BASICS OF MATERIAL & ENERGY BALANCE
(CHEN 2103)

Time Allotted : 2½ hrs **Full Marks : 60**

Figures out of the right margin indicate full marks.

Candidates are required to answer Group A and any 4 (four) from Group B to E, taking one from each group.

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

Group – A

1. Answer any twelve: **12 × 1 = 12**

Choose the correct alternative for the following

(i) For the equation D (m) = **a** t (s) + b, the units of **a** are
(a) m (b) m/s
(c) s/m (d) none of the above.

(ii) Air contains 21 mol% O_2 (mol.wt. = 32) and 79 mol% N_2 (mol.wt = 28). The average molecular weight of air is
(a) 28.84 (b) 30.00
(c) 25.24 (d) 27.50.

(iii) A 20% (by mass) NaCl solution in water (solution density 1.127 kg/L) has molality (mol/kg)
(a) 3.85 (b) 4.275
(c) 5.780 (d) None of the above.

(iv) Solutions having same osmotic pressure are called
(a) ideal solution (b) isotonic solution
(c) saturated solution (d) supersaturated solution.

(v) Unit of mass velocity is
(a) kg/m s (b) kg/m^2 s
(c) kg/m^2 (d) kg/s.

(vi) Enthalpy of a vapour gas mixture may be increased by increasing the
(a) temperature at constant humidity (b) humidity at constant temperature
(c) temperature and humidity (d) all of these.

(vii) Recycling in a chemical process facilitates
(a) increased yield (b) enrichment of product
(c) heat conservation (d) all of these.

(viii) Heat of reaction is function of
(a) pressure (b) temperature
(c) both ‘a’ & ‘b’ (d) neither ‘a’ nor ‘b’.

(ix) With rise in pressure, the solubility of gases in solvent at a fixed temperature
(a) increases (b) decreases
(c) remain unchanged (d) first decreases then increases.

(x) The value of universal gas constant 'R' in kcal/mol K
(a) 1.987 (b) 1.987×10^{-3}
(c) 8.314 (d) 8.314×10^{3}

Fill in the blanks with the correct word

(xi) A sample of LDO (density 0.85kg/L) from a refinery contains 0.68 mass% sulfur. The concentration of this impurity in ppm is _____

(xii) For saturated air, percentage humidity is _____ relative humidity.

(xiii) Kopp's rule is helpful in finding _____ of solids.

(xiv) _____ chart is a graph related to Antoine equation.

(xv) The mass percentage of oxygen present in air is _____.

Group - B

2. (a) A mixture of gases contains O_2 10%, N_2 60%, CO_2 25% and CO 5% by moles. The gas mixture is at 30^0C and 755 mm Hg pressure. Find its average molecular weight. *[(CO2)(Evaluate/LOCQ)]*

(b) The concentration of CO_2 is measured to be 0.206 kmol / kmol MEA in a 20 mass % aqueous MEA ($NH_2CH_2CH_2OH$). Assuming the density of the solution to be equal to 1.0 kg/L, find the concentration of CO_2 as mass percent of the solution. *[(CO2)(Evaluate/IOCQ)]*

(c) It is required to make 1000 kg of mixed acid containing 60% H_2SO_4, 32% HNO_3 and 8% water by blending (i) the spent acid containing 11,3% HNO_3, 44.4% H_2SO_4 and 44.3% H_2O (ii) 90% HNO_3 and (iii) 98% H_2SO_4. Calculate the quantities of these three acids required for blending. All percentages are by mass.. *[(CO2)(Analyse/IOCQ)]*

4 + 4 + 4 = 12

3. (a) A solution of $K_2Cr_2O_7$ in water contains 13% $K_2Cr_2O_7$ by weight. From 1000 kg of this solution are evaporated 640 kg of water. The remaining solution is cooled to 20^0C. Calculate the amount and the percentage yield of $K_2Cr_2O_7$ crystal produced. Data: Solubility of $K_2Cr_2O_7$ at 20^0C is 0.390 kmol/1000kg water. Molecular weight of $K_2Cr_2O_7$ = 294 *[(CO2) (Evaluate/LOCQ)]*

(b) The average molecular weight of a flue gas sample is calculated by two different engineers. One engineer uses the correct molecular weight of 28 for N_2 and determines the average molecular to be 30.08; the other engineer, using an incorrect value of 14, calculates the average molecular weight to be 18.74. If the remaining components of the flue gas are CO_2 and O_2, determine the molar composition of the flue gas. *[(CO2) (Evaluate/IOCQ)]*

