INDUSTRIAL STOICHIOMETRY
(BIOT 2102)

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) An Ideal liquid solution follows
(a) Raoult's Law (b) Modified Charles Law
(c) Boyle'e Law (d) None of these.

(ii) When the temperature of a binary mixture is less than its bubble point then it is a
(a) Saturated liquid mixture (b) Equilibrium vapour liquid mixture
(c) Saturated vapour mixture (d) Subcooled liquid mixture.

(iii) Which of the following statements is NOT true?
(a) 4 gmol of O_2 is equal to 4 available electrons
(b) Vapour-liquid mixture has a range of boiling points
(c) Gauge pressure = Absolute pressure – Atmospheric pressure
(d) Change in internal energy is equal to the heat added at constant pressure

(iv) How many milliliters of 2 M NaCl solution are required to make 1 liter of 0.4 M NaCl solution?
(a) 5000 ml (b) 800 ml (c) 200 ml (d) 0.2 ml.

(v) Number of available electrons of an element is
(a) equal to its valency
(b) equal to -3 for nitrogen
(c) is used to determine the degree of reduction of an organic compound
(d) all of the above.

(vi) Conversion factor to change inches in to cm. is
(a) 2.54 (b) 1/2.54 (c) 1/30.48 (d) 12.

(vii) There were 15 moles of a substance present initially in a system, 25 moles were added to it and a reaction occurred so that its moles are reduced by 50%, what are the final moles of a substance in the system?
(a) 10 (b) 15 (c) 20 (d) 40.

(viii) A flue gas mixture has the following molar composition of CO_2= 10%, H_2O= 25%, O_2= 20% and N_2= 45%. What will be the molar composition of O_2 in the dry flue gas?
(a) 26.67 (b) 20
(c) 13.33 (d) None of these.

(ix) Ideal liquid solution follows
(a) Henry's law (b) Boyle's Law
(c) Charles' Law (d) Raoult's Law.

(x) For a gaseous mixture, composition of the components in volume fraction is equal to their composition
(a) in weight fraction (b) in volume fraction
(c) in partial pressure fraction (d) both (b) and (c).

Fill in the blanks with the correct word

(xi) The heat of combustion of carbon is _____.

(xii) A vapor whose partial pressure is less than its equilibrium vapor pressure is called a _____ vapor

(xiii) Degree of reduction of $CH_{1.8}O_{0.5}N_{0.2}$ with respect to nitrogen is _____.

(xiv) In a particular reaction, one of the reactants limits the amount of products formed. That is called as _____.

(xv) Material balance is a law of conservation of _____.

Group - B

2. Biomass growth with respect to time follows the equation $X=Xoe^{\mu t}$., where X= biomass concentration at any time t, Xo= biomass concentration at t=to and μ= specific growth rate. Find the value of Xo and μ from the following batch data.

T hr	7	12	15	20	24
X (mg/L)	5.73	8.39	10.53	15.40	20.88

[(CO3)(Analyse/HOCQ)]
12

3. The following data has been gathered from an experiment to determine the relationship which exist between the diameter of a ring (d) and its period of oscillation (T) as a pendulum:

Ring dia (d) (cm)	3.51	7.26	13.7	28.5	38.7
Time period (T)(sec)	0.376	0.532	0.768	1.08	1.32

If the relationship existing between T and d is given as $T=Ad^n$, then find out the value of A and n using log-log graph paper. *[(CO2)(Analyse/HOCQ)]*
12

Group - C

4. (a) 1000 Kg of mixed acid of composition 40% H_2SO_4, 45% HNO_3 and 15% H_2O is to be produced by strengthening waste acid of composition 30% H_2SO_4, 36% HNO_3

and 34% H_2O by weight. Concentrated H_2SO_4 of strength 95% and concentrated HNO_3 of strength 80% are available for this purpose. How many Kg of waste acid and concentrated acids are to be mixed together? *[(CO3)(Evaluate/HOCQ)]*

(b) Write down the material balance equation for a continuous reacting system under steady state condition. *[(CO3)(Remember/LOCQ)]*

8 + 4 = 12

5. (a) The chlorination of methane occurs by the following reaction

$$CH_4 + Cl_2 \rightarrow CH_3Cl+HCl$$

Determine the product composition in mol% if the conversion of the limiting reactant is 67%, and the feed contains 40 gmol CH_4, 50 gmol Cl_2, and 10 gmol N_2. *[(CO3)(Evaluate/IOCQ)]*

(b) Antimony is obtained by heating pulverised stibnite (Sb_2S_3) with scrap iron and drawing antimony (Sb) from the bottom of the reactor vessel.

