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.

Question Nos. **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

1. *(a)* Explain the following terms with suitable illustrations for an operation involving reaction with recycle : 5

(i) Overall conversion

(ii) Single-pass conversion

(b) Define the following terms for combustion reaction : 5

(i) Theoretical oxygen demand

(ii) Percentage of excess air

(c) Define degrees of freedom of each of the following equilibrium systems using Gibbs' phase rule : 5

(i) A vapour-liquid mixture of four hydrocarbons

(ii) NaCl crystals suspended in an aqueous NaCl solution

(d) State Raoult's law and indicate its applications in vapour-liquid equilibrium calculations. 5

(e) Define half-life time $[t_{1/2}]$ of a reaction and derive the half-life time expression for first-order reaction. 5

(f) What are the factors that influence the selection of a catalyst for a catalytic reaction? 5

(g) What is an equation of state? What is the ideal gas equation? At what conditions does the ideal gas equation provide the most accurate estimates? 5

(h) What are the factors that influence the choice of good refrigerant for a refrigeration unit? 5

2. *(a)* Methane burns in a reactor according to the following stoichiometry :

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O$$
$$CH_4 + 1{\cdot}5O_2 \rightarrow CO + 2H_2O$$

One hundred mol/h of methane is fed to a reactor.

(i) What is the theoretical O_2 flow rate if the complete combustion occurs in the reactor?

(ii) What is the theoretical O_2 flow rate assuming that only 70% methane reacts?

(iii) What is the theoretical flow rate of air?

(iv) If the actual flow rate of air is such that 300 mol O_2/h enters the reactor, what is the percent excess air? 20

(b) Explain Hess' law of heat summation with its significance. Suppose heats of reaction at 25 °C are measured experimentally for the following set of reactions :

$$2A + B \rightarrow 2C \quad : \Delta\hat{H}^{\circ}_{r_1} = -1000 \text{ kJ/mol}$$

$$A + D \rightarrow C + 3E \quad : \Delta\hat{H}^{\circ}_{r_2} = -2000 \text{ kJ/mol}$$

Using Hess' law, calculate the heats of reaction for the following reaction at 25 °C : 20

$$B + 6E \rightarrow 2D$$

3. (a) An ice plant working on a reversed Carnot cycle heat pump produces 20 tonnes of ice per day. The ice is maintained at 0 °C. The heat is rejected to the atmosphere at 27 °C. The heat pump which is used to run the ice plant is coupled to a Carnot engine which absorbs heat from a source which is maintained at 227 °C by burning fuel of 45000 kJ/kg calorific value and rejects the heat to the atmosphere. Determine the consumption of fuel per hour and the power developed by the engine. Take enthalpy of fusion of ice = 334·5 kJ/kg. 20

(b) An equimolar liquid mixture of Benzene (B) and Toluene (T) is in equilibrium with its vapour. What is the system pressure and the composition of vapour?

Hint : The Antoine equation may be used to estimate the vapour pressure of Benzene (B) and Toluene (T) :

$$\log_{10} P^{*}_{B} = 6{\cdot}906 - \frac{1211}{T + 220{\cdot}8}$$

$$\log_{10} P^{*}_{T} = 6{\cdot}9533 - \frac{1343{\cdot}9}{T + 219{\cdot}38}$$

where P^{*}_{B} and P^{*}_{T} are vapour pressures of Benzene and Toluene in mm Hg and T is the temperature in °C. 20

4. (a) In a batch reactor, decomposition reaction in liquid phase takes place with a first-order kinetics. 50% of the reactant is converted to product in 5 minutes experimental run.

(i) What is the value of rate constant?

(ii) How much longer would it take to reach 75% conversion? 20

(b) Consider a series reaction with the following stoichiometry which takes place in an ideal plug flow reactor :

$$A \xrightarrow{k_1 = 0{\cdot}1 \text{ min}^{-1}} R \xrightarrow{k_2 = 0{\cdot}1 \text{ min}^{-1}} S$$

The feed is introduced into the reactor at 1000 litres/h and the feed contains only the reactant with the concentration of 1 g mole/litre.

(i) What is the maximum concentration of R in the product stream?

(ii) What is the volume of the reactor? 20

SECTION—B

5. *(a)* Discuss in detail about setting and hardening of cement. 5

(b) Describe the various methods for extraction of vegetable oils. 5

(c) Differentiate between hazards, risk and safety. Give the classification of hazards. 5

(d) What are the by-products of sugar industry? Mention their utilizations. 5

(e) What are the preventive and protective measures to prevent fire in chemical industry? 5

(f) Discuss in detail about various legislations for safety control presently applicable in chemical process plants. 5

(g) Explain the different methods for determining the depreciation of process equipments and compare them. 5

(h) Explain the various factors to be considered while deciding the plant location. 5

6. *(a)* What are the characteristics of alkaline pulp? Explain in detail about the kraft pulping process with a neat sketch. 20

(b) Differentiate between soaps and detergents. Explain the continuous process for the production of fatty acids and soap in detail. 20

7. *(a)* Compare aerobic and anaerobic methods for composting of municipal solid wastes. Discuss in detail about various treatments adopted for the treatment of industrial wastewater with neat sketch. 20

(b) Discuss the safety aspects in the design of chemical plants and suggest a suitable control scheme for safe operation of chemical reactor. 20

8. *(a)* The following equation shows the effect of variables x and y on the total cost for a particular operation :

$$C_T = 2 \cdot 33x + \frac{11900}{xy} + 1 \cdot 86y + 10$$

Determine the values of x and y which will give the least total cost. 15

(b) A chemical plant requires ₹50,00,000 of fixed capital investment. If annual profits and annual depreciation costs are ₹15,00,000 and ₹7,50,000 respectively, find the payback period on total investment. 10

(c) Explain the break-even chart for the production schedule with neat sketch and explain its significance for optimum analysis. 15

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