

## 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.*

*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

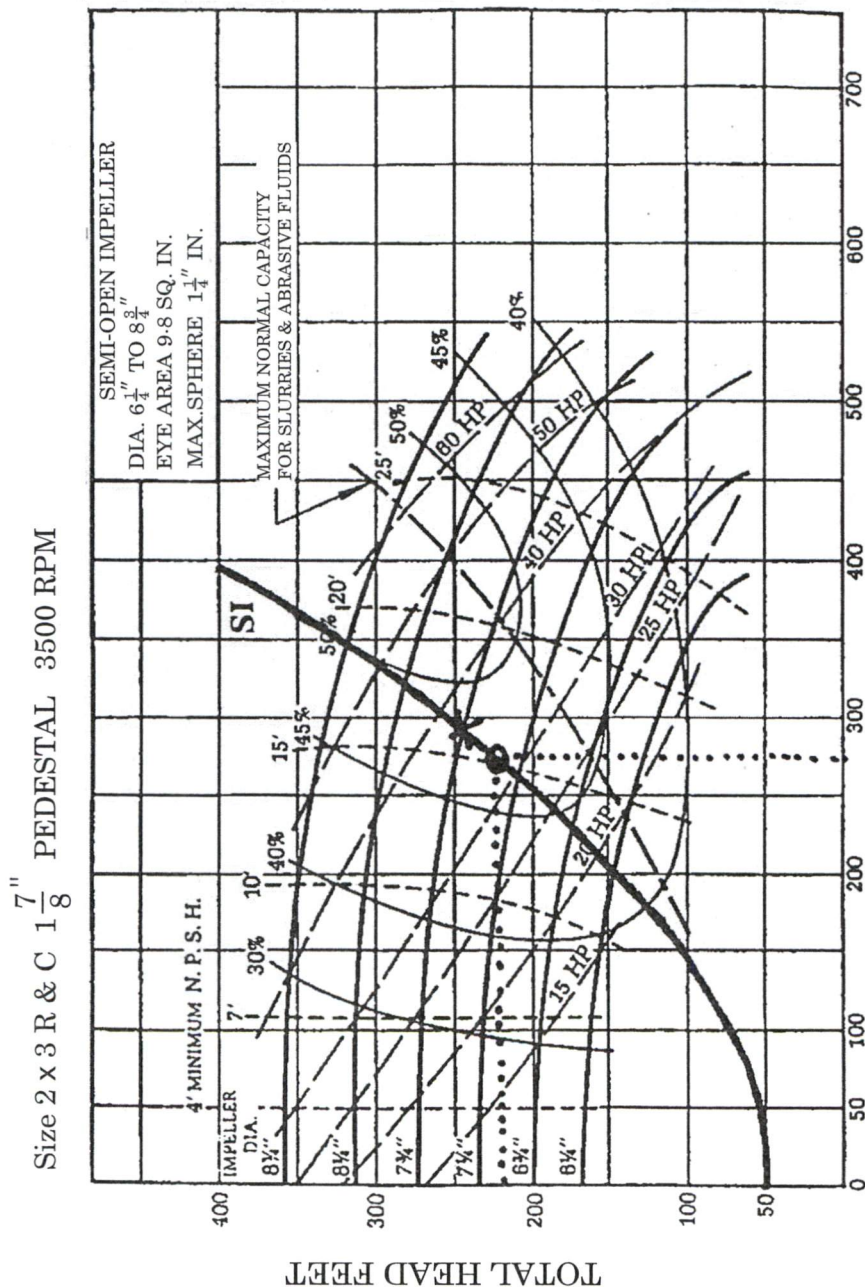
- Q1.** (a) What are the limitations on the use of Bernoulli Equation ? Explain any three. 8
- (b) State Bond Crushing Law and define Work Index.  
What is the power required to crush 100 ton/h of limestone if 80 percent of the feed passes a 2-in. screen and 80 percent of the product a  $\frac{1}{8}$ -in. screen ? 8
- (c) What is an azeotrope ? Draw a schematic of T-x-y diagram for minimum boiling azeotrope and maximum boiling azeotrope. Also draw the schematic of corresponding equilibrium curve diagram. 8
- (d) For steady state conduction in one dimension, derive rate of heat transfer through hollow sphere. Assume suitable notations, wherever necessary. 8
- (e) Derive an expression of Radiation Exchange in a two-surface Gray enclosure – 8

$$\frac{Q_{1\text{net}}}{A_1} = \frac{\sigma (T_1^4 - T_2^4)}{\frac{1}{\varepsilon_1} + \frac{1}{\varepsilon_2} - 1}$$

