CHEMICAL ENGINEERING

Paper – II

*Time Allowed : **Three** Hours*

*Maximum Marks : **200***

Question Paper Specific Instructions

Please read each of the following instructions carefully before attempting questions :

*There are **EIGHT** questions in all, out of which **FIVE** are to be attempted.*

*Questions no. **1** and **5** are **compulsory**. Out of the remaining **SIX** questions, **THREE** are to be attempted selecting at least **ONE** question from each of the two Sections A and B.*

Attempts of questions shall be counted in sequential order. Unless struck off, attempt of a question shall be counted even if attempted partly. Any page or portion of the page left blank in the Question-cum-Answer Booklet must be clearly struck off.

All questions carry equal marks. The number of marks carried by a question/part is indicated against it.

Unless otherwise mentioned, symbols and notations have their usual standard meanings.

Assume suitable data, if necessary, and indicate the same clearly.

Neat sketches may be drawn, wherever required.

*Answers must be written in **ENGLISH** only.*

SECTION A

Q1. (a) A mixture of hydrogen, nitrogen and carbon dioxide of 1000 m^3 volume at 423 K was found to have the partial pressures of gases in the ratio as given : $p_{H_2} : p_{N_2} : p_{CO_2} = 1 : 4 : 3$. If the total pressure is 3 atm.; calculate :

(i) the mole fraction of each gas

(ii) the average molecular weight

(iii) the weight percentage of these gases

(iv) the weight of carbon dioxide present in kilograms

Use R = 0·082 m^3 atm./kmole – K. *8*

(b) Explain the following :

(i) Recycle, Bypass and Purging operations *6*

(ii) Heat of reaction *2*

(c) For a reversible adiabatic process involving an ideal gas with constant C_p, the relationship between temperature and pressure is given by the expression :

$$\frac{T_2}{T_1} = \left[\frac{P_2}{P_1}\right]^{\frac{\gamma-1}{\gamma}}$$

Determine the equivalent expression for an ideal gas with temperature-dependent specific heat, *8*

$$C_p = a + bT + cT^2$$

(d) Pasteurization is useful for the preservation of food material. Cow's milk is pasteurized if it is heated to 57°C for 40 minutes, but if it is heated to 77°C, it only needs 0·25 minutes for the level of pasteurization. Find the activation energy of this process. *8*

(e) Define an "Autocatalytic reaction". Also, derive the formula :

$$ln\frac{C_R / C_{R_0}}{C_A / C_{A_0}} = (C_{A_0} + C_{R_0})\,kt$$

for autocatalytic reaction A + R $\longrightarrow$ R + R. Notations have their usual meanings. *8*

Q2. (a) Carbon monoxide at 100°C is burnt under atmospheric condition with air (dry) at 500°C in 90% excess of that theoretically required. The products of combustion leave the reaction chamber at 950°C. Assuming complete combustion, calculate the heat evolved in the reaction chamber in kilo calories per kilogram mole of carbon monoxide burnt. The heat of combustion of carbon monoxide is 67640 kcal/kmole. The following average values of specific heats in kcal/kg mole – °C may be used :

$CO\ (18 - 100°C) = 7{\cdot}00$; Air $(18 - 500°C) = 7{\cdot}25$

$CO_2\ (18 - 950°C) = 11{\cdot}8$; O_2; $N_2\ (18 - 950°C) = 7{\cdot}5$ *15*

(b) Explain the significance of the thermodynamic energy functions – Internal energy, Enthalpy, Helmholtz free energy and Gibb's free energy. How are these functions interrelated through their natural variables and differential forms ? Derive the Maxwell's relations from these interrelations. *15*

(c) For the following first order aqueous phase reaction :

$$A \xrightarrow{k} R$$

Derive that $-ln(1 - X_A) = kt$.

For this reaction, rate constant $k = 1{\cdot}05 \times 10^4\ sec^{-1}$ and initial concentration of reactant A is 0·06 mol/litre. Calculate the time (hr) required for 60% conversion of reactant A. Notations used in this problem have their usual meanings. *10*

Q3. (a) The standard free energy change for the following reaction

$$C_4H_8\,(g) \rightleftharpoons C_4H_6\,(g) + H_2\,(g)$$

is given by the relation :

