Indian Forest Services (Main)
Examination-2025

DJSM–U–CHME

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.

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

1\. *(a)* A tube of $0 \cdot 05 \text{ m}^2$ cross-sectional area is packed with spherical particles up to a height of $0 \cdot 25 \text{ m}$. The porosity of the bed is 0·35. It is desired to fluidize the particles with water (density, $\rho = 1000 \text{ kg/m}^3$ and viscosity, $\mu = 10^{-3}$ Pa-s). Calculate the minimum velocity of fluidization. (Given that the diameter of solid particle is 0·01 m and density is 2600 kg/m^3) 8

(b) For a given crusher, the volume-surface mean diameters for feed and product are 20 mm and 5 mm respectively. The power required to crush 20 tonnes per hour is 8 kW. What will be the power consumption if the capacity is reduced to 10 tonnes per hour? 8

(c) What are the differences between the Total reflux ratio conditions and Minimum reflux ratio conditions? 8

(d) Write the differences between the following :

(i) Local mass transfer coefficient and Overall mass transfer coefficient

(ii) Film theory and Penetration theory 8

(e) In a chemical plant, steam is carried in a 0·45 m diameter pipe having surface temperature of 600 K. The pipe is located inside the room at 400 K. The convective heat transfer coefficient between the pipe surface and the air in the room is $30 \text{ W/m}^2\text{-K}$. Calculate the combined heat transfer coefficient and the rate of heat loss per meter of pipe length. (Given, Stefan-Boltzmann coefficient (σ) is $5 \cdot 67 \times 10^{-8} \text{ W/m}^2\text{-K}^4$) 8

2\. *(a)* The model equation for a non-Newtonian fluid is $\tau = k\left(\frac{du}{dy}\right)^n$, where $n = 0 \cdot 8$ and $k = 0 \cdot 05 \text{ N-s/m}^2$. It flows through a tube of 6 mm bore diameter under the influence of a pressure drop of 6400 N/m^2 per meter length. Obtain an expression for the velocity profile and evaluate—

(i) the centreline velocity;

(ii) the mean velocity. 15

(b) A cylindrical tube of inside radius r_1 and outside radius r_2 is surrounded by insulating material with r_3 as the outer radius of insulation. Show that the rate of heat flow (Q) is given by

$$Q = \frac{(T_1 - T_2)}{\dfrac{(r_2 - r_1)}{2\pi r_{m1} k_1 L} + \dfrac{(r_3 - r_2)}{2\pi r_{m2} k_2 L}}$$

where

r_{m1} is the log mean radius of the tube

r_{m2} is the log mean radius of the insulation layer

L is the length of the cylindrical tube

T_1 is the temperature inside the tube

T_2 is the temperature at the outer edge of the insulation

k_1 is the thermal conductivity of metal wall

k_2 is the thermal conductivity of the insulation layer 15

(c) A continuous distillation column is used to separate methanol from water from a mixture containing 40 mole% of methanol. The total feed is 5000 kg/hr. The feed is a saturated liquid. The distillate contains 98 mole% methanol and bottom product contains 98 mole% water. A reflux ratio of 1·5 times the minimum is to be maintained. Determine the *(i)* top and bottom products flow rate and *(ii)* reflux ratio.

Equilibrium data :

x (mole fraction of methanol in liquid)	0	0·1	0·2	0·3	0·4	0·5	0·6	0·7	0·8	0·9	1·0
y (mole fraction of methanol in vapour)	0	0·42	0·58	0·67	0·73	0·78	0·83	0·87	0·92	0·96	1·0

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3. *(a)* A plate absorption column is used to reduce the concentration of a pollutant A in an airstream from 5·4% to 0·5% by volume in a countercurrent scrubbing with solvent S. This solvent is fresh on entering the top of a column, and the gas stream enters at the bottom of the column at a flow rate of 2·4 m^3/s at the column operation conditions of 293 K and 1 atmosphere. The equilibrium data is given below :

X (kmole A/kmole S)	0	0·005	0·010	0·020	0·030	0·040	0·045
Y (kmole A/kmole air)	0	0·002	0·005	0·015	0·032	0·053	0·065

(i) Determine the minimum flow rate needed for fresh solvent S.

