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.

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

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.

SECTION A

Q1. Answer all of the following questions : *8×5=40*

(a) A gas mixture has the following composition by volume : C_2H_4 = 50%, C_2H_6 = 35% and CH_4 = 15%. Calculate : *8*

(i) Average molecular weight.

(ii) The composition of the gas in weight %.

(iii) The density of the gas mixture in kg/m^3 at 25°C and 1 atm.

(b) If 5 kg of methanol and 2 kg of NH_3 are reacted to form 2·5 kg of CH_3NH_2 by the reaction :

$$CH_3OH + NH_3 \longrightarrow CH_3NH_2 + H_2O$$

determine : *8*

(i) the limiting reactant

(ii) excess reactant and its percentage

(iii) degree of completion.

(c) Prove that Joule – Thompson coefficient of an ideal gas is zero. *8*

(d) The heterogeneous gas phase reaction A + B → R + S, catalyzed by a solid takes place according to the following mechanism :

$A(g) + \sigma \rightleftharpoons A\sigma$ (Chemisorption of A)

$A\sigma + B(g) \rightleftharpoons R\sigma + S(g)$ (Surface reaction)

$R\sigma \rightleftharpoons R(g) + \sigma$ (Desorption of R)

Derive an expression for the rate of disappearance of A, assuming surface reaction step as rate limiting. *8*

(σ, (Sigma) active site).

(e) Calculate the bubble-point pressure and dew-point pressure of an equimolar mixture of benzene and toluene at 100°C. The vapour pressures of benzene and toluene at 100°C are 1344 mm Hg and 554·8 mm Hg respectively. Assume the Raoult's law to be valid. *8*

Q2. (a) A saturated solution of sodium chloride is prepared at 373 K using 100 kg of sodium chloride.

(i) How much water is required ?

(ii) If the saturated solution at 373 K is cooled to 273 K, how much salt is precipitated ? *10*

Data : Solubility of sodium chloride is 39·8 kg/100 kg of water at 373 K and 35·7 kg/100 kg water at 273 K.

(b) An elementary liquid phase reaction A + B $\rightarrow$ R is carried out in a PFR. Starting with A and B with a concentration of 0·9 mol/lit (both A and B), a conversion of 60% is obtained. A CSTR, twice the volume of the PFR is to be arranged in series with the existing PFR. If the exit conversion remains at 60%, calculate by how much the feed rate can be increased compared to the single PFR for the following arrangements : *20*

(i) PFR followed by CSTR

(ii) CSTR followed by PFR

(c) The activity coefficients in a binary system are represented by :

$$ln\ \gamma_1 = Ax_2^2 \quad \text{and} \quad ln\ \gamma_2 = Ax_1^2$$

Show that the azeotropic composition of the system is

$$x_1 = \frac{1}{2}\left(1 + \frac{1}{A}\, ln\, \frac{P_1^{sat}}{P_2^{sat}}\right)$$ *10*

Q3. (a) 1000 k mol/h of fresh feed consisting of 2% propane and 98% propylene by volume is mixed with the recycle stream and enters the reactor. Propylene is converted to hexene by the reaction : $2\ C_3H_6 \rightarrow C_6H_{12}$ and a conversion of 80% is obtained. The product is completely separated in a separator from the unconverted gases. A small fraction of the unconverted gases are purged such that the propane concentration does not exceed 5 mol% in the combined feed entering the reactor.

Calculate *15*

(i) the amount recycled and its composition.

(ii) the composition of the stream leaving the reactor.

(iii) the amounts of purge and product.

(b) The irreversible gas phase reaction $A \rightarrow 2B$ is to be carried out in an isothermal batch reactor at 400 K. The reactor is filled with a mixture of 50 mol% A and 50 mol% inerts. The rate of the reaction

$$-r_A \text{ (mol/m}^3\text{/h)} = 0{\cdot}75 \text{ (m}^3\text{/mol/h)} \; C_A^2 \; .$$

The initial total pressure is 90 kPa. Calculate the time required to obtain 60% conversion in a

(i) Constant volume batch reactor.

