INDUSTRIAL STOICHIOMETRY
(BIOT 2102)

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) Which of the following does the concept of material balance based upon?
(a) Conservation of mass (b) Conservation of energy
(c) Conservation of momentum (d) Conservation of Volume

(ii) 2 litres of nitrogen at N.T.P. weighs ________ gms.
(a) 2.5 (b) 1.25 (c) 28 (d) 14

(iii) Find out the incorrect statement
(a) Δ°F = Δ°R and Δ°C = Δ°K (b) Δ°C = 1.8 Δ°F and Δ°K = 1.8 Δ°F
(c) Both (a) and (b) are correct (d) Both (a) and (b) are incorrect

(iv) Pick out the correct conversion.
(a) 1 BTU = 453.6 calories (b) 1 calorie = 252 BTU
(c) 1 BTU = 252 calories (d) 1 calorie = 453.6 BTU

(v) With reference to the following reaction, if 100 g of N_2 and 100 g of H_2O are mixed and the maximum possible reaction occurs, what mass of O_2 is produced?
$2N_2 + 6H_2O = 4NH_3 + 3O_2$
(a) 100 (b) 171 (c) 88.9 (d) 2.78

(vi) Calculate the heat gained by one kmol of a gas when heated from 400K to 800K whose heat capacity is given by C_p = a+ bT KJ/(kmol.K) where a= 50 and b= 0.02.
(a) 24800KJ (b) 24800KW (c) 2160KW (d) 21600KJ

(vii) Degree of reduction of $CH_{1.8}O_{0.5}N_{0.2}$ with respect to nitrogen is
(a) 4.8 (b) 4.2 (c) 4 (d) indeterminate.

(viii) When the temperature of a binary mixture is at its dew point, then it is a
(a) saturated liquid mixture (b) equilibrium vapour liquid mixture
(c) saturated vapour mixture (d) subcooled liquid mixture.

(ix) Degree of freedom of a binary mixture of ethanol and water is
(a) more than one (b) less than one (c) one (d) indeterminate.

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

Group- B

2. (a) An ideal gas mixtures has the following stoichiometic analysis.

Component	% by mass
N_2	40
CO_2	10
CO	13
O_2	17
H_2	8
CH_4	12

(i) Find the analysis on a volume basis.
(ii) What is the volume of 1 kg of this gas when pressure = 1.5 MPa and T = 30°C
[(CO1)(Calculate/IOCQ)]

(b) Prove that for mole fraction of a component in an ideal gas mixture is same as its volume fraction. [(CO1)(Prove/IOCQ)]

(6 + 3) + 3 = 12

3. In case of liquids, the local heat transfer coefficient (h) for long tubes is expressed by the following empirical equation

$$H = 0.023\frac{G^{0.8}Cp^{0.5}K^{0.67}}{D^{0.2}\ \mu^{0.47}}$$

H = Heat transfer coefficient ,Btu/(hr.ft².°F)
G = Mass velocity, lb/(ft².sec)
K = Thermal conductivity , (Btu/(ft. hr.°F)
D = Diameter of pipeline, m
Cp = Specific heat, Btu/(lb.°F)
μ = Viscosity, lb/(ft.sec)
Convert the equation to the following form and Find the value of A

$$H' = A\frac{G'^{0.8}Cp'^{0.5}K'^{0.67}}{D'^{0.2}\ \mu'^{0.47}}$$

Where the units of the converted parameters are
H′, Cal/(sec.m².°C)
G′ , Kg/(m².sec)
K′, Cal/(m. sec. °C)
D′, m
Cp′, Cal/(kg.°C)
μ′, Kg/(m.sec). [(CO2)(Critical/HOCQ)]

12

Group - C

4. In a process of Cl_2 manufacture, a dry mixture of HCl gas and air is passed over a heated catalyst which promotes oxidation of the acid. Air is used in 20% excess of that stoichiometrically required.

$$4HCl + O_2 \rightarrow 2Cl_2 + 2H_2O$$

Calculate
(i) Weight of air supplied per kg of acid.
(ii) Composition by weight of gas entering the reaction chamber.
(iii) Assuming that 60% of the acid is oxidised in the process, calculate the composition by weight of the gas leaving the chamber. [(CO4)(Design/HOCQ)]

(4 + 4 + 4) = 12

5. Assume that experimental measurements for a certain organism have shown that cells can convert 2/3 rd (wt/wt) of substrate carbon (glucose) to biomass. Calculate
(i) Stoichiometric coefficients for the following biological reactions.

$$C_6H_{12}O_6\ \ aO_2 + bNH_3 \rightarrow cC_{4.4}H_{7.3}N_{0.86}O_{1.2}) + d\ H_2O + eCO_2$$

(ii) Calculate the yield coefficients Yx/s and Y_X/O_2 for the reaction.

[(CO4)(Evaluate/IOCQ)]

(8 + 4) = 12

Group - D

6. Temperature of pure oxygen is raised from 350K to 1500K.
(i) Calculate the amount of heat supplied for raising the temperature of 1kmol oxygen using the following C_p data and absolute enthalpies.
(ii) Calculate the error % in calculating using absolute enthalpies.

$$C_p = a + bT + cT^2 + dT^3\ kJ/(kmol.K)$$

Absolute enthalpy at 350K = 10,129KJ/kmol and at 1500K = 49,273 KJ/kmol

a	$b \times 10^3$	$c \times 10^6$	$d \times 10^9$
26.02	11.75	-2.342	-0.5623

[(CO4)(Analyze/IOCQ)]

12

7. (a) Calculate the heat of formation of liquid 1,3-butadiene, where the heats of combustion of 1,3-butadiene, carbon and hydrogen are -2522.1KJ/mol, -393.51KJ/mol and -241.82KJ/mol respectively. [(CO5)(Calculate/LOCQ)]
(b) Water from a tank at a height Z_1 m from the ground is pumped with a velocity U_1 m/s into a reactor containing $CaCO_3$ resulting in an exothermic reaction. The product is transferred into a reservoir at a height Z_2 m from the ground at a velocity of U_2 m/s. Balance the energy components considering a steady flow process.

[(CO4)(Derive/IOCQ)]

6 + 6 = 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 ($C_3H_6O_2$) = - 1527.3KJ/gmol
   Heat of combustion of Acetic acid ($C_2H_4O_2$) = - 874.2KJ/gmol
   Heat of combustion of Butyric acid ($C_4H_8O_2$) = - 2183.6KJ/gmol
   Heat of combustion of Lactic acid ($C_3H_6O_3$) = - 1368.3KJ/gmol
   Heat of combustion of Sucrose ($C_{12}H_{22}O_{11}$) = - 5644.9KJ/gmol
   Heat of combustion of ammonia = - 382.6KJ/gmol. [(CO6)(Evaluate/HOCQ)]
   12

9. *Aspergillus niger* is used to produce citric acid in a batch reactor operated at 30°C. Over a period of three days, 4500kg glucose and 1050kg oxygen are consumed to produce 3000kg citric acid, 1000kg biomass and other products. Ammonia is used as nitrogen source. Power input to the system by mechanical agitation of the broth is about 15kW; approximately 200kg water is evaporated over the culture period. Estimate the cooling requirements. Latent heat of vapourization of water at 30°C is 2430.7kJ/kg.
   [(CO6) (Solve/HOCQ)]
   12

Cognition Level	LOCQ	IOCQ	HOCQ
Percentage distribution	6.25	43.75	50

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.