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) In the process of producing a fruit product, crushed fruit containing 14% soluble solids is mixed in a mixer with sugar (1·22 kg sugar/kg crushed fruit) and pectin (0·025 kg pectin/kg crushed fruit). The resultant mixture is then evaporated in a kettle to produce the fruit product containing 67 wt% soluble solids. For a feed of 1000 kg crushed fruit, calculate : *8*

(i) kg mixture from the mixer

(ii) kg of water evaporated

(iii) kg of fruit product produced

(b) One kilogram of air is heated reversibly at constant pressure from an initial state of 298 K and 1 bar until its volume doubles. Calculate W, Q, ΔU, and ΔH for the process. Assume ideal behaviour. *8*

Data for air : $R = 83{\cdot}14$ bar cm^3 mol^{-1} K^{-1}

$C_p = 29$ J mol^{-1} K^{-1}, Molar mass = 28·851

(c) A first order irreversible reaction

$$A \longrightarrow B; \; r_A = kC_A$$

is to be carried out in a plug flow reactor. If $k = 0{\cdot}01$ s^{-1} and volumetric flow rate is 10^{-3} m^3/s, for a 30% conversion determine the reactor volume and residence time. *8*

(d) With the help of a P – T diagram, explain the behaviour of pure substances. *8*

(e) Natural gas containing 79% CH_4, 14% C_2H_6, 0·5% CO_2 and 6·5% N_2 is burnt with 30% excess air. 70% of the hydrocarbons in the natural gas are burnt to CO_2 and rest to CO. Determine : (i) Total moles of O_2 supplied and moles of O_2 remaining unused, and (ii) Total moles of CO and CO_2 leaving the furnace. *8*

Q2. (a) Ammonia is to be burnt to form nitric oxide in the following reaction :

$$4NH_3 + 5O_2 \longrightarrow 4NO + 6H_2O$$

(i) If NH_3 is fed to a continuous reactor at a rate of 100 kmol NH_3/hr, what oxygen feed rate (kmol/hr) would correspond to 40% excess O_2 ? *5*

(ii) If 50 kg of NH_3 and 100 kg of O_2 are fed to a batch reactor, determine the limiting reactant, the percentage by which the other reactant is in excess, extent of reaction and mass of 'NO' produced (kg) if the reaction proceeds to completion. *10*

(b) (i) Define Helmholtz energy (A) and the Gibbs energy (G). Starting from the first law for a closed system, derive the fundamental property relations : dU, dH, dA, dG for a homogeneous fluid of constant composition. *10*

(ii) Considering the two canonical variables of P and T for G; i.e., G = G(P, T), derive *5*

$$\frac{V}{RT} = \left[\frac{\partial(G/RT)}{\partial P}\right]_T \quad \text{and}$$

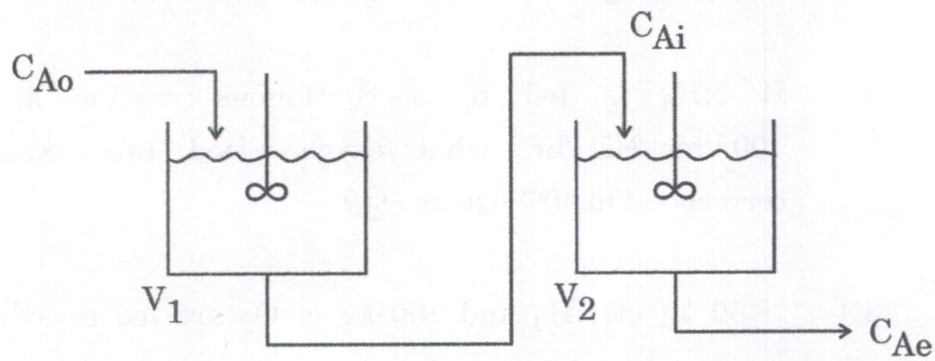
$$\frac{H}{RT} = -T\left[\frac{\partial(G/RT)}{\partial T}\right]_P$$

(c) (i) Calculate the volume of a PFR and a CSTR required for 90% conversion of reactant by a first order reaction.

$$A \longrightarrow B, \ r_A = kC_A, \ \frac{v_T}{k} = 1 \text{ m}^3$$

v_T = volumetric flow rate (m^3/s) *5*

(ii) Calculate the total volume of two CSTR's (both of same volume) in series required for 90% conversion, using data of the above.



