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**UPSC IFS**  
**Previous Year Paper**  
**(Chemical Engineering**  
**Paper - I) 2020**



## 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.

JKLO-U-CHME

## SECTION A

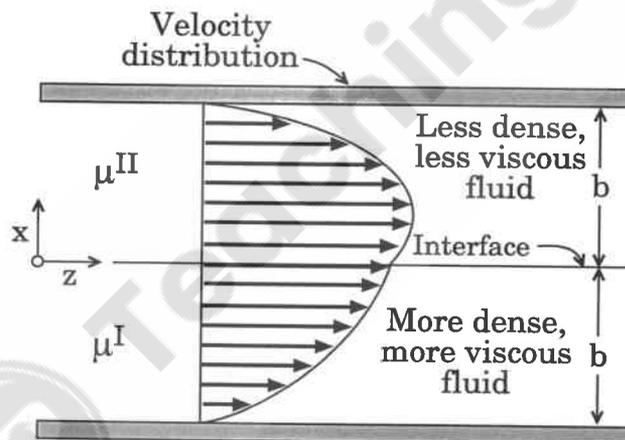
- Q1.** (a) The water flows steadily through a pipe of length  $L$  and radius  $R = 75$  mm. The velocity distribution across the outlet is given by

$$\frac{u}{U_{\max}} = 1 - \frac{r^3}{R^3}$$

The value of  $U_{\max} = 3$  m/s. The inlet velocity is uniform and expressed as  $U$ . Find the net rate of volumetric flow out from the outlet control surface ( $\text{m}^3/\text{s}$ ) and the value of  $U$  (m/s).

8

- (b) Two immiscible, incompressible liquids are flowing in the  $z$ -direction (Refer Figure) in a horizontal thin slit of length  $L$  and width  $W$  under the influence of a pressure gradient  $((p_o - p_L) / L)$ . The fluid flow rates are adjusted so that the slit is half filled with fluid I (the denser phase) and half filled with fluid II (the less dense phase). The fluids are flowing sufficiently slow that no instabilities occur and the interface remains exactly planar.



The velocity variation for the fluid II is given by

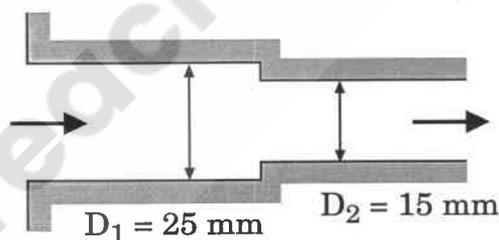
$$v_z^{\text{II}} = \frac{(p_o - p_L) b^2}{2 \mu^{\text{II}} \cdot L} \left[ \left( \frac{2 \mu^{\text{II}}}{\mu^{\text{I}} + \mu^{\text{II}}} \right) + \left( \frac{\mu^{\text{I}} - \mu^{\text{II}}}{\mu^{\text{I}} + \mu^{\text{II}}} \right) \left( \frac{x}{b} \right) - \left( \frac{x}{b} \right)^2 \right]$$

Find the value of  $\left( \frac{x}{b} \right)$  at the plane of zero shear stress for  $\mu^{\text{I}} = 3 \mu^{\text{II}}$ .

8

- (c) Distinguish between Ponchon–Savarit method and McCabe–Thiele method. What are the assumptions made in these methods? 8
- (d) A 5 cm diameter copper sphere is initially at a uniform temperature of 200°C. It is suddenly exposed to an environment at 20°C having heat transfer coefficient  $h = 300 \text{ W/m}^2 \text{ }^\circ\text{C}$ . Using the lumped-capacity method of analysis, calculate the time necessary for the sphere temperature to reach 90°C. Consider the copper property data as : density = 8954 kg/m<sup>3</sup>; specific heat = 383 J/kg K; thermal conductivity = 374 W/m °C. 8
- (e) Derive the shell side equivalent diameter (hydraulic diameter) for the triangular and square pitch arrangement of tubes in terms of tube outside diameter ( $d_o$ ) and pitch ( $p_t$ ). 8

- Q2.** (a) Water at 40°C (density = 992 kg/m<sup>3</sup>; viscosity =  $6.53 \times 10^{-4} \text{ Pa}\cdot\text{s}$ ) flows from the reservoir (constant height is maintained) in a pipe (Material of construction = Galvanized Iron) system in which diameter is decreased from 25 mm (Section 1 is of 10 m length) to 15 mm (Section 2 is of 5 m length) and exiting to the atmosphere at  $Re = 10,000$ .