(ii) If the actual fresh solvent flow rate is 1·15 times the minimum, estimate the number of ideal plates required using the graphical method. 20

(b) For a flow of viscous fluid (density, ρ and viscosity, μ) through a circular pipe, establish the Hagen-Poiseuille formula

$$h_f = \frac{\Delta P}{\rho g} = \frac{32\mu \bar{u} L}{\rho g D^2}$$

for the calculation of drop of pressure for a given length L of a pipe having diameter D, frictional head loss h_f and average velocity $\bar{u}$. 10

(c) A 200 W heater has a spherical casing of diameter 200 mm. The heat transfer coefficient for conduction and convection from the casing to the ambient air is obtained from $\text{Nu} = 2 + 0{\cdot}6\,(\text{Re})^{1/2}\,(\text{Pr})^{1/3}$ with $\text{Re} = 10^4$ and $\text{Pr} = 0{\cdot}69$. The temperature of the ambient air is 30 °C and thermal conductivity of air is 0·02 W/m-K. Calculate the—

(i) heat flux from the surface at steady state;

(ii) steady-state surface temperature of the casing. 10

4. (a) (i) For filtration of a sludge in a washing plate and frame filter, the filtration equation is represented by $V^2 = kt$, where V is the volume of the filtrate obtained in time t. At constant pressure, 30 m^3 of filtrate is obtained in 10 hours.

(1) Calculate the washing time if 4 m^3 of wash water is forced to the cake at the end of filtration. (Given that the rate of washing is one-fourth of the final rate of filtration)

(2) If the filtering area/surface is doubled keeping all other things constant, how long would it take to obtain 50 m^3 of filtrate? 10

(ii) Briefly describe the methods for the prevention of swirling and vortex formation in agitated vessels. 5

(b) Two rectangles, 50 cm × 50 cm, are placed perpendicularly with a common edge. One surface has temperature ($T_1 = 1000$ K), emissivity ($\varepsilon_1 = 0{\cdot}6$), while the other surface is insulated and in radiant balance with a large surrounding room at 300 K. Determine the temperature of the insulated surface and the heat lost by the surface at temperature 1000 K. (The values of shape factors are $F_{12} = F_{21} = 0{\cdot}2$) 15

(c) Pure aniline is evaporating through a stagnant film of 1 mm thickness at 300 K and a total pressure of 100 kPa. The vapour pressure of aniline at 300 K is 0·1 kPa. The diffusivity of aniline in air is $0{\cdot}75 \times 10^{-5}$ m^2/s. Find the rate of evaporation of aniline. 10

SECTION—B

5. *(a)* Describe the different types of protective coatings used to prevent corrosion in process equipments. 8

(b) Discuss the design aspects for shell design of large storage tanks. 8

(c) Explain the concentration polarization which occurs in membrane separators. Write the relation between permeance and permeability of a membrane. 8

(d) Solve the differential equation using Laplace transform :

$$4\left(\frac{dy}{dt}\right) + 5y = 3;\ \ y(0) = 1$$ 8

(e) Explain the proportional band (PB) in proportional control, and also write the relation between proportional band (PB) and proportional gain. 8

6. *(a)* Derive the expressions for frequency response characteristics (amplitude ratio, AR and phase angle, ϕ) of *(i)* proportional-integral (PI) controller and *(ii)* proportional-derivative (PD) controller with representative plots. 15

(b) *(i)* Find out the thickness of the torispherical head using the following data :

Knuckle radius	=	100 mm
Crown radius	=	1500 mm
Joint efficiency	=	0·85
Design pressure	=	10 atm
Allowable stress	=	105 N/mm^2

