

**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<sub>2</sub> (mol.wt. = 32) and 79 mol% N<sub>2</sub> (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<sup>2</sup> s  
(c) kg/m<sup>2</sup> (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)  $1.987 \times 10^{-3}$   
 (c) 8.314 (d)  $8.314 \times 10^3$

*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<sub>2</sub> 10%, N<sub>2</sub> 60%, CO<sub>2</sub> 25% and CO 5% by moles. The gas mixture is at 30°C and 755 mm Hg pressure. Find its average molecular weight. [[CO2](Evaluate/LOCQ)]
- (b) The concentration of CO<sub>2</sub> is measured to be 0.206 kmol / kmol MEA in a 20 mass % aqueous MEA (NH<sub>2</sub>CH<sub>2</sub>CH<sub>2</sub>OH). Assuming the density of the solution to be equal to 1.0 kg/L, find the concentration of CO<sub>2</sub> as mass percent of the solution. [[CO2](Evaluate/IOCQ)]
- (c) It is required to make 1000 kg of mixed acid containing 60% H<sub>2</sub>SO<sub>4</sub>, 32% HNO<sub>3</sub> and 8% water by blending (i) the spent acid containing 11.3% HNO<sub>3</sub>, 44.4% H<sub>2</sub>SO<sub>4</sub> and 44.3% H<sub>2</sub>O (ii) 90% HNO<sub>3</sub> and (iii) 98% H<sub>2</sub>SO<sub>4</sub>. 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<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> in water contains 13% K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> by weight. From 1000 kg of this solution are evaporated 640 kg of water. The remaining solution is cooled to 20°C. Calculate the amount and the percentage yield of K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> crystal produced. Data: Solubility of K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> at 20°C is 0.390 kmol/1000kg water. Molecular weight of K<sub>2</sub>Cr<sub>2</sub>O<sub>7</sub> = 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<sub>2</sub> 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<sub>2</sub> and O<sub>2</sub>, 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)]

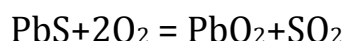
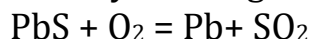
**4 + 4 + 4 = 12**

### Group - C

4. (a) A sample of coal has the following ultimate analysis: carbon 50.22%, hydrogen 2.8%, sulfur 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<sub>2</sub> react to yield 6 kgs of Pb and 1 kg of PbO<sub>2</sub> according to the reaction:



Calculate (i) the amount of PbS that does not react, (ii) percentage excess O<sub>2</sub> based on the amount of PbS that actually reacts, (iii) amounts of SO<sub>2</sub> 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<sub>2</sub>-H<sub>2</sub> 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<sub>2</sub>-H<sub>2</sub> mixture contains 0.25 parts of argon to 100 part of N<sub>2</sub>-H<sub>2</sub> mixture. The tolerance limit of argon entering the reactor is assumed to 8 part of N<sub>2</sub>-H<sub>2</sub> mixture. Estimate the fraction of recycle that is continuously purged.

[[CO4](Analyze/HOCQ)]

- (b) Propane is burned with excess air to ensure complete combustion. If 55 kg of CO<sub>2</sub> 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<sub>4</sub> 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<sub>4</sub>.

T, in K	303	313	323	333	343
$\mu$ , 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<sup>3</sup> 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<sub>2</sub>, 52.96 for H<sub>2</sub>O, 38.67 for O<sub>2</sub> and 37.13 for N<sub>2</sub>. 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.