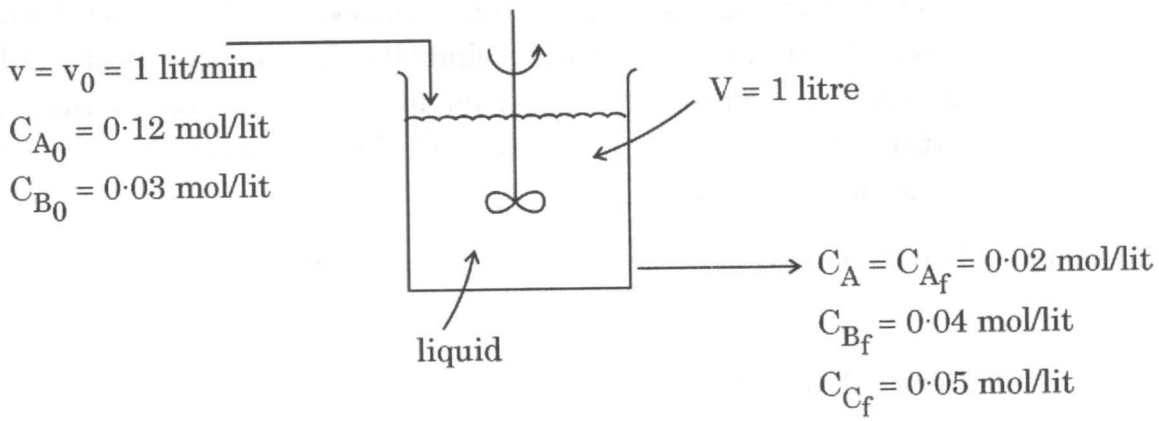
$$\Delta G^\circ_T = 1{\cdot}03665 \times 10^5 - 20{\cdot}9759 \cdot T \cdot ln(T) + 12{\cdot}9372 \cdot T$$

where ΔG°_T is in J/mol and T is in K.

(i) Calculate the equilibrium conversion of the reaction at 773 K, using a feed of pure butene, for operations at 1 bar and 3 bar.

(ii) Calculate the equilibrium conversion of the reaction at 773 K, when the feed consists of 50 mole percent butene and 50 mole percent inert components, for operations at 1 bar and 3 bar. *15*

(b) Mixed flow reactors are fed with reactants and outgoing stream consists of some products and some amount of unconverted reactants. 1 litre/min of liquid containing reactants A and B (C_{A_0} = 0·12 mol/litre, C_{B_0} = 0·03 mol/litre) flows into a mixed flow reactor (V = 1 litre). Assume this system as constant density reaction system. The outlet stream from the reactor contains A, B and C (C_{A_f} = 0·02 mol/litre, C_{B_f} = 0·04 mol/litre, C_{C_f} = 0·05 mol/litre) as shown in the following figure. Find the rate of disappearance of A, B and C for the conditions within the reactor. *15*



(c) Nitrobenzene is produced commercially by nitrating benzene with mixed acid containing 39% nitric acid, 53% sulphuric acid and 8% water. A charge is made up of 655 kg benzene and 1360 kg of mixed acid. The reaction is 95% complete. Calculate :

(i) the quantity of nitrobenzene produced.

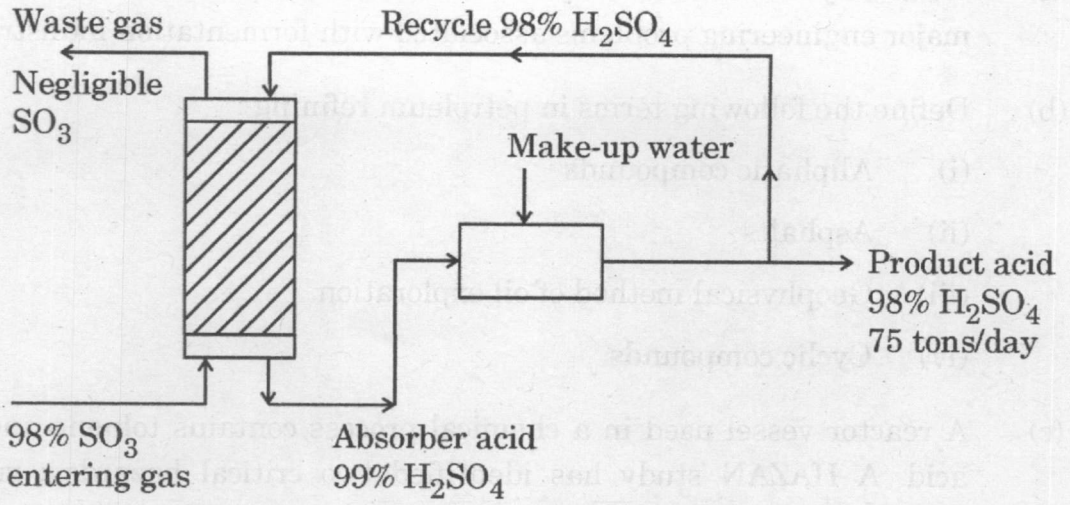
(ii) the composition of spent acid. *10*

Q4. (a) Discuss the "Ideal Batch Reactor".

For the reaction A $\longrightarrow$ Products, derive the following design equation for the Batch reactors with the help of suitable assumptions. Assume that the density of the reaction system remains constant. *15*

$$t = -\int_{C_{A_0}}^{C_A} \frac{dC_A}{(-r_A)} = C_{A_0} \int_0^{X_A} \frac{dX_A}{(-r_A)}$$

(b) The SO_3 absorption tower in sulphuric acid plant uses sulphuric acid (98% H_2SO_4 by weight) as a liquid absorbent because SO_3 is partially soluble in 98% acid.



As shown in the figure, 98% acid is fed into the tower where it absorbs SO_3 leaving as 99% acid. Make-up water dilutes this acid back to 98% and is partly withdrawn as product and the rest is recycled to the absorber. Calculate :

(i) the flow rate of make-up water.

