# CHEMICAL ENGINEERING

## Paper – II

| *Time Allowed : **Three** Hours* | *Maximum Marks : **200*** |
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### 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 coal having the following composition is burnt in a boiler :

| | |
|---|---|
| C | 80% |
| H | 5% |
| O | 4·5% |
| Ash | 7·0% |
| Moisture | 3·5% |

Calculate the theoretical air required for complete combustion of 100 kg of coal. *8*

(b) A coal containing 15% ash and 85% carbon is burnt in a combustion chamber. The residue is found to contain 80% ash and 20% carbon. Find out the amount of residue formed and $CO_2$ produced for 100 kg of coal. *8*

(c) Does the Kelvin-Planck Statement of Second Law of Thermodynamics prohibit the complete conversion of energy absorbed in the form of heat into work by a device in a process ? Explain with an example. *8*

(d) A reaction A $\longrightarrow$ B is carried out at 77°C which required 25 minutes time for completion. If the same reaction is carried out at 97°C, the time required to complete the reaction is reduced by 80%. Calculate the activation energy of the reaction. R = 8·314 J/mol . K. *8*

(e) A liquid reactant decomposes by 1st order reaction kinetics in a batch reactor.

$$A \xrightarrow{1^{st}\ order} Product$$

50% of A is converted to product in 10 minutes. How much time would it take to achieve a conversion of 80% ? *8*

**Q2.** (a) We wish to explore various reactor set-ups for the transformation of A into R. The feed contains 99% A and 1% R. The desired product is to consist of 10% A and 90% R. The transformation takes place by means of the elementary reaction

$$A + R \longrightarrow R + R$$

Rate constant K = 1·0 litre/mol.min.

The concentration of active materials is

$C_{A0} + C_{R0} = C_A + C_R = 1{\cdot}0$ mol/litre

throughout.

Calculate reactor holding time to get a product with $C_R = 0{\cdot}90$ mol/litre for

(i) Mixed flow reactor

(ii) Plug flow reactor

by graphical method. *15*

(b) Lime is produced from limestone according to the following reaction :

$$CaCO_3 \xrightarrow{\Delta} CaO + CO_2$$

$$\Delta H = 19278 \text{ kcal/kmol}$$

If the heating value of coal is 7780 kcal/kg, how many kilograms of coal must be used to supply the heat of reaction of 1 tonne of limestone assuming it to be 100% calcium carbonate, if 25% of the heat of combustion of coal is lost through the stack and 5% is lost by radiation. *10*

Data : Atomic weights of Ca : 40
C : 12
O : 16

(c) The normal boiling temperature of helium is – 268·8°C with latent heat of vaporization 0·085 kJ/mol. It is required to produce 10 tons of liquid helium from helium vapour at – 268·8°C in winter time, when the ambient temperature is 21°C.

Calculate :

(i) Maximum COP of the unit.

(ii) Minimum amount of work to be done on the refrigeration unit. *15*

**Q3.** (a) 100 litres/hr of radioactive fluid having a half-life of 20 hours is to be treated by passing it through two ideal CSTR in series, V = 40,000 litres each. In passing through this system, how much will the activity decay ? Also calculate the percentage of activity disappeared. *15*

(b) A producer gas with the composition by volume, 27·3% CO, 5·4% $CO_2$, 0·6% $O_2$, 66·7% $N_2$, is burnt with 20% excess air. If the combustion is 98% complete, calculate the composition by volume of the flue gases. *15*

(c) Develop a generalized relationship for change of temperature with respect to pressure at constant entropy conditions from basic principles, $\left(\frac{\partial T}{\partial P}\right)_S$. Prove that for ideal gas $\left(\frac{\partial T}{\partial P}\right)_S = \frac{V}{C_P}$. *10*

**Q4.** (a) A first order reversible liquid phase reaction as follows,

$$A \underset{\longleftarrow}{\longrightarrow} R$$

takes place in a constant volume batch reactor. The initial concentration of A and R, $C_{A0}$ = 0·5 mol/litre and $C_{B0}$ = 0·0 mol/litre respectively. After 8 minutes, conversion of A is 33·3%, while equilibrium conversion is 66·67%. Find the rate for this reaction. *10*

(b) A solid material with 15 wt% water is dried to 7 wt% water under the following conditions. Fresh air is mixed with recycled air and blown over the solid. Fresh air contains 0·01 kg moisture per kg of dry air and recycled air which is part of the air leaving the drier contains 0·1 kg moisture per kg of dry air. Mixed air entering the drier contains 0·03 kg moisture per kg of dry air.