- Q2.** (a) Propane is to be stripped from a non-volatile oil by steam in a counter-current tower. Four moles of steam is supplied at the bottom of the tower for every 100 moles of oil-propane feed at the top. The oil originally contains 2.55 mole% propane, and this concentration needs to be reduced to 0.25 mole%. The tower is maintained at 135°C and 4 atm. absolute pressure. The molecular weight of the heavy oil is 300, and the molecular weight of propane is 44. The equilibrium relationship is  $y = 24x$ , where  $y$  = mole fraction of propane in vapour and  $x$  = mole fraction of propane in liquid. Find the number of equilibrium stages. 20

- (b) A centrifugal pump with the characteristics shown in figure is to be used to pump an organic liquid from a reboiler to a storage tank through a 2 in. sch 40 line, at a rate of 200 rpm. The pressure in the reboiler is 2.5 atm, and the liquid has a vapour pressure of 230 mm Hg, an SG of 0.85, and a viscosity of 0.5 C<sub>p</sub> at the working temperature. If the suction line upstream of the pump is also 2 in. sch 40 and has elbows and one globe valve, and the pump has a  $7\frac{3}{4}$  in. impeller, what is the maximum height above the reboiler that the pump can be located without cavitating ? Velocity of the pipe  $V_s = 19.1$  ft/sec. elbow :  $k_1 = 800$ ,  $k_\infty = 0.091$ ,  $k_d = 4.0$ ; globe valve :  $k_1 = 1000$ ,  $k_\infty = 1.7$ ,  $k_d = 3.6$ ;  $Re = 5.23 \times 10^5$ ,  $f = 0.00493$ . Assume suction line is vertical.

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CAPACITY - U.S. GALLONS PER MINUTE  
Figure - Typical pump characteristic curves. (From TRW Mission Pump Brochure)

- (c) A single effect evaporator, vertical short tube type is used to concentrate a syrup from 10% to 40% solids at the rate of 2000 kg of feed per hour. The feed enters at 30°C and a reduced pressure of 0.33 kg/cm<sup>2</sup> is maintained in the vapour space. At this pressure the liquor boils at 75°C. Saturated steam at 115°C is supplied to the steam chest. No subcooling of the condensate occurs. Calculate the steam requirement and number of tubes (0.0254 m, 16 BWG) if the height of the calandria is 1.5 m. The following data are given :

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$$\text{Sp. heat of liquor} = 0.946 \frac{\text{kcal}}{\text{kg } ^\circ\text{C}}$$

$$\text{Latent heat of steam at } 0.33 \frac{\text{kg}}{\text{cm}^2} = 556.5 \text{ kcal/kg.}$$

$$\text{Boiling point of water at this pressure} = 345 \text{ K.}$$

$$\text{The overall heat transfer coefficient} = 2150 \text{ kcal/h m}^2 \text{ } ^\circ\text{C}$$

- Q3.** (a) A heat transfer oil (specific heat = 0.454 kcal/kg °C) leaving a hydraulic system at a rate of 10,000 kg/h at 85°C has to be cooled at 50°C before it can be circulated back to the system. It is desired to determine whether an existing 1 – 2 pass exchanger having an area of 15 m<sup>2</sup> would be suitable. Water is available at 30°C and must not be heated to above 38°C. An overall heat transfer coefficient (including the dirt factor) of 400 kcal/h m<sup>2</sup> °C can be attained in the exchanger. Water flows through the shell and the oil through the tube. How will the heat transfer rate and the exit oil temperature be affected if the water flow rate is increased by 20% ? The overall heat transfer coefficient  $U_d$  is assumed to remain unchanged.

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Given correlations :

For one shell pass, 2, 4, 6 tube passes.

$$\text{effectiveness } \eta = 2 \left[ 1 + C + (1 + C^2)^{1/2} \times \frac{1 + \exp [-N(1 + C^2)^{1/2}]}{1 - \exp [-N(1 + C^2)^{1/2}]} \right]^{-1}$$

$$\text{NTU} = -(1 + C^2)^{-1/2} \times \ln \left[ \frac{\frac{2}{\eta} - 1 - C - (1 + C^2)^{1/2}}{\frac{2}{\eta} - 1 - C + (1 + C^2)^{1/2}} \right]$$

where

$$C = \frac{C_{\min}}{C_{\max}} \text{ \& } \text{NTU} = \frac{UA}{C_{\min}}$$

- (b) Describe centrifugal pump characteristics in terms of its working, heat calculations, and efficiency. 10
- (c) A liquid mixture containing 25 mole% benzene and 75 mole% ethyl alcohol, in which components are miscible in all proportions, is heated at a constant pressure of 1 atm from a temperature of 60°C to 90°C. Using T-x-y experimental data, perform calculations to determine the answers of (i) and (ii).

