

CHEMICAL ENGINEERING

PAPER—I

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.

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.

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.

Answers must be written in ENGLISH only.

SECTION—A

1. (a) The cone and plate viscometer is used frequently to characterize the fluids. It consists of a flat plate and a rotating cone with a very obtuse angle (the angle between the cone surface and the plate is 0.5 degree). The apex of the cone just touches the plate surface and the liquid to be tested fills the narrow gap formed by the cone and the plate. For a particular fluid, the following data are obtained :

Speed of the cone (r.p.m.)	10	20	30	40	50	60
Apparent viscosity, η (Pa-s)	0.121	0.139	0.153	0.159	0.172	0.178

What kind of non-Newtonian fluid is this?

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- (b) A wall 2 cm thick is to be constructed from a material that has an average thermal conductivity of 1.3 W/m-°C. The wall is to be insulated with a material having an average thermal conductivity of 0.038 W/m-°C, so that the heat loss per square metre will not exceed 1830 W. Consider that the inner surface temperature is 1300 °C and the outer surface of insulation is exposed to environment at 30 °C (assume heat transfer coefficient of 10 W/m²-°C). Calculate the thickness of insulation required.

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- (c) What are the basic conditions necessary for application of Fenske equation to estimate the number of ideal trays required for separation in a distillation column?

A binary mixture of benzene and toluene having 40% benzene is to be separated at a rate of 20 tons/hour into a top product containing 95% benzene and a bottom product with 4% of it. Determine the number of ideal trays using Fenske equation, given that the relative volatility of benzene in the mixture is 2.5.

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- (d) Explain briefly the difference among a fan, a blower and a compressor.

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- (e) Briefly describe the working principle of a cooling tower.

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2. (a) Air containing 1.5% sulfur dioxide is to be scrubbed with water as solvent to remove 99% of sulfur dioxide from the air in an absorption tower. The tower is having a diameter of 1.122 m. The sulfur dioxide-water solution follows Henry's law and constant $H = 1.75$. The inlet gas flow is 1.0 kg/s.

(i) Estimate the minimum liquid solvent (water) rate using graphical technique.

(ii) If the solvent (water) rate is 1.6 times the total gas flow rate, draw the operating line on the graphical plot.

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- (b) A certain crusher takes rock whose average particle diameter is 0.035 m and crushes it to a product whose average particle diameter is 0.027 m at the rate of 30000 kg/hr. At this rate, the mill takes 700 (kgf-m/s) of power and to run it empty power required is 40 (kgf-m/s). What would be the power consumption for the same capacity if the average particle diameter of the product is 0.009 m? 15

- (c) Give brief answers of the following :

- (i) Define blackbody.
- (ii) What is critical thickness of insulation?
- (iii) What is the effect of baffle spacing on the shell-side heat transfer coefficient?
- (iv) What is elevation of boiling point?
- (v) What is view factor in radiation? 10

3. (a) An incompressible Newtonian fluid, filled in an annular gap between two concentric vertical cylinders of radii R_1 and R_2 , is flowing under steady-state conditions. The outer cylinder is rotating with an angular velocity of ω , while the inner cylinder is stationary. For $(R_2 - R_1) \ll R_1$, determine the expression of θ component of the velocity (v_θ). The equation of motion for Newtonian fluid with constant density and viscosity for cylindrical coordinates is given by the θ -component equation

$$\rho \left(\frac{\partial v_\theta}{\partial t} + v_r \frac{\partial v_\theta}{\partial r} + \frac{v_\theta}{r} \frac{\partial v_\theta}{\partial \theta} + v_z \frac{\partial v_\theta}{\partial z} + \frac{v_r v_\theta}{r} \right) = -\frac{1}{r} \frac{\partial p}{\partial \theta} + \mu \left[\frac{\partial}{\partial r} \left(\frac{1}{r} \frac{\partial}{\partial r} (r v_\theta) \right) + \frac{1}{r^2} \frac{\partial^2 v_\theta}{\partial \theta^2} + \frac{\partial^2 v_\theta}{\partial z^2} + \frac{2}{r^2} \frac{\partial v_r}{\partial \theta} \right] + \rho g_\theta$$

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- (b) A counter-current double-pipe heat exchanger is used to heat 70 kg/s of water from 35 °C to 90 °C with an oil flow of 95 kg/s. The oil has a specific heat of 2.1 kJ/kg-°C and enters the heat exchanger at a temperature of 175 °C. The overall heat transfer coefficient is 425 W/m²-°C. Calculate the area of heat exchanger. If the flow rate of the water is reduced in half with the entrance temperatures of both fluids remaining the same, what are the exit temperatures of both fluids under these new conditions and how much will be the reduction in heat transfer rate? The relation of heat exchanger effectiveness (ϵ) with NTU (N) is given below :

$$\epsilon = \frac{1 - \exp[-N(1 - C)]}{1 - C \exp[-N(1 - C)]}, \text{ where } C = \frac{C_{\min}}{C_{\max}}$$

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(c) Write very briefly on the following :

- (i) Relative volatility
- (ii) Adiabatic saturation temperature
- (iii) Selectivity of solvent
- (iv) Bound moisture
- (v) Partial condenser and total condenser

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4. (a) A solution of organic colloids is to be concentrated from 15% to 50% solids in a vertical tube evaporator. Assume that the solution has negligible elevation in the boiling point and the specific heat of the feed is $3894 \text{ J/kg}^\circ\text{C}$. The steam is available at 0.8 atm absolute pressure and at 93.7°C temperature, and its heat of vaporization is 2273.9 kJ/kg . The pressure in the tube side is 100 mm Hg absolute (saturation temperature = 51.1°C , heat of vaporization = 2379.5 kJ/kg). The feed enters at 15°C . Consider the value of overall heat transfer coefficient to be $1700 \text{ W/m}^2\text{-}^\circ\text{C}$. Find the surface area (m^2) and steam consumption (kg/hr) for water evaporation of 25000 kg/hr .

