Indian Forest Service (Main)
Examination, 2024

JBNV–B–CHME

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 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 (QCA) 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 concept of multiple steady states in reactor operation. Under what conditions can multiple steady states occur, and what are the implications for reactor stability? 8

(b) In a typical chemical process, the reactor effluent is divided into recycle, purge and product streams, with a portion of the feed bypassing the reactor.

(i) What are the advantages and disadvantages of the recycle stream?

(ii) Explain the necessity of a purge stream and the potential consequences of improper purge rates.

(iii) How does a bypass stream affect the process, and when is it useful?

(iv) Discuss the influence of inerts in the feed on the decisions regarding the use of purge and recycle streams. 8

(c) If T_1 and T_2 are respective temperatures of the source and sink, then which of the following cases is more effective way to increase the efficiency of a Carnot engine? Give justification : 8

Case—I : Increasing T_1, keeping T_2 constant

Case—II : Decreasing T_2, keeping T_1 constant

(d) Discuss the role of diffusion in heterogeneous catalytic reactions. How does pore diffusion resistance affect the overall reaction rate, and what methods are used to minimize this resistance? 8

(e) The analysis of a bituminous coal sample reveals the following composition :

1% sulphur, 5% oxygen, 1% nitrogen, 12% ash and 4% water

The mole ratio of carbon to hydrogen in the residuum is found to be 8 : 1. Calculate the weight fraction composition of coal, when ash and moisture are excluded. 8

2. *(a)* What factors influence the theoretical flame temperature of a fuel? A gaseous fuel containing 35% carbon monoxide, 40% hydrogen, 10% carbon dioxide and rest 15% nitrogen is burnt with 110% excess air. Calculate the theoretical flame temperature of the fuel, if both air and the fuel are at 25 °C, initially. ΔH_c° for carbon monoxide and hydrogen are –67·636 kcal-mol^{-1} and –68·317 kcal-mol^{-1} respectively. The mean molar heat capacities of carbon dioxide, water vapour, oxygen and nitrogen, between 25 °C and theoretical flame temperature, are 12·5, 10·0, 8·2 and 7·6 cal-mol^{-1}-K^{-1} respectively. 15

(b) Air at initial velocity of 50 m/s and temperature of 25 °C passes through a heat exchanger, where its temperature is increased to 800 °C. It then enters a turbine with same velocity and expands till the temperature of air falls to 600 °C. The air leaving the turbine enters into a nozzle with a velocity of 60 m/s and leaves the nozzle at 500 °C temperature. Take the enthalpy of air as $h = C_p t$, where C_p is the specific heat equal to 1·005 kJ/kg-K and t is temperature.

For the air flow rate of 2 kg/s, calculate—

(i) the rate of heat transfer to the air in the heat exchanger;

(ii) the power output from the turbine, assuming no heat loss;

(iii) the velocity at exit from the nozzle, assuming no heat loss. 15

(c) What are the key characteristics and typical applications of ideal flow reactors? How do the ideal assumptions of continuous stirred tank reactor (CSTR) and plug flow reactor (PFR) affect their performance, and what challenges arise when applying these ideal models to real industrial applications? 10

3. *(a)* Waste cooking oils can be converted into biodiesel using different methods. One method is gas phase pyrolysis.

$$\text{Waste cooking oils} \longrightarrow \text{Biodiesel} + 3CO_2$$

$$A \xrightarrow{k} B + 3C$$

This reaction is characterized as a first-order irreversible reaction with a rate constant $k = 5 \times 10^{-3}$ min^{-1}, measured at 150 °C, and an activation energy of $E_a = 85$ kJ-mol^{-1}.

Pure cooking oil is introduced into a hot reactor, maintained at 227 °C, at a rate of 2·5 moles per minute. At this temperature, all the components are in the vapour phase. The reactor maintains a steady-state pressure of 10 atm.

(i) If the reactor is a CSTR, what reactor volume is required to achieve 87% conversion?

(ii) If the reactor is a PFR, what reactor volume is required to achieve 93% conversion? 15

(b) Ethyl acetate along with water is produced, when acetic acid is esterified in the liquid phase with ethanol at 100 °C and at atmospheric pressure according to the following reaction :

$$\text{Acetic acid } (l) + \text{Ethanol } (l) \rightarrow \text{Ethyl acetate } (l) + \text{Water } (l)$$

Estimate the mole fraction of ethyl acetate in the reaction mixture at equilibrium, if one mole each of acetic acid and ethanol is present initially.