Experimental T-x-y data for Benzene-Ethyl alcohol at 1 atm

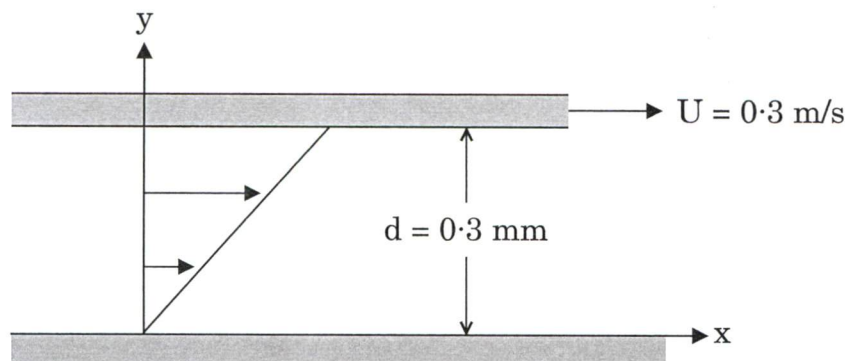
| Temperature (°C)               |      |    |      |    |      |      |      |      |    |      |      |
|--------------------------------|------|----|------|----|------|------|------|------|----|------|------|
| 78.4                           | 77.5 | 75 | 72.5 | 70 | 68.5 | 67.7 | 68.5 | 72.5 | 75 | 77.5 | 80.1 |
| Mole percent benzene in vapour |      |    |      |    |      |      |      |      |    |      |      |
| 0                              | 7.5  | 28 | 42   | 54 | 60   | 68   | 73   | 82   | 88 | 95   | 100  |
| Mole percent benzene in liquid |      |    |      |    |      |      |      |      |    |      |      |
| 0                              | 1.5  | 5  | 12   | 22 | 31   | 68   | 81   | 91   | 95 | 98   | 100  |

- (i) At what temperature does vaporization begin ?
- (ii) What is the composition of the first bubble of equilibrium vapour formed ? 10

- Q4.** (a) An infinite plate is moved over a second plate on a layer of liquid as shown. For small gap width  $d$ , we assume a linear velocity distribution in the liquid. The liquid viscosity is 0.65 centipoise and its specific gravity is 0.88.

Determine,

- (i) The absolute viscosity of the liquid in  $\text{lbf}\cdot\text{s}/\text{ft}^2$ .
- (ii) The kinematic viscosity of the liquid in  $\text{m}^2/\text{sec}$ .
- (iii) The shear stress on the upper plate in Pa.
- (iv) The shear stress on the lower plate in Pa.
- (v) The direction of each shear stress calculated in parts (iii) and (iv). 20



- (b) There is a 2 mm thick layer of water on the floor of a room. The water vaporizes and diffuses through a stagnant film of air of estimated thickness of 2.5 mm on the water surface. The mean air-film temperature can be taken as 25°C. The diffusivity of water vapour in air is 0.22 cm<sup>2</sup>/s at 1 std atmosphere and 0°C. The partial pressure of water vapour on the water layer side of the air film is 20.9 mmHg and on other side is 17.3 mmHg. The total pressure is 1 atm. Calculate the time required (in hours) for the water layer to completely evaporate.

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- (c) Trichloroethylene (TCE) is an important solvent. A manufacturer of porous battery separators uses it to leach out a non-volatile oil dispersed in the moulded PVC sheet in order to generate pores. TCE is recovered by stripping it out of the solution containing the oil followed by condensation.

Condensation of the vapour leaving the stripper is done in a horizontal condenser at essentially the atmospheric pressure. The vapour, which is of virtually pure TCE, condenses on the outside of 25.4 mm o.d. tubes having a surface temperature of 25°C.

Calculate the rate of condensation of TCE on a single horizontal tube, 0.7 m long.

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The data for TCE are available.

Normal Boiling Point = 360.4 K.

Heat of vaporization = 320.8 kJ/kg

Specific heat = 1.105 kJ/kg °C

Liquid viscosity = 0.45 C<sub>p</sub>

Thermal conductivity of liquid = 0.1064 W/m °C

Liquid density = 1375 kg/m<sup>3</sup>

Density of vapour = 4.44 kg/m<sup>3</sup>

The liquid properties are taken at the mean film temperature [i.e. (25 + 87.4)/2 = 56.2°C].

## SECTION B

- Q5.** (a) Write a short note on “Ultrafiltration” process along with its industrial applications. 8
- (b) Explain the term “Fatigue” in the design of process equipments. Also enumerate the factors which influence fatigue. 8
- (c) Give the importance of economic considerations during estimation of fabrication cost of a process equipment. 8
- (d) What is inverse response ? Under what conditions does a second order system with numerator dynamics exhibit inverse response ? 8
- (e) The following second order process is controlled by a proportional controller of gain 1.6.

$$G(s) = \frac{5}{(s+1)(2s+1)}$$

For unit step input in its set point, find the offset. 8

- Q6.** (a) What do you mean by “Supercritical fluid” ? Explain the extraction process of products from solid and liquid natural materials with the help of suitable schematic diagrams. 20
- (b) A process has transfer function  $G(s) = \frac{2e^{-0.2s}}{s+1}$ . Compare the PI controller settings for the two different design approaches : (a) IMC Tuning method, and (b) ITAE performance index (disturbance). Which controller setting is more conservative ?