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- (b) 1000 kilograms of an aqueous feed containing 40% by mass pyridine is contacted with pure chlorobenzene as solvent in a single batch operation. The mass ratio of the feed to solvent is 1 : 1.5.

Calculate the mass and composition of the extract and also the percentage of pyridine in the raffinate.

The equilibrium and the tie line data of the system water (A)-chlorobenzene (B)-pyridine (C) at 25°C are given below :

Water (A)	Chlorobenzene (B)	Pyridine (C)	Water (A)	Chlorobenzene (B)	Pyridine (C)
x_A	x_B	x_C	x_A	x_B	x_C
99.92	0.08	0	0.05	99.95	0
94.82	0.16	5.02	0.67	88.28	11.05
88.71	0.24	11.05	1.15	79.90	18.95
80.72	0.38	18.90	1.62	74.28	24.10
73.92	0.58	25.50	2.25	69.15	28.60
62.05	1.85	36.10	2.87	65.58	31.55
50.57	4.48	44.95	3.95	61.00	35.05
37.90	8.90	53.20	6.40	53.00	40.60
13.20	37.80	49.00	13.20	37.80	49.00

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(c) Explain briefly the following terms :

- (i) Minimum velocity for fluidization
- (ii) NPSH
- (iii) Vena contracta
- (iv) Terminal velocity
- (v) Mach number

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SECTION—B

5. (a) A thermometer having a time constant of 30 seconds is initially at 30 °C. At time $t=0$, it is immersed in a bath maintained at 100 °C. Determine the temperature readings at $t=1$ minute and 1.5 minutes.

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(b) A proportional controller is used to control temperature within the range of 70 °C to 100 °C. The controller is adjusted so that the output goes from 100 kPa (valve fully opened) to 150 kPa (valve fully closed) as the measured temperature goes from 81 °C to 86 °C with the set point held constant. Find the proportional band and the gain.

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(c) Find out the thickness of the torispherical top head for the following data :

Knuckle radius = 100 mm

Crown radius = 1500 mm

Joint efficiency = 0.85

Design pressure = 5 atm

Allowable stress = 95 N/mm²

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(d) Explain the difference between feedback and feed-forward control system.

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(e) Explain the operating principle of electrodialysis process.

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6. (a) A process is described by the transfer function

$$G(s) = \frac{3e^{-2s}}{(3s+1)(1-s)}$$

Find the expression of response $y(t)$ for a unit step change in $u(t)$. If time delay term is approximated by 1/1 Padé approximation, write the resulting transfer function. Also, find the response $y(t)$ for a unit step change in input $u(t)$ for the approximated transfer function. Compare both the responses and comment on the nature of output.

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- (b) Determine the shell thickness at different heights of a cylindrical storage tank for the given data :

Storage capacity = 1000 m^3

Density of fluid = 900 kg/m^3

Joint efficiency = 0.85

Corrosion allowance = 2 mm

Available plate = $5 \text{ m} \times 1.5 \text{ m}$

Height to dia ratio for tank = 1.5

Nominal thicknesses of standard plates are 5 mm, 6 mm, 8 mm, 10 mm, 12 mm and 14 mm

Consider allowable stress, $f = 90 \text{ N/mm}^2$

Also find the total number of plates for each layer required to fabricate the vessel. 15

- (c) (i) What are the commercial applications of dialysis operation? 5
(ii) Explain the process of pervaporation. 5

7. (a) For the transfer function

$$G(s) = \frac{10e^{-s}}{(0.2s+1)} - \frac{5}{(0.3s+1)}$$

draw the corresponding block diagram and identify the poles and zeros of the transfer function. Find out the process response to a unit step input change and plot (qualitative) the output response with time. For time delay approximation, 1/1 Padé approximation can be used. 20

- (b) What are the various nozzles and mountings provided on storage tanks? 10
(c) Compare the performance of resistance temperature detector and thermocouple in terms of sensitivity and response time. 10

8. (a) Consider the feedback control system with the following transfer functions :

$$G_p(s) = \frac{0.4e^{-s}}{s(5s+1)} \quad G_v(s) = \frac{2}{s(0.5s+1)}$$

$$G_m(s) = 1 \quad G_d(s) = \frac{3}{(5s+1)}$$

$$G_c(s) = K_c$$

Find the limiting value of K_c for stability using Routh's array analysis (consider 1/1 Padé approximation for time delay terms). 15

(b) Write brief notes on the following non-metallic materials of construction :

(i) Carbon and graphite

(ii) Glass

(iii) Rubber

(iv) Plastic

(v) Reinforced plastic

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(c) Write explanatory notes on the following :

(i) Molecular distillation

(ii) Super-critical fluid extraction

(iii) Ultrafiltration

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