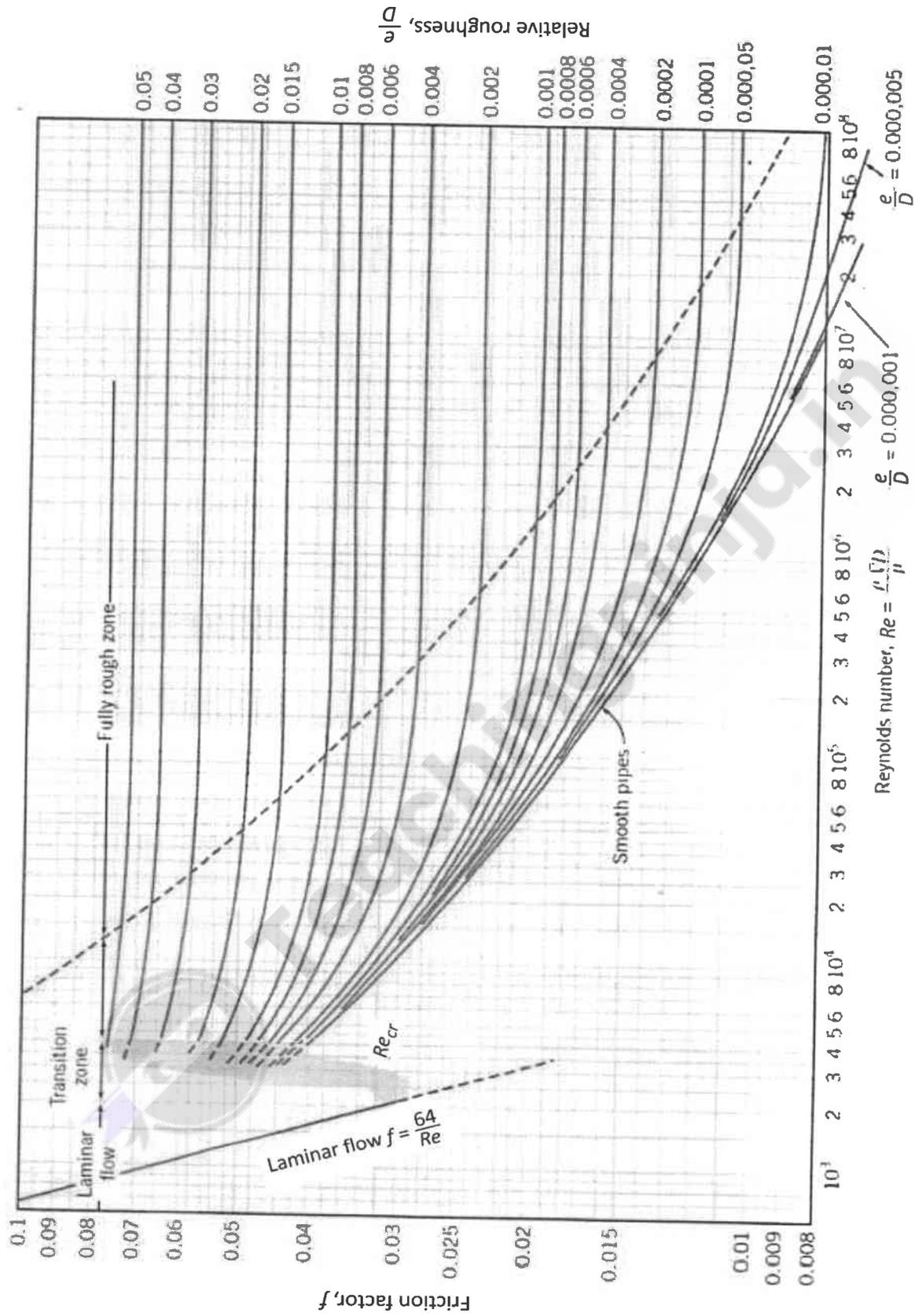
Given data :