Comment on the values of the volume obtained for two CSTR's in series with that of the volume for one CSTR and volume required for a PFR. 5

Q3. (a) 1000 kg/hr of a liquid mixture of 70% acetone (wt%), 30% benzene (wt%) is heated from 10°C to 50°C in a heat exchanger using steam. Steam enters the heat exchanger as saturated vapour at 200°C of 90% quality and exits as saturated liquid at 200°C. Determine the amount of steam required in kg/hr. (Assume negligible heat loss and the exchanger is an adiabatic heat exchanger) 10

Data : $C_p = a + bT + cT^2 + dT^3$, kJ/kg °C

Acetone : $a = 0{\cdot}123$, $b = 18{\cdot}6 \times 10^{-5}$, $c = 0$, $d = 0$

Benzene : $a = 0{\cdot}1265$, $b = 23{\cdot}4 \times 10^{-5}$, $c = 0$, $d = 0$

Latent heat of vaporization = 1939·2 kJ/kg

(b) Using van Laar equations, calculate the y-x equilibrium compositions at atmospheric pressure for a mixture of chloroform and acetone. These components form an azeotrope which contains 66·6 mole% chloroform and boils at 64·5°C. The vapour pressures of chloroform and acetone at 64·5°C are 858 and 1000 mm Hg respectively. 15

(c) A gas phase reaction is to be carried out in an isothermal batch reactor

$$2A \longrightarrow B$$

The reaction is second order : $r_A = kC_A^2$. A conversion of 90% must be achieved.

Calculate the ratio of the residence time of a constant volume reactor to residence time of a constant pressure reactor. Initially both reactors are of the same volume and at the same pressure, and no product B is present. Why is the ratio of residence times greater than, or less than unity ? (Both reactors operate at the same temperature and mixture behaves as a perfect gas) *15*

Q4. (a) A purification system with recycle is used to recover the solvent DMF from a waste gas containing 55% (mole%) DMF in air. The product is to have only 10% (mole%) DMF. Calculate the recycle fraction assuming that the purification unit can remove $\frac{2}{3}$ of DMF in the combined feed to the unit. *15*

(b) Define 'Ton of Refrigeration' and express its power. From this, calculate the minimum power in ton of refrigeration of an air-conditioner for a room of size 4 m × 3 m × 3·5 m to only sustain the energy loss of 150000 kJ/day on an average. *10*

Data : Latent heat of fusion of water, $\lambda_f = 335$ kJ/kg

Take 1 kg = 2·205 lb.

(c) (i) For a gas-solid reaction of

$$A\ (g) + bB\ (s) \longrightarrow \text{Solid product}$$

where the spherical particle of unchanging size is undergoing reaction through shrinking core model, draw the concentration profile and write the steps in succession during the reaction.

(ii) Explain how the gas film, ash layer and chemical reaction controls the profiles independently for the above case.

(iii) What are the limitations of the shrinking core model ? *15*

SECTION B

Q5. (a) Differentiate between soaps and detergents. Discuss in brief, the continuous hydrolysis and saponification process by writing the chemical reactions involved. *8*

(b) Define refinery crude petroleum classification. Discuss in brief, the pyrolysis and cracking process. *8*

(c) Define biotic and abiotic structure of ecosystem. Discuss the impact of greenhouse gases and ozone layer depletion on the environment. *8*

(d) Discuss salient features of the Environment (Protection) Act, 1986. Describe the organization and functions of Central Pollution Control Board. *8*

(e) What are the salient features of Fixed capital and Working capital ? Briefly explain, distinguishing the two. *8*

Q6. (a) How would you classify the paper industry based on the raw materials and the manufactured products ?

Describe with a neat sketch, the preparation of wood pulp by sulphate process. *15*

(b) (i) Define the threshold limit values i.e., Time Weighted Average (TLV – TWA), Short Term Exposure Limit (TLV – STEL), Ceiling Limit (TLV – C).

(ii) A reactor vessel contains 5000 kg of TNT. If due to its explosion, the overpressure is 3·0 psi at 100 m distance, what kind of damage will be produced by this overpressure ?

If probit equation for structural damage is $Y = -23{\cdot}8 + 2{\cdot}92 \ln P$, estimate the % structural damage due to this explosion. *10*

TABLE 2-4 THE TRANSFORMATION FROM PERCENTAGES TO PROBITS.*

%	0	1	2	3	4	5	6	7	8	9
0	–	2·67	2·95	3·12	3·25	3·36	3·45	3·52	3·59	3·66
10	3·72	3·77	3·82	3·87	3·92	3·96	4·01	4·05	4·08	4·12
20	4·16	4·19	4·23	4·26	4·29	4·33	4·36	4·39	4·42	4·45
30	4·48	4·50	4·53	4·56	4·59	4·61	4·64	4·67	4·69	4·72
40	4·75	4·77	4·80	4·82	4·85	4·87	4·90	4·92	4·95	4·97
50	5·00	5·03	5·05	5·08	5·10	5·13	5·15	5·18	5·20	5·23
60	5·25	5·28	5·31	5·33	5·36	5·39	5·41	5·44	5·47	5·50
70	5·52	5·55	5·58	5·61	5·64	5·67	5·71	5·74	5·77	5·81
80	5·84	5·88	5·92	5·95	5·99	6·04	6·08	6·13	6·18	6·23
90	6·28	6·34	6·41	6·48	6·55	6·64	6·75	6·88	7·05	7·33
%	0·0	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9
99	7·33	7·37	7·41	7·46	7·51	7·58	7·65	7·75	7·88	8·09