(ii) Constant pressure batch reactor. *15*

(c) Prove the thermodynamic property relation

$$\left(\frac{\partial H}{\partial V}\right)_T = \frac{(T\beta - 1)}{\alpha}$$

where β = volume expansivity

α = isothermal compressibility. *10*

Q4. (a) A producer gas analyzing 2% CO_2, 30% CO, 2% O_2, 8% H_2 and 58% N_2 is burned with 20% excess air. Calculate the composition of the flue gases on a dry basis. *10*

(b) For catalyst regeneration, derive a relation for the time (t) necessary for the solid carbon interface to recede inward to a radius R using the shrinking core model. What would be the time necessary to consume all of the carbon in the catalyst pellet of radius R_0 ? *15*

(c) An equimolar mixture of CO and H_2O enters a reactor which is maintained at 10 bar and 1000 K. The reaction is $CO\,(g) + H_2O\,(g) \rightleftharpoons CO_2\,(g) + H_2\,(g)$. If the equilibrium constant for the above reaction is 1·5, calculate the degree of conversion and the composition of the gas mixture that leaves the reactor. The reaction mixture is assumed to behave like an ideal gas. *15*

SECTION B

Q5. Answer all of the following questions : *5×8=40*

(a) Define the turbidity of water and also write the sources of it and its impact on the environment. *5*

(b) Write the important aspects in the implementation of sanitary landfills of solid wastes. Explain the principal methods used for the landfilling. *5*

(c) Why is safety audit necessary in the Process industries ? Discuss some functions of safety audits. *5*

(d) Differentiate between TNT equivalency and TNO multi-energy method. *5*

(e) Describe the various factors affecting the investment and production cost in Process industries. *5*

(f) Define the Payout/Payback period and also explain the calculation of payout period with or without considering interest charge. *5*

(g) Classify Portland cement on the basis of varying percentage of constituents and strength characteristics. *5*

(h) Differentiate between sulphite pulping and sulphate pulping. *5*

Q6. (a) Explain the indirect coal liquefaction technology and draw the schematic block diagram of the process. *15*

(b) A secondary clarifier is to be designed to produce an underflow concentration of 30,000 mg/L from influent with mixed liquor solid content of 4500 mg/L. The wastewater flow rate is 0·06 m^3/s, and overflow rate is 0·04 m^3/s.

Calculate the required clarifier area, and thickening area.

The following data obtained from a settling test in 100 mL cylinder are given : *15*

Time, minutes	Interface height, cm
0	100
2	87·5
4	75
6	63
8	53
10	46
14	36
18	29
22	25
26	23
30	20

(c) If an amount 'P' is invested at an interest rate '(i)' and after 'n' years of compound interest, if an amount 'A' is invested further in each year, then show that annual capital charge ratio is *10*

$$\frac{[i(1+i)^n]}{[(1+i)^n - 1]}$$

Q7. (a) Explain the manufacturing of soaps with a neat block diagram from coconut oil and refined tallow (animal fats). *15*

(b) A plant is producing 10,000 metric tons per year (10 KMTA) of ethyl alcohol. The overall yield is 70% on a mass basis (kg of product per kg of raw material). The raw material costs $ 500/metric ton and the product sells for $ 900/metric ton. The process has been now modified that will increase the yield to 75% for which additional cost required is $ 1,250,000 and operating costs are negligible. Is the modification worth making ? *15*

(c) Calculate the 5-day BOD (Biochemical Oxygen Demand) of domestic wastewater based on the following data :

300 mL of test bottle is filled with 2% of wastewater with dilution water. The initial and 5-day DO (dissolved oxygen) levels are found to be 8·1 and 4·2, respectively.

What is the ultimate BOD assuming k value (rate constant) of 0·1/day ? *10*

Q8. (a) Explain the photochemical smog with all reactions involved and also present the dynamic behaviour of photochemical smog for the complete day. *15*

(b) Give the various routes of manufacturing of Alcohols, and discuss the production of bioethanol using molasses as feedstock, with a block diagram. *15*

(c) Original value of an equipment is ₹ 10,00,000 completely installed and ready for use. Its salvage value is estimated to be 10% of original cost at the end of a service life estimated to be 10 years.

Determine the asset (or book) value of the equipment at the end of 5 years using

(i) Straight-line method

(ii) Declining-balance method. *10*