Roughness parameter of Galvanized Iron pipe = 0.15 mm

Minor loss coefficient of contraction = 0.32

Minor loss coefficient of entrance = 0.5

Find the height required in the reservoir to overcome all energy losses (major, minor and head losses). 20



Friction factor vs. Reynolds Number chart

- (b) After crystallization, a solution of calcium chloride in water contains 62 parts of calcium chloride per 100 parts of water. Calculate the weight of this solution necessary to dissolve 250 kg of  $\text{CaCl}_2 \cdot 6\text{H}_2\text{O}$  crystals at a temperature of 298 K.

Solubility of  $\text{CaCl}_2$  at 298 K is 7.38 kg moles of  $\text{CaCl}_2$  per 1000 kg of  $\text{H}_2\text{O}$ .

10

- (c) For the natural convection vertical heated flat plate system (Wall temperature =  $T_w$ ; Free stream fluid temperature =  $T_\infty$ ), verify the temperature profile given below using appropriate boundary conditions.

$$\frac{T - T_\infty}{T_w - T_\infty} = \left(1 - \frac{y}{\delta}\right)^2$$

where,  $y$  = distance from the wall, and  
 $\delta$  = boundary layer thickness.

Using the above temperature profile, find the relation of the Nusselt number with boundary layer thickness.

10

- Q3.** (a) A mixture of A and B with 45 mole% A is to be distilled. The concentration of A in the distillate is 95 mole% and 90% of all A is to be in the distillate. The feed is half vapour. The relative volatility of A with respect to B is 2.50. Determine the number of theoretical stages if the optimum reflux ratio is twice that of the minimum reflux ratio.

