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 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.

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

   (iii) Percentage saturation of a vapour bearing gas is always _____ the relative saturation.
         (a) higher than
         (b) smaller than
         (c) equal to
         (d) either (a) or (b) depending on amount of vapour.

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

   (v)   The negative of the standard heat of combustion of a fuel with water vapour as combustion product is known as
         (a) gross calorific value   (b) net calorific value
         (c) standard heat of formation   (d) heat of vaporization.

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7. (a) Define the following related to psychrometric chart: (i) absolute humidity, (ii) saturation humidity, (iii) relative humidity, (iv) percentage humidity.

   (b) 40 kg/h of water is to be removed in a dryer. Air is supplied to drying chamber at a temperature of 65°C, a pressure of 101 kPa, and a dew point of 5°C. If the leaves the drier at a temperature of 35°C, a pressure of 100kPa, and a dew point of 25°C, calculate the volume of air that must be supplied per hr at the initial conditions. Given: vapour pressure of water at 5°C and 24°C are 0.87 kPa and 2.98 kPa respectively.

   6 + 6 = 12

Group – E

8. (a) A continuous fractionating column is used to separate 1000kg/h of solution of benzene and toluene containing 0.4 mass fraction of benzene into an overhead product containing 97% benzene and bottom product of 2% benzene. A reflux ratio of 3.5 is being used. Calculate the condenser and boiler heat duty from the following data given: Enthalpy of feed 171 kJ/kg, enthalpy of distillate 67 kJ/kg, enthalpy of bottom product 200 kJ/kg, enthalpy of overhead vapour 540 kJ/kg.

   (b) In a mechanically agitated batch reactor preheating of 2 Kg reactant from 25°C to 200°C is to be carried out by condensing saturated steam in the jacket. The reactor made of stainless steel 316 weighs 3.5 Kg. If the heating rate is 450 W, find the time required to achieve this heating.
        Data: Heat capacities of reactant and reactor vessel material are respectively 0.90 and 0.12 kcal/kg K. Take negligible reaction and no phase change during heating and negligible energy added to the system by the stirrer.

   6 + 6 = 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.

   (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.

   5 + 7 = 12

(vi)   The value of universal gas constant R is 8.314
        (a) kJ/mol K   (b) cal/mol K
        (c) J/kmol K   (d) kJ/kmol K.

(vii)   In _____ process, ions of salts react with water to produce acidity or alkalinity.
        (a) hydration   (b) hydrolysis
        (c) electrolysis   (d) dialysis.

(viii) Oxygen percentage by mass in atmospheric air is
        (a) 32   (b) 23   (c) 21   (d) 16.

(ix)   Heat of solution in a system in which both solute and solvent are liquid are termed as
        (a) heat of salvation   (b) heat of hydration
        (c) standard integral heat of solution   (d) heat of mixing.

(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)   A natural gas has the following composition, all figures are in volumetric percent: Methane, CH_4 83.5%, Ethane, C_2H_4 12.5%, Nitrogen, N_2 = 4.0. Calculate the average molecular weight and density of the gas mixture at 35^0C and 1.5 atm.

    (b)   The equation for the economic nozzle diameter is given by $D = 0.059 \dfrac{w^{0.45}}{\rho^{0.31}}$,

          where, D = economic nozzle diameter, inch, w = mass flow rate of fluid, lb / hr, and ρ = density of fluid, lb / ft^3. Transform the equation into a new form $D' = \alpha' \dfrac{w'^{0.45}}{\rho'^{0.31}}$ where, D' = economic nozzle diameter in mm, w = mass flow rate of fluid in kg/hr and ρ'= density of fluid in kg /m^3. Determine the value of α. Data: 0.3048 m = 1 foot and 0.4536 kg = 1 lb.

                                                              5 + 7 = 12

3. (a)   In a particular drying operation, it is necessary to hold the moisture content of feed to a dryer to 20% (w/w) to prevent lumping and sticking. This is accomplished by mixing the feed having 40% moisture content with a recycle stream of dried materials having 3% moisture content. Determine the fraction of dried product that must be recycled.

    (b)   A 1:2 mixture of A and B is distilled in a continuous distillation column to produce 90% A as distillate and 99% B as bottom product. Based on 10000 kg/h of feed flow rate calculate the mass flow rate of distillate and bottom product.

                                                              8 + 4 = 12

Group – C

4. (a)   A sample of coal has the following ultimate analysis: carbon 50.22%, hydrogen 2.8%, sulphur 0.41%, nitrogen 2.1%, ash 19.5%, oxygen 18.05% and rest is moisture. Predict the Orsat analysis of the flue gas produced from the coal taking 100% excess air.

    (b)   Iron pyrites FeS_2 is burnt with air 100 % in excess of that required to oxidize all iron to Fe_2O_3 and all sulphur to sulphur dioxide. Calculate the composition of the exit gases in mole% and weight %, if 80% of sulphur is oxidized to sulphur dioxide and the rest to sulphur trioxide. All iron is oxidized to Fe_2O_3.

                                                              7 + 5 = 12

5. (a)   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).

    (b)   In production of sulphur trioxide (SO_3) 100 k mol of SO_2 and 200 k mol of O_2 are fed to the reactor. The product stream is found to contain 80 kmol of SO_3. Find the percent conversion of SO_2.

                                                              (3 + 3 + 3) + 3 = 12

Group – D

6. (a)   When air (21 mole% O_2 and 79 mol% N_2) is placed in contact with 1000 cm^3 of liquid water at 36.9^0C and 1 atm pressure, approximately 14.1 standard cubic centimeters of gas (measured at 0^0C and 1 atm) are absorbed in the water at equilibrium. Subsequent analysis of the liquid reveals that 33.4 mol% of the dissolve gas is oxygen and the balance is nitrogen. Estimate the Henry's law constants (atm/mol fraction) of oxygen and nitrogen at 36.9^0C. Data: Density of water = 1 gm/cm^3.

    (b) CO_2 is absorbed from a gas stream by counter-current flow of liquid monoethanolamine (MEA) solution in an absorption column. Feed gas enters into the column at a volumetric flow rate of 14 m^3/min with CO_2 mole percent 12.3%. Treated gas has CO_2 concentration 2.5 mole%. Liquid MEA solution fed to the column at a rate of 30 kg/min with MEA mass fraction 32.5%. Determine the exit liquid and gas flow rate with their composition. Take molecular weight of MEA to be 61.

                                                              5 + 7 = 12