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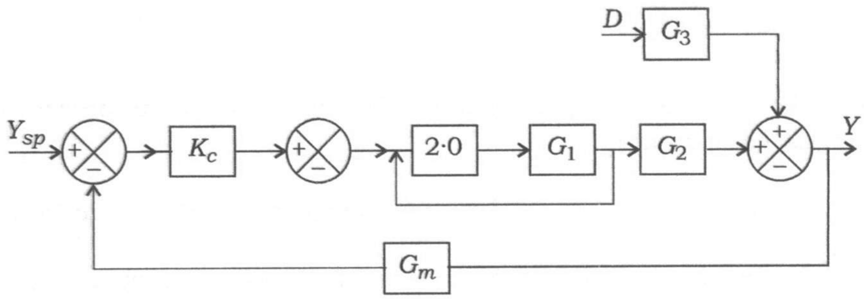
(ii) Write the difference between Butt welding and Lap welding. 5

(c) What is the principle of electrodialysis for separating ions from the mixture? How does the electric current facilitate this separation? 10

7. *(a)* *(i)* What are the desirable properties of supercritical fluids? What are the disadvantages of H_2O as supercritical fluid in supercritical extraction? 5

(ii) Write the mechanism of solubilization of solute from solid material in the supercritical extraction process. Discuss the rapid expansion of supercritical solution technique used in supercritical extraction with schematic diagram. 10

(b) The block diagram of a feedback controller is shown below :



$$G_1 = \frac{1}{(s+3)}; \quad G_2 = \frac{2}{(s-1)}$$
$$G_3 = \frac{6}{(4s+1)}; \quad G_m = \frac{1}{(s+10)}$$

Determine the values of K_c for the stable closed-loop system response. 15

(c) Find out the thickness of the elliptical head using the following data :

Major axis of the ellipse	=	1200 mm
Minor axis of the ellipse	=	800 mm
Joint efficiency	=	0·85
Design pressure	=	5 atm
Allowable stress	=	95 N/mm^2

10

8. *(a)* A gas mixture of methane and ethane is to be partially separated with a composite membrane having a 1 μm thick porous skin with an average pore size of 20 Å and a porosity of 30%. The tortuosity of pores can be assumed as 1·6. The pressure (P) on either side of a membrane is 8 atm and temperature is 100 °C. The ordinary diffusivities in cm^2/s for methane and ethane are found to be dependent on total pressure (in atm) with a relation of $0 \cdot 72 / P$ at temperature of 100 °C. Estimate the permeabilities of both the components. 15

(b) The data related to saddle support for horizontal vessel are given below. Calculate the stresses due to bending at the topmost fibre of cross-section, at the bottom-most fibre of cross-section and calculate the stress at the mid-span.

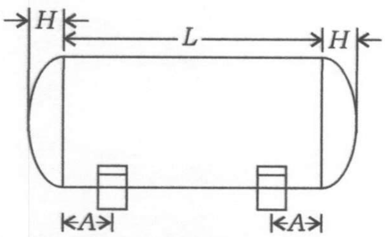
Data :

Vessel diameter	=	1250 mm
Length of shell	=	9000 mm
Total depth of head	=	257 mm
Working pressure	=	5 atm
Shell thickness	=	12 mm
Corrosion allowance	=	2 mm
Weight of vessel and contents	=	11950 kg
Distance of saddle centreline from shell end	=	300 mm

Consider the following formula for bending moment and refer the figure for variables :

Bending moment at support, $M_1 = QA\left[1-\dfrac{1-\dfrac{A}{L}+\dfrac{(R^2-H^2)}{2AL}}{1+\dfrac{4}{3}\dfrac{H}{L}}\right]$

Bending moment at the centre of the span, $M_2 = \dfrac{QL}{4}\left[\dfrac{1+2\left(\dfrac{R^2-H^2}{L^2}\right)}{1+\dfrac{4}{3}\dfrac{H}{L}}-\dfrac{4A}{L}\right]$



Schematic of saddle support

where

$Q=\frac{w}{2}(L+\frac{4}{3}H)$

w= uniformly distributed load

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(c) A system has a transfer function

$$\frac{Y}{X}=\frac{10}{(s^2+1\cdot6s+4)}$$

A step change of 4 units magnitude is introduced in the system. Find the percent overshoot and decay ratio. 10

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