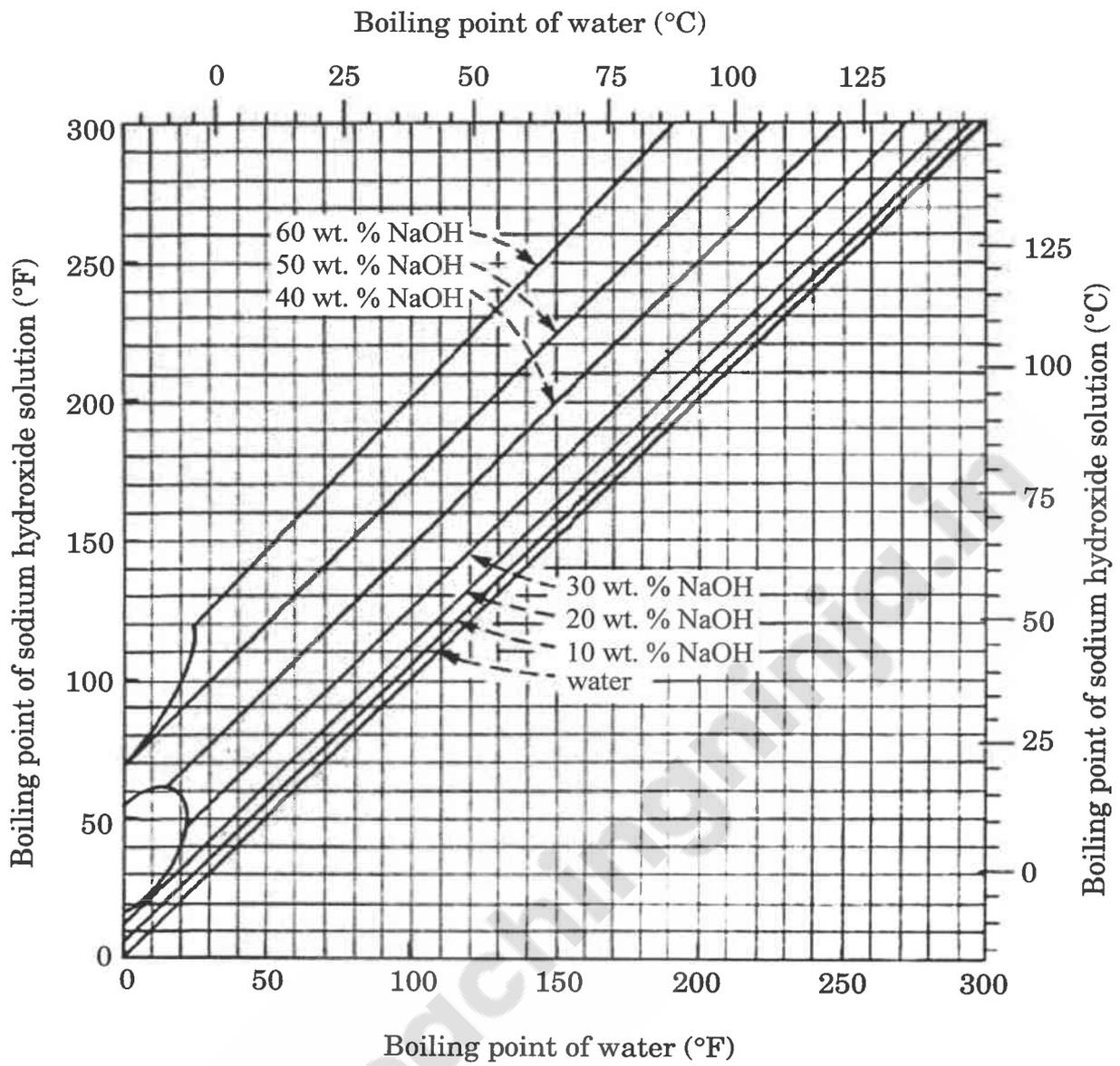
20

- (b) A triple effect evaporator is to be used to produce a 60% NaOH solution from a feed containing 15% NaOH. The steam is available at 138°C and the vapour from the last stage is condensed at 38°C. The backward feed type arrangement is used. If equal amounts of water are removed in each effect, find the following :

- (i) The concentrations in the intermediate effects.
- (ii) The boiling point elevation in each effect.
- (iii) The net temperature difference available for heat transfer.

Consider 66°C, 52°C and 38°C as the boiling temperatures of water at the pressures in effects 1, 2 and 3 respectively.

12



*Dühring lines for aqueous solutions of sodium hydroxide*

(c) Write short notes on the following :