Sb_2S_3 3Fe → 2Sb +3FeS

Suppose that 0.600 Kg of stibnite (Sb_2S_3, MW= 340) and 0.25 Kg of Fe (MW = 56) are heated together to give 0.20 Kg of Sb metal (MW =121.8), determine

(i) Which reactant is limiting reactant?

(ii) % excess reactant. *[(CO4)(Calculate/IOCQ)]*

6 + 6 = 12

Group - D

6. Pyrites fines are roasted in a chamber plant for making sulphuric acid. The gases leaving the roaster are at 775 K and have molar composition SO_2= 7.09%, O_2= 10.55%, SO_3= 0.45% and N_2= 81.91%.Calculate the heat content of 1 kmol gas mixture over 298 K, using the following heat capacity data.$C_p=a+bT+cT^2+dT^3$ kJ/kmol.K.

Compounds	a	$b\times10^3$	$c\times10^6$	$d\times10^9$	$e\times10^{12}$
SO_2	2.346	-5.67	6.345	-234.1	-
O_2	5.243	6.997	-4.234	7.865	-
SO_3	9.876	-432.98	79.567	-4568	-
N_2	12.765	789.765	-567.98	9.766	-

[(CO3)(Analyse/HOCQ)]

12

7. Combustion of solid wastes produces a flue gas of the following composition: CO_2=9%, CO=2%, O_2=7% and N_2=82%. Find the difference in enthalpies for this gas between the bottom and the top of the stack if the temperature of the gas at the bottom is 600 K and that at the top is 375K. The heat capacities of the gas are:

CO: $C_p= 26.586+ 7.582\times10^{-3}T- 1.12\times10^{-6}T^2$

CO_2: $C_p= 26.540+ 42.454\times10^{-3}T- 14.298\times10^{-6}T^2$

O_2: $C_p= 25.74+ 12.987\times10^{-3}T- 3.864\times10^{-6}T^2$

N_2: $C_p= 27.03+ 5.815\times10^{-3}T- 0.289\times10^{-6}T^2$ where C_p is in KJ/(Kmol.K) and T is in K.

[(CO3)(Analyse/HOCQ)]

12

Group - E

8. *Propionibacterium* species ($CH_{1.8}O_{0.5}N_{0.2}$) are tested for commercial scale production of propionic acid. Propionic and other acids are synthesized in anaerobic culture using sucrose as substrate and ammonia as nitrogen source. Overall yields from sucrose are as follows:
   Propionic acid=40%(w/w), acetic acid=20%(w/w), butyric acid=5%(w/w), lactic acid=3.4%(w/w) and biomass=12%(w/w). Bacteria are inoculated into a vessel containing sucrose and ammonia; a total of 30kg sucrose is consumed over a period of 10days. What are the cooling requirements?
   Heat of combustion of Propionic acid ($C_3H_6O_2$) = -1527.3 KJ/gmol
   Heat of combustion of Acetic acid ($C_2H_4O_2$) = -874.2 KJ/gmol
   Heat of combustion of Butyric acid ($C_4H_8O_2$) = -2183.6 KJ/gmol
   Heat of combustion of Lactic acid ($C_3H_6O_3$) = -1368.3 KJ/gmol
   Heat of combustion of Sucrose ($C_{12}H_{22}O_{11}$) = -5644.9 KJ/gmol
   Heat of combustion of ammonia = -382.6 KJ/gmol. *[(CO2)(Apply/IOCQ)]*
   12

9. *Azetobacter vinelandii*is used to produce alginate in a continuous reactor from sucrose at room temperature. The yield of alginate was 4 g/gof O_2 consumed. The required rate of alginate production was 5 kg/h. The mechanical energy requirement to run the reactor could not be neglected and power requirement was estimated to be 1.5 kW. Estimate the cooling requirements. (energy released per gmole of electron transferred = -115 kJ). *[(CO5)(Apply/IOCQ)]*
   12

Cognition Level	LOCQ	IOCQ	HOCQ
Percentage distribution	4.17	37.5	58.33

Course Outcome (CO):

After completion of the course, the students will be able to:
1. Solve problems related to units and conversions and fit the given data using the methodologies.
2. Able to make *material balances* on unit operations and processes.
3. Understand stoichiometry of microbial growth and product formation.
4. Solve problems related to energy balance for steady state processes.
5. Determine the heat of reaction for processes with biomass and secondary metabolite production.
6. Design simultaneous material and energy balances in biochemical processes.

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