*D.J. Finney, *Probit Analysis,* 1971, p. 25. Reprinted by permission of Cambridge University Press.

TABLE 2-5 PROBIT CORRELATIONS FOR A VARIETY OF EXPOSURES.

THE CAUSATIVE VARIABLE IS REPRESENTATIVE OF THE MAGNITUDE OF THE EXPOSURE.*

Type of injury or damage	Causative variable	Probit parameters	
		k_1	k_2
Fire :			
Burn deaths from flash fire	$t_e I_e^{4/3}/10^4$	– 14·9	2·56
Burn deaths from pool burning	$tI^{4/3}/10^4$	– 14·9	2·56
Explosion :			
Deaths from lung haemorrhage	p°	– 77·1	6·91
Eardrum ruptures	p°	– 15·6	1·93
Deaths from impact	J	– 46·1	4·82
Injuries from impact	J	– 39·1	4·45
Injuries from flying fragments	J	– 27·1	4·26
Structural damage	p°	– 23·8	2·92
Glass breakage	p°	– 18·1	2·79
Toxic release :			
Chlorine deaths	$\Sigma C^{2.75}\, T$	– 17·1	1·69
Chlorine injuries	C	– 2·40	2·90
Ammonia deaths	$\Sigma C^{2.75}\, T$	– 30·57	1·385

t_e = effective time duration (s)
I_e = effective radiation intensity (W/m^2)
t = time duration of pool burning (sec)
I = radiation intensity from pool burning (W/m^2)
p° = peak overpressure (N/m^2)
J = impulse ($N\ s/m^2$)
C = concentration (ppm)
T = time interval (min)

*Selected from Frank P. Lees, *Loss Prevention in the Process Industries*, Butterworths, London, 1986, p. 208.

(c) (i) When a chemical plant is to be erected in the Southern region, the construction labour cost is estimated at 75 lakh rupees. What would be the construction labour cost if a similar plant is to be erected at the same time in the East ?

Following are the relative factors : 5

Area	Relative labour rate	Relative productivity factor
South	0·95	1·05
East	1·10	0·90

(ii) Explain the method of 'Discounted Cash Flow Rate of Return' (DCFR) in the process of investment. How is it different from other profitability evaluation criteria ? 10

Q7. (a) What are different constituents of cement ? Write the chemical reactions involved in the manufacturing process of Portland cement. 10

(b) (i) An electrostatic precipitator having each plate of length 6 m × 3 m with an air flow rate of 1000 m^3/min and having average particle diameter of 1·0 μ is subjected to an electric field of 40000 V/m. Calculate the number of plates required to achieve an efficiency of 99%, given the drift velocity is $3{\cdot}5 \times 10^{-4}$ m/s. What would be the impact on efficiency if the distance between the plates is reduced ?

(ii) Discuss the working principle and mechanism of electrostatic precipitator with a neat sketch. 15

(c) Derive the relation between amount of ordinary annuity and the uniform periodic payment.

In a chemical plant, a glass-lined reactor is installed with an initial cost of ₹ 15·0 lakh. The scrap value of it at the end of 10 years is ₹ 3·0 lakh. Depreciation is at the rate of 10 percent and charged at an equal amount each year starting from the end of first year. Calculate the yearly cost due to depreciation to accumulate an amount equal to the decrease in the reactor value. Use the above derived equation. *15*

Q8. (a) Describe various methods of condensation polymerization and addition polymerization. Discuss the classification of polymers based on physical properties. *10*

(b) An activated sludge system having flow rate of 10000 m^3/d of industrial wastewater is to be used for secondary treatment. The influent BOD after primary treatment is 200 mg/L and the effluent BOD is 20 mg/L after treatment in a completely mixed reactor. If MLSS concentration is 3500 mg/L, kinetic constant $Y = 0{\cdot}5$ kg/kg and $k_d = 0{\cdot}05/d$, determine the volume of the reactor required and the mass of solid sludge generated each day. Mean cell residence time θ_c may be taken as 10 days. *15*

(c) Write notes on plant location and layout indicating the factors to be considered and the significance of such factors. *15*