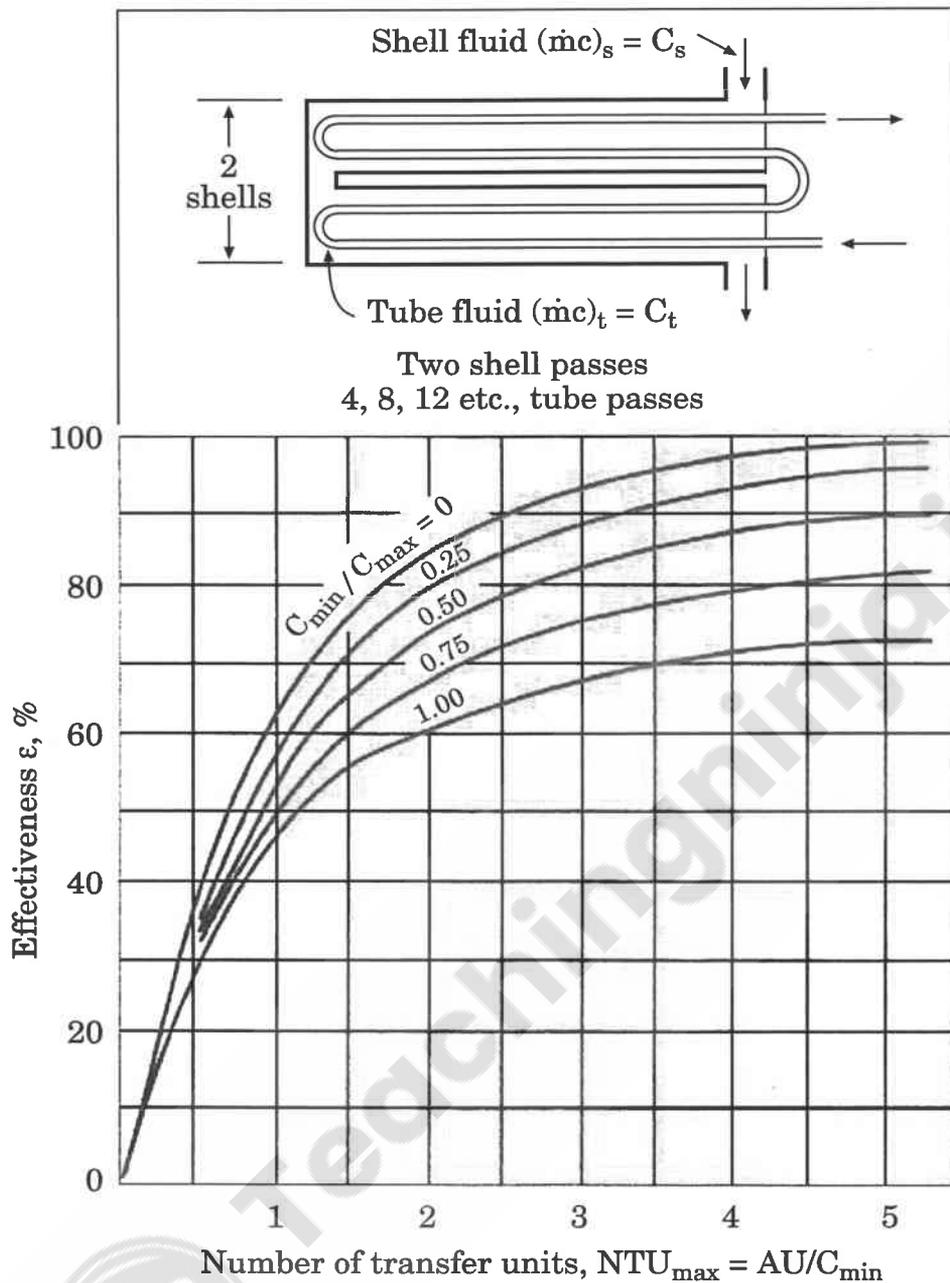
4+4=8

- (i) Critical speed of ball mill
- (ii) Working principle and operation of cyclone

**Q4.** (a) A newly procured shell and tube heat exchanger operates with two shell passes and four tube passes. The shell fluid is ethylene glycol, which enters at 100°C and leaves at 60°C with a flow rate of 30,000 kg/hr. Water flows in tubes, entering at 35°C and leaving at 75°C. The overall heat transfer coefficient for this system is 425 W/m<sup>2</sup> °C. The tube details are : 20 mm outside dia, 16 mm inside dia, 4.88 m long with triangular pitch arrangement. Calculate the water flow rate and number of tubes in this assembly. Consider LMTD correction factor value as 0.88. The specific heats at average temperature are : Water = 4179 J/kg K; Ethylene Glycol = 2650 J/kg K. After six months of operation, due to fouling the heat transfer duty is decreased. It is found that fouling factor for ethylene glycol and water is 0.00005 and 0.0002 m<sup>2</sup> °C/W respectively. What would be the ethylene glycol exit temperature ?