Compute :

(i) the amount of water removed per 100 kg of wet material fed to the drier.

(ii) the amount of dry air in fresh air per 100 kg of wet material.

(iii) the amount of dry air in recycled air per 100 kg of wet material. *15*

(c) Develop an expression to determine the fugacity coefficient for a van der Waals gas. Determine the fugacity and fugacity coefficient for n-octane vapour at 427·85 K and 0·215 MPa. *15*

The van der Waals constants for n-octane are

$a = 3{\cdot}789$ Pa $(m^3/mol)^2$, and

$b = 2{\cdot}37 \times 10^{-4}$ $m^3/mol$.

$v = 15{\cdot}675 \times 10^{-3}$ $m^3/mol$, molar volume of saturated vapour.

## SECTION B

**Q5.** (a) Give comparative analysis of mechanical and solvent methods of extracting vegetable oils along with flow diagrams. *8*

(b) Describe unit operations used in upstream and downstream processing for manufacture of penicillin by fermentation and draw the flowchart. *8*

(c) What are the properties of solid waste for which solid waste is hazardous waste ? Explain the disposal technique of a solid petroleum sludge with the help of a neat diagram. *8*

(d) Explain the fire triangle with diagram to prevent fire and explosion. *8*

(e) What are present worth method and annual equivalent method of comparing alternatives ? Explain giving examples. *8*

**Q6.** (a) Explain Sulphate (Kraft) process for preparation of paper with neat flowchart and compare it with Soda process. *15*

(b) What is the significance of cut size particle diameter in cyclone design ? Explain with the help of diagram how high efficiency and high throughput cyclones are designed. *10*

(c) The fixed cost associated with the production of a cosmetic item is ₹ 10,00,000. The variable cost per unit is ₹ 50 and the selling price per unit is ₹ 100.

Find :

(i) Break even sales quantity.

(ii) Break even sales.

(iii) If the actual production quantity is 60,000, find contribution. (Amount of earnings remaining after all direct costs have been subtracted from revenue) *15*

**Q7.** (a) Describe with flowchart, hydrogenation process of powdered coal to produce aromatic liquids. Explain the reaction and reaction conditions. *15*

(b) A process plant emits its off gases with dust particles 3000 mg/m$^3$. A horizontal parallel plate ESP consisting of 5 m height, 6 m depth plates with 30 cm plate to plate spacing is used to control the dust. The dust laden gas at 50,000 m$^3$/hr at 150°C flows through the ESP and collection efficiency is 99%.

Calculate :

(i) Bulk velocity of gas at ESP.

(ii) Outlet concentration of dust from ESP.

(iii) Particle migration velocity.

(iv) Efficiency of ESP if the flow rate of gas is doubled. *15*

(c) A company has extra capacity that can be used to produce a sophisticated fixture which it has been buying for ₹ 900 each. If the company makes the fixtures, it will incur material cost of ₹ 300 per unit, labour cost of ₹ 250 per unit and variable overhead cost of ₹ 100 per unit. The annual fixed cost associated with the unused capacity is ₹ 10,00,000. Demand over the next year is estimated at 5,000 units. Would it be profitable for the company to make the fixtures ? *10*

Assume : The unused capacity has alternative use.

**Q8.** (a) Explain catalytic cracking process of hydrocarbons with a neat flowchart. What are the process variables and how do they influence the cracking process ? *10*

(b) A gravity settling chamber of dimension 4 m length, 1·5 m width and 2 m height is used to remove dust particles from an ore crushing plant. The dust laden gas flows through the settling chamber at 0·5 m/s at 75°C. Calculate the minimum size of the particle that can be removed with 100% efficiency of settling chamber. Density of dust = 2000 kg/m$^3$, Viscosity of gas = $2{\cdot}2 \times 10^{-5}$ kg/m.s.

Find out the efficiency of collection for average particle diameter of 60 μm. Density of the gas may be neglected. *15*

(c) The original value of a piece of equipment is ₹ 10,00,000 completely installed and ready for use. Its salvage value after an estimated service life of 10 years is estimated to be ₹ 80,000. Determine the asset value of the equipment (or book value) at the end of 5 years using :

(i) Straight-line method.

(ii) Textbook declining balance method. *15*