(ii) the weight of 98% acid recycled into the tower in a plant producing 75 tons/day of 98% H_2SO_4. *15*

(c) Define saturation pressure and saturation temperature for a pure substance. How do these parameters indicate phase equilibrium between a vapour and a gas ? Further, explain the physical significance of the triple point and critical point. Discuss how these thermodynamic states relate to the microscopic and macroscopic behaviour of the substance during phase transitions. *10*

SECTION B

Q5. (a) What do you understand by the term "Fermentation" ? Also, discuss the major engineering problems associated with fermentation industries. *8*

(b) Define the following terms in petroleum refining : *2×4=8*

(i) Aliphatic compounds

(ii) Asphalts

(iii) Geophysical method of oil exploration

(iv) Cyclic compounds

(c) A reactor vessel used in a chemical process contains toluene and nitric acid. A HAZAN study has identified two critical hazards : runaway reaction and vapour cloud formation.

(i) Apply relevant HAZOP guidewords to propose potential deviations and their causes for this system.

(ii) Analyze how the identified hazards would influence the Fire and Explosion Index of the process.

(iii) Recommend suitable engineering and administrative control measures to mitigate the identified hazards. *8*

(d) Explain the Greenhouse effect and the contribution of anthropogenic activities to global warming. *8*

(e) Define the following terms :

(i) Cost index *2*

(ii) Gross profit, Net profit and Cash flow *4*

(iii) Breakeven point *2*

Q6. (a) Define the term "Biogas". Discuss two stages, methanogenesis and acetogenesis, used in biogas production process. Also, draw the flow diagram of biogas production mechanism from organic matter through various steps. *15*

(b) A fertilizer manufacturing plant emits NO_x gases at a constant rate of 90 g/s from a stack of 100 m height. The wind speed at 10 m above the ground is measured at 3 m/s, and follows the power-law wind profile :

$$u(z) = u_{ref}\left(\frac{z}{z_{ref}}\right)^{\alpha}$$

where $\alpha = 0{\cdot}2$ for neutral stability.

Estimate the ground-level concentration at the plume centreline 2 km downwind, assuming the receptor is elevated by 15 metres relative to the stack base. Neutral atmospheric conditions (Pasquill stability class D) prevail with stack emissions exiting at 12 m/s through a 1·5 m diameter stack. The ambient temperature is 298 K, while the stack gas is released at 450 K. *15*

Include plume rise in the effective stack height calculation using the Briggs formula :

$$\Delta H = 1{\cdot}6\left(\frac{F}{u}\right)^{1/3}$$

where :

$$F = \frac{g\,v\,D^2(T_s - T_a)}{4T_a}$$

Use :

$g = 9{\cdot}81\ m/s^2$

Gaussian model parameters :

$\sigma_y = 0{\cdot}16x\,(1 + 0{\cdot}0004x)^{-0{\cdot}5}$

$\sigma_z = 0{\cdot}14x\,(1 + 0{\cdot}0003x)^{-0{\cdot}5}$

(c) Discuss the role of plant layout in determining the construction and manufacturing costs of the product in the chemical industry. *10*

Q7. (a) Explain the scope and significance of The Environment (Protection) Act in regulating and safeguarding India's environmental resources. Mention key provisions related to the protection of air, water and forest resources. *15*

(b) (i) A firm manufactures steel bolts with nuts and makes an estimate of the cost as follows on the basis of 1000 bolts with nuts :

	(₹)
Cost of material	3,000
Direct labour cost	
Forge shop	1,200
Machine shop	1,100
Cost of tools	700
Overhead expenditures	
Forge shop 200% of the labour	
Machine shop 150% of the labour	
Establishment charges of office expenses 25% of factory cost	
Cost of packing and transport	100

Competitive price ₹ 12·5 per piece.

Determine, by calculations, whether the firm is making a profit or loss per piece. *10*

(ii) Estimate the cost of a reactor of 1·2 m^3 glass-lined jacketed reactor in 2020, if the purchased cost of a similar reactor of 0·2 m^3 capacity was ₹ 7·0 crore in 2010. Use the exponent for cost versus capacity as 0·54. Use : *5*

Cost Index	361	382
Year	2010	2020

(c) Define the term "Antibiotics". Also, discuss the industrial method of production of antibiotics, along with a few examples of antibiotics. *10*

Q8. (a) A piece of equipment requires a fixed capital investment of ₹ 1,00,000. The service life is estimated at 10 years and scrap value is estimated as ₹ 20,000. Money may be invested at 6% interest. Determine the asset value of the equipment after 4 years by :

(i) Straight line method.

(ii) Reducing balance method.

(iii) Sinking fund method. *15*

(b) Discuss the importance of reforming process in petroleum refining. Also, draw the flow diagram for high pressure platinum catalyst reforming process along with the reactions involved. *15*

(c) Describe the relationship between ecological balance and environmental sustainability. How are natural ecosystems affected by human interference ? Illustrate your answer with two examples and propose effective measures to protect or restore ecological balance. *10*