20

Effectiveness for 2-4 multipass counterflow exchanger performance



- (b) Air (density =  $1.22 \text{ kg/m}^3$ ; viscosity =  $1.9 \times 10^{-5} \text{ Pa}\cdot\text{s}$ ) is flowing through a bed of a diameter  $0.5 \text{ m}$  and height of  $2.5 \text{ m}$ . The bed has spherical particles of diameter  $10 \text{ mm}$  and density  $1200 \text{ kg/m}^3$ . The air mass flow rate is  $0.5 \text{ kg/s}$ . The porosity of bed at minimum fluidization velocity is  $0.38$ . Determine whether the bed is in fluidized state or not. 10
- (c) (i) What is relative volatility,  $\alpha$  of a binary mixture? Explain. 5
- (ii) For ideal solutions following Raoult's law, prove that  $\alpha$  is the ratio of the vapour pressures for a binary solution. 5

### SECTION B

- Q5.** (a) Derive the expressions of longitudinal and circumferential stress for a thin walled cylindrical vessel in terms of internal pressure, diameter and thickness of the cylinder. 8
- (b) Define Gasket Seating Stress and Gasket Factor. State any six types of gaskets. 8
- (c) Write a short note on Ultrafiltration. 8
- (d) What are the desirable properties of thermocouples for industrial use ?  
What are the most commonly used thermocouples and their temperature range ? 8
- (e) By using transform method, solve  $\frac{d^2x}{dt^2} - 2\frac{dx}{dt} + x = e^t$ , with the conditions  $x = 2$  and  $\frac{dx}{dt} = -1$  at  $t = 0$ . 8
- Q6.** (a) A reactor ( $I_D = 1000$  mm) has hemispherical head at the bottom. Inside working pressure is  $9.81$  N/mm<sup>2</sup> and temperature is  $70^\circ\text{C}$ . Reactor is covered with plain jacket such that 75% length of shell and complete bottom hemispherical head are covered with jacket. Cooling water is circulated in the jacket with a pressure of  $0.5884$  N/mm<sup>2</sup>. The hemispherical head is fabricated from SA 516 Grade 70 plate. The maximum allowable stress of this plate at design temperature is  $59.82$  N/mm<sup>2</sup>.  
Modulus of elasticity of plate material =  $193 \times 10^3$  N/mm<sup>2</sup>  
Poisson's ratio =  $0.3$   
Density of plate material =  $7830$  kg/m<sup>3</sup>  
Joint efficiency =  $0.85$   
Corrosion allowance =  $3$  mm  
Find thickness of head and weight of head. 15
- (b) How do you determine the stability with Routh Test ? Write the theorems. From this, test the stability of a system for which the characteristic equation is  
$$2s^4 + 6s^3 + 10s^2 + 8s + 4 = 0.$$
 15
- (c) With suitable examples, describe the process of Supercritical Fluid Extraction. 10

- Q7. (a) Calculate the base plate thickness and gusset plate thickness for bracket support.

Data :

Weight of vessel with contents = 7 tons

Diameter of vessel = 1.5 m

Height of vessel = 2 m

Vessel clearance from foundation = 1 m

Height of bracket from foundation = 2 m

Number of brackets = 4

Bolt circle diameter = 1.6 m

Permissible bending stress of the material = 160 N/mm<sup>2</sup>

Base plate size = 15 cm × 15 cm

Space between gusset = 12 cm

Height of gusset plate = 120 cm

Vessel is kept inside the room.

Formula for stress calculation :  $f = 0.7 p_{\text{avg}} \frac{B^2}{T_1^2} \left( \frac{a^4}{a^4 + B^4} \right)$  in base plate

Formula for stress calculation in Gusset plate  $f = \frac{3 PC}{T_2 h^2} \frac{1}{\cos \theta}$ . 15

- (b) With a neat sketch explain a general membrane separation process.

What are different membrane separation processes ? Give their industrial applications. 15

- (c) Define the Laplace transform of a function  $f(t)$ . From this definition and from first principles, find the transforms of  $\frac{d f(t)}{dt}$  and  $\frac{d^2 f(t)}{dt^2}$ . 10

- Q8.** (a) Write a short note on Ion Exchange. Indicate its industrial applications. 15
- (b) Write short notes on the following : 5+5+5=15
- (i) Transportation lag
  - (ii) Damping in a second order system
  - (iii) Root locus method
- (c) Discuss in detail the various types of jackets used for heating and cooling. 10

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