2940.5}{T - 35.9}$; $\ln P_B^S = 14.3 - \frac{2945.5}{T - 49.15}$; where T is in Kelvin and P is in kPa. Assume that the solution formed by this are ideal. Calculate the composition of the vapour and the liquid in equilibrium at 327 K and 65 kPa. [(CO5)(Apply/HOCQ)]

6 + 6 = 12

7. (a) The progress of a homogeneous chemical reaction is followed and it is desired to evaluate the rate constant (k) and the order of the reaction (n). The rate law expression for the reaction is known to follow the equation given as $-r = kC^n$. The experimental data of $-r$ (gmol/l.s) vs C (gmol/l) is provided in the table below:

$-r$ (gmol/l.s)	4	2.25	1.45	1.0	0.65	0.25	0.06
C (gmol/l)	0.398	0.298	0.238	0.198	0.158	0.098	0.048

Use appropriate graphical approach to evaluate k and n. [(CO3)(Apply/HOCQ)]

(b) Also apply linear least square regression to calculate the value of k and n analytically. Now justify the discrepency in the value of k and n thus obtained by two different methods. [(CO3)(Understand/LOCQ)]

7 + 5 = 12

Group - E

8. (a) A continuous fractionating column operating at a pressure of 100 kPa is used to separate 1000 kg/h of benzene and toluene containing 60% (by weight) of toluene.

The column produces an overhead product containing 97% (by weight) benzene and a bottom product of 98% (by weight) toluene. A reflux ratio of 3.5 is to be used. Calculate the condenser and reboiler heat duty from the following data given: enthalpy of feed is 170 kJ/kg, enthalpy of distillate is 67 kJ/kg, enthalpy of bottom product is 200 kJ/kg, latent heat of condensation of vapour at the condenser is 470 kJ/kg. [(CO1,2)(Evaluate/IOCQ)]

(b) A mixture of aniline and water containing 10% (by weight) aniline is sub-cooled in a condenser from 90°C to 30°C at rate of 8000 kg/h. Find the heat removal rate of the condenser with the following data given: C_P (kJ/kmol K) of aniline = 206.27-0.2115T and C_P (kJ/kmol K) of water = 50.845+0.213T where, T is in Kelvin. [(CO5,2)(Analyze/IOCQ)]

7 + 5 = 12

9. (a) Calculate the Gross Calorific Value (GCV) and Net Calorific Value (NCV) of natural gas at 298 K, which has the following molar composition: methane 89.4%, ethane 5%, propane 1.9%, iso-butane 0.4%, n-butane 0.6%, carbon dioxide 0.7% and nitrogen 2%. The standard heat of combustion in kJ/mol of the following components has been given at 298K: methane 890.65, ethane 1560.69, propane 2219.17, iso-butene 2868.2, n-butane 2877.4. [(CO5)Remember/LOCQ]

(b) Calculate the flame temperature of carbon monoxide gas when it is burned with 100% excess air in a furnace where the combustion is 90% complete and 5% of the heat evolved during the combustion process is lost. Consider the reactants (both air and carbon monoxide) are fed to the furnace at 127°C. The standard heat of combustion of carbon monoxide at 298 K is -283 kJ/mol. The heat capacity in J/mol K has been given for the following constituents: carbon monoxide 29.23, oxygen 34.83, nitrogen 33.03 and carbon dioxide 53.59. [(CO2,5)Evaluate/HOCQ]

6 + 6 = 12

Cognition Level	LOCQ	IOCQ	HOCQ
Percentage distribution	29.17	25	45.83

Course Outcome (CO):

After completion of the course students will be able to:

1. Generate ability to handle elementary flow-sheeting given a specific process.
2. Identify skills to develop equations for energy and mass balance given a specific process.
3. Analyze any physical phenomena to obtain a functional relation between dimensionless numbers associated with the process.
4. Identify recycle, bypass and purge points in a chemical process and perform calculations with them.
5. Describe equations of state and properties of gases and liquids, including phase transition

*LOCQ: Lower Order Cognitive Question; IOCQ: Intermediate Order Cognitive Question; HOCQ: Higher Order Cognitive Question.