Data given :

TABLE-A : Standard enthalpies and Gibbs' energy of formation at 298·15 K in joules per mole of the substance formed

Sl. No.	*Chemical species*	*Molecular formula*	$\Delta H^{\circ}_{f\,(298)}$	$\Delta G^{\circ}_{f\,(298)}$
1.	Ethyl acetate (l)	$CH_3COOC_2H_5\,(l)$	–480000	–332200
2.	Acetic acid (l)	$CH_3COOH\,(l)$	–484500	–389900
3.	Ethanol (l)	$C_2H_5OH\,(l)$	–277690	–174780
4.	Water (l)	$H_2O\,(l)$	–285830	–237130

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(c) A distillation column separates a binary mixture of benzene and toluene. The feed stream enters the column at a rate of 500 kg-h^{-1}, containing 40% benzene and 60% toluene by mass. The column produces a distillate stream containing 95% benzene and 5% toluene by mass, and a bottom stream containing 10% benzene and 90% toluene by mass.

(i) Calculate the mass flow rates of the distillate and bottom streams.

(ii) If the feed stream is at 300 K and the distillate and bottom streams exit at 350 K and 320 K respectively, calculate the heat duty of the column assuming no heat losses and constant specific heat capacities.

Given the specific heat capacities :

$$C_p, \text{ benzene } = 1\cdot 74 \text{ kJ/kg-K}$$

$$C_p, \text{ toluene } = 1\cdot 70 \text{ kJ/kg-K}$$ 10

4. (a) A plant processes material at the rate of 5000 kg-h^{-1}, containing 70% water and 30% solids. The material is first granulated and then dried to a final moisture content of 12·5%. Fresh feed is mixed with part of the final product leaving the drier, therefore, the effective water content in the feed to the granulator is 40%. Air entering the drier contains 3% moisture, while air leaving the drier contains 6% moisture. Calculate the recycle rate to the granulator and the rate of hot air flow to the drier. 15

(b) A batch reactor is used to carry out a chemical reaction where reactant A is converted to product B. The reaction rate law is given by $-r_A = k C_A (1 + C_A)$, where k is rate constant and C_A is concentration of reactant A.

(i) Derive the expression for the concentration of A as a function of time.

(ii) If the initial concentration of A in the reactor is 3 mol-L^{-1}, and the value of rate constant k is 0·3 min^{-1}, then calculate the concentration of reactant A remaining in the reactor after 15 minutes. 15

(c) Explain Joule-Thomson expansion for cooling and liquefying gases. Also show the variation of Joule-Thomson coefficient with the state of the gas with the help of inversion curve. 10

SECTION—B

5. (a) Give a comparative analysis of oil-based paints and water-based paints with respect to manufacturing steps and applications. 8

(b) Explain, with flow diagram, petroleum fermentation process to produce food proteins. 8

(c) Explain unit processes in municipal wastewater treatment with flowchart. 8

(d) What is micrometeorology? Explain its role in monitoring and controlling air pollution. 8

(e) Explain the steps involved in scheduling a project. How are PERT and CPM useful to achieve timeline target of a project? 8

6. (a) Describe, with a neat sketch, extraction of sugarcane to produce crystalline white sugar. 15

(b) If the terminal velocity of the smallest particle retained by a cyclone separator is $3 \cdot 83 \times 10^{-4}$ m/s, find the particle size at which theoretical cut will occur using Stokes' law. The cyclone separator, 0·3 m in diameter and 1·2 m long, has a circular inlet 75 mm in diameter and an outlet of the same size. The gas enters at a velocity of 1·5 m/s. The viscosity of air is 0·018 mN-s/m^2, the density of air is 1·3 kg/m^3 and the density of the particles is 2700 kg/m^3. 15

(c) Explain break-even point on a graph where rate of production is plotted against total product cost with constant fixed cost and increasing trend of total income. 10

7. (a) Explain the manufacturing process for ethyl alcohol from molasses by fermentation with flow diagram. 15

(b) Explain the main causes of disaster and their effects. What are the stages of disaster management and how is it made efficient using technology? 15

(c) What factors should be considered in selecting a location and site for thermal power plant? 10

8. (a) Explain polymerization of ethylene to polyethylene with chemical equations. Give the applications of high-density polyethylene and linear low-density polyethylene. 10

(b) What is the definition of hazardous waste? Give the classification of hazardous waste and their impacts in the environment. 15

(c) Find the break-even point in kilogram of product per year for a plant operating at 80 percent capacity with annual variable production costs of ₹ 5 crore. The sum of the annual fixed charges, overhead costs and general expenses is ₹ 3 crore and may be considered not to change with production rate. The total annual sales are ₹ 10 crore and the product sells for ₹ 100/kg. Also find the gross annual profit (depreciation included) and net annual profit for this plant at 100 percent capacity if the income-tax rate is 40 percent of gross profit. 15

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