(c) One thousand kg per hour of a mixture of benzene (B) and Toluene (T) containing 50% benzene by mass is separated by distillation into two fractions. The mass flow rate of benzene in the top stream is 450 kg Benzene /h and that

of toluene in the bottom stream is 475 kg/h. The operation is at steady state. Write balance on benzene and toluene to calculate the unknown component flow rates in the output streams. *[(CO2)(Evaluate/HOCQ)]*

4 + 4 + 4 = 12

Group - C

4. (a) A sample of coal has the following ultimate analysis: carbon 50.22%, hydrogen 2.8%, sulfer 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. *[(CO2)Analyze/HOCQ]*

(b) 10 kg of PbS and 3 kgs of O_2 react to yield 6 kgs of Pb and 1 kg of PbO_2 according to the reaction:

$$PbS + O_2 = Pb + SO_2$$
$$PbS + 2O_2 = PbO_2 + SO_2$$

Calculate (i) the amount of PbS that does not react, (ii) percentage excess O_2 based on the amount of PbS that actually reacts, (iii) amounts of SO_2 formed (iv) percentage conversion of PbS to Pb. (Atomic weight of Pb =207.2)

[(CO2)(Analyze/IOCQ)]

6 + 6 = 12

5. (a) In the operation of a synthetic ammonia plant, a 1:3 N_2-H_2 mixture is fed to the convertor resulting in a 30% conversion of ammonia. The ammonia formed is separated by condensation and the unconverted gas is recycled to the reactor. The initial N_2-H_2 mixture contains 0.25 parts of argon to 100 part of N_2-H_2 mixture. The tolerance limit of argon entering the reactor is assumed to 8 part of N_2-H_2 mixture. Estimate the fraction of recycle that is continuously purged.

[(CO4)(Analyse/HOCQ)]

(b) Propane is burned with excess air to ensure complete combustion. If 55 kg of CO_2 and 15 kg of CO are obtained when pure propane is completely burned with 500 kg air, determine the composition of flue gas. *[(CO2)(Analyze/IOCQ)]*

8 + 4 = 12

Group - D

6. (a) The vapour pressure of chloroform is given by Antoine equation

$$\ln P^s = 13.9582 - \frac{2696.8}{T - 46.16}$$

where, pressure is in kPa and temperature in K. Determine the boiling point of chloroform at 0.5 bar pressure. Also determine the vapour pressure of chloroform at 27°C. *[(CO3)Evaluate/LOCQ]*

(b) Over short temperature ranges, the viscosity of liquid CCl_4 appears to follow the relationship as $\mu = A\exp\left(\frac{B}{T}\right)$. Determine the values of A and B from the following data of CCl_4.

T, in K	303	313	323	333	343
μ, in mPa-s	0.843	0.739	0.651	0.585	0.524

[(CO3)Analyze/HOCQ]

4 + 8 = 12

7. (a) Define the following related to vapour gas system: relative humidity, percentage humidity, humid volume. *[(CO5)Remember/LOCQ]*

(b) 2.5 m^3 of air initially at 50°C and 101.3 kPa with a molar humidity of 0.03 is compressed isothermally to 506.5 kPa and finally cooled to 21°C. Calculate the weight of water condensed and final volume of air. The vapour pressure of water at 50°C and 21°C are 12.34 kPa and 2.49 kPa respectively.

[(CO5) Analyze/IOCQ]

6 + 6 = 12

Group - E

8. (a) What is adiabatic flame temperature of fuel? Why theoretical flame temperature is greater than actual flame temperature of a furnace using the same fuel?

[(CO5)(Understand/LOCQ)]

(b) Water is pumped with a 25 kW pump (pump efficiency 60%) from a reservoir to an overhead tank situated 15 m above the ground at the rate of 1 l/s. A heater is to be installed during its transfer from the reservoir to over head tank so as to keep the overhead tank temperature 10°C above the ground reservoir temperature. Assuming that there is a constant heat loss of 2 kW in the surrounding what capacity heater is required for the purpose.

[(CO1,2)(Analyze/HOCQ)]

4 + 8 = 12

9. (a) Define the following term: (i) The standard heat of reaction, (ii) The standard heat of combustion, (iii) The standard heat of formation. *[(CO2)Remember/LOCQ]*

(b) Calculate the maximum flame temperature attained when methane is burned with theoretical amount of air. Methane and air are initially at 298 K. The mean heat capacities in J/mol K are 62.75 for CO_2, 52.96 for H_2O, 38.67 for O_2 and 37.13 for N_2. The standard heat of combustion of methane at 298 K is -802.625 kJ/mol. *[(CO2) Analyze/IOCQ]*

6 + 6 = 12

Cognition Level	LOCQ	IOCQ	HOCQ
Percentage distribution	29.2	35.4	35.4

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.*