Given data :

IMC based PID controller settings for  $G_c(s)$  :

| Model                               | $k_c k$                        | $\tau_I$ | $\tau_D$ |
|-------------------------------------|--------------------------------|----------|----------|
| $\frac{ke^{-\theta s}}{\tau s + 1}$ | $\frac{\tau}{\tau_c + \theta}$ | $\tau$   | —        |

Controller design relations based on the ITAE performance index :

| Type of Input | Type of controller | Mode | A     | B       |
|---------------|--------------------|------|-------|---------|
| Disturbance   | PI                 | P    | 0.859 | — 0.977 |
|               |                    | I    | 0.674 | — 0.680 |

Design relation :  $Y = A \left( \frac{\theta}{\tau} \right)^B$ , where  $Y = k/k_c$  for proportional mode,  $\frac{\tau}{\tau_I}$  for the integral mode. 10

- (c) What do you understand by the term “Low carbon steel” ? Also discuss the various types of non-metals used in the design of industrial equipments.

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- Q7.** (a) Calculate the bending moments (longitudinal) and stresses in shell at the saddle, during design of horizontal vessel supported with saddle. Assume suitable data, if missing.

Data :

Material – low carbon steel

Vessel diameter – 1230 mm

Length of shell – 8000 mm

Torispherical head – crown radius – 1250 mm

Knuckle radius – 6% of diameter

Total depth of head – 257 mm

Working pressure –  $0.5 \text{ N/mm}^2$

Shell thickness – 10 mm

Head thickness – 12 mm

Corrosion allowance – 1.5 mm

Permissible stress –  $95 \text{ N/mm}^2$

Weight of vessel and contents – 119430 N

Distance of saddle centre line from shell end – 320 mm

Arm of force of weight of vessel (R) – 615 mm

Take for  $\theta = 120^\circ$ ,  $k_1 = 0.107$

for  $\theta = 12^\circ$ ,  $k_2 = 0.192$

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- (b) Define the term “Ion-exchange”. A commercial ion-exchange resin is made from 88 wt% styrene and 12 wt% divinylbenzene. Estimate the maximum ion-exchange capacity in eq/kg resin.

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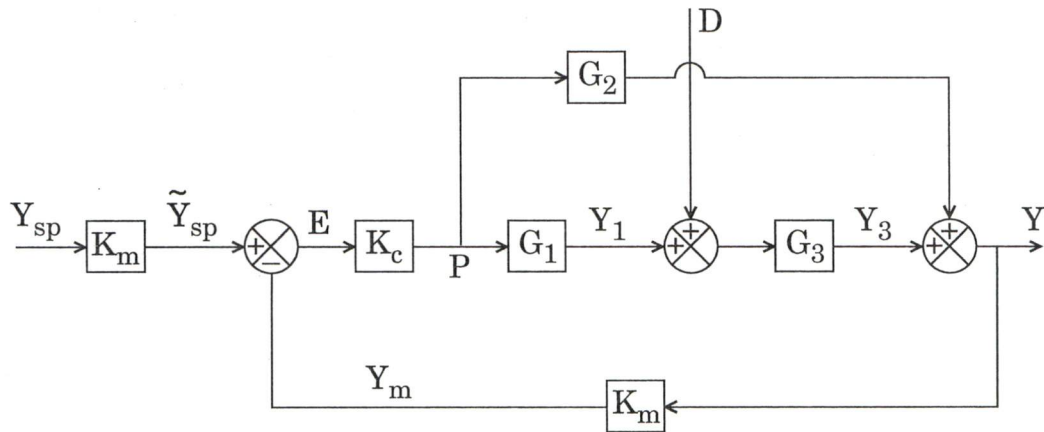
- (c) Draw the instrumentation diagram of Cascade Control strategy using an appropriate example.

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- Q8.** (a) (i) A block diagram of a closed-loop system is shown in the figure. For the following transfer functions, what values of  $K_c$  will result in a stable closed-loop system ?

$$G_1(s) = 5 \quad ; \quad G_3(s) = \frac{1}{s-1}$$

$$G_2(s) = \frac{4}{2s+1} \quad ; \quad K_m = 1$$



- (ii) Derive the closed loop transfer function for servo problem. 20
- (b) Enumerate and discuss various types of “Removable Closures” for high pressure vessel design, with the help of suitable diagrams. 10
- (c) Enumerate the applications of “Electrodialysis” in separation process. Also explain the various parameters for estimation of the performance of RO (reverse osmosis) membranes. 10

