Ref. No.: Ex/Che/PC/B/T/314/2025

B.E. CHEMICAL ENGINEERING 3rd YEAR 1st SEMESTER EXAM, 2025

Process Heat Transfer

Time : Three hours **Full Marks: 100**

(Use separate answer script for each part.)

Part I (50 Marks)

Answer any two questions

Assume any missing data

Question 1: CO-1, CO-2

(a) The temperature (t) distribution for laminar flow of a fluid over a flat plate is given by

$$\frac{t-t_w}{t_\infty-t_w} = \frac{3}{2}\left(\frac{y}{\delta}\right) - \frac{1}{2}\left(\frac{y}{\delta}\right)^3 \qquad \delta = \frac{4.64}{Re_x^{0.5}}$$

where y is the distance from the surface of the plate, and Re_x is the Reynolds number based on distance, x from the leading edge of plate. Calculate the heat transfer coefficient at $x = 0.1m$ and fluid velocity of 1.0 m.s^{-1}.

The density, viscosity, thermal conductivity, bulk temperature of the fluid (t_∞) and temperature of the surface of the plate (t_w) may be assumed to be 993 kg.m^{-3}, 725x10^{-6} kg.m^{-1}.s^{-1}, 0.625 W.m^{-1} °C^{-1}, 30 °C and 90 °C respectively. [7]

(b) Air at 20 °C flows past a 200 mm long plate at a velocity of 45 m.s^{-1}. If the surface temperature is maintained at 100 °C, determine the rate of heat transfer per unit width from the entire plate to air.

Data:

Critical Reynolds number = 5x10^5

The Nusselt number (Nu_x) at a distance x from the leading edge of the plate is given by

$$laminar\ flow: Nu_x = 0.332(Re_x)^{0.5}(Pr)^{0.33}$$

$$turbulent\ flow: Nu_x = 0.0.03(Re_x)^{0.8}(Pr)^{0.33}$$

where Pr is the Prandtl number and Re_x is the Reynold's number at a distance, x from the leading edge of plate.

The density, thermal conductivity, kinematic viscosity and Prandtl number of air may be taken to be 0.9 kg.m^{-3}, 0.04 W.m^{-1} °C^{-1}, 28x0^{-6} m^2.s^{-1} and 0.69 respectively. [15]

© Explain why the correlations given in Q1 (b) are not applicable for flow of molten metal over flat plate [3]

[Turn over

Question 2: CO-2, CO-5

Water (flow rate = 4 kg.s^{-1}) flows through the tubes of a 1-1 shell and tube heat exchanger. The inner diameter and outer diameter of the tubes is 0.02 m and 0.024 m respectively. The average velocity of water in the tubes is 0.4 m.s^{-1} and is heated from 35 °C to 50 °C by oil (flow rate = 5.0 kg.s^{-1}) entering at 95 °C. Because of space limitation, the tube length must not exceed 4m. Calculate the

(i) temperature of oil exiting the heat exchanger.
(ii) number of tubes per pass
(iii) overall heat transfer coefficient
(iv) number of tube passes
(v) length of tube consistent with the restriction

Data

The heat transfer coefficient in the shell side is 1000 W.m^{-2} °C^{-1}.

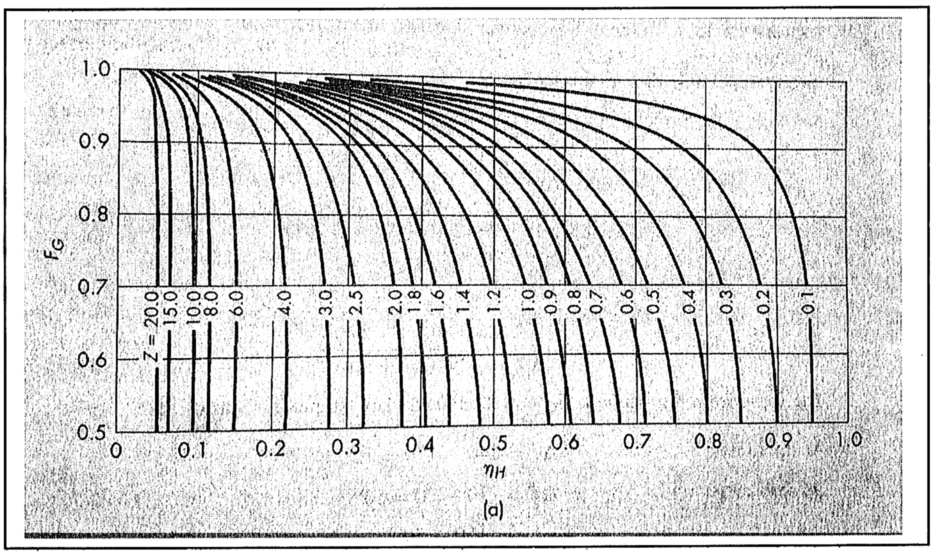
The average heat transfer coefficient in the tube side ($\bar{h}$) may be calculated from

$$\overline{Nu_D} = 0.023(Re_D)^{0.8}(Pr)^{0.4}$$

Where the Reynolds number (Re_D) and Nusselt number (Nu_D) is calculated based on tube diameter (D). The magnitude of the Prandtl number (*Pr*) is 0.5.

The inside and outside fouling factor is 2500 W.m^2.°C^{-1} and 1500 W.m^2.°C^{-1} respectively.

The density and heat capacity of oil may be taken to be 850 kg.m^{-3} and 2400 J.kg^{-1}K^{-1} respectively. The density heat capacity, viscosity, thermal conductivity and Prandtl number of water may be assumed to be 1000 kg.m^{-3}, 4187 J.kg^{-1}K^{-1}, 0.86x10^{-3} kg.m^{-1}.s^{-1}, 0.6 W.m^{-1}.s^{-1} and 5.5 respectively.



Question 3: CO-4, CO-5, CO-6

A single effect evaporator used to concentrate 5000 kg/h sodium hydroxide solution entering at 100 °F from 20 wt% to 50 wt% is shown. The absolute pressure in the vapor space is 150 mm Hg (saturation temperature = 65 °C). A 1-1 shell and tube heat exchanger is used to heat the solution with saturated steam at 2 atm (gauge) undergoing film wise condensation on the outer surface of the tubes. Each tube is 5m long having inside and outside diameter of 0.02m and 0.024m respectively. Calculate

(i) capacity of evaporator
(ii) boiling point elevation of solution
(iii) Steam economy
(iv) overall heat transfer coefficient assuming laminar flow of the condensing water.
(v) heating surface required assuming the temperature of the liquid inside the tubes is constant and at the boiling point of the solution.
(vi) number of tubes in the heat exchanger
(vii) Reynolds number and average thickness of the falling film.

Data:

The heat transfer coefficient inside tubes may be assumed to be 3000 W.m^{-2}.°C^{-1}. The thermal resistance of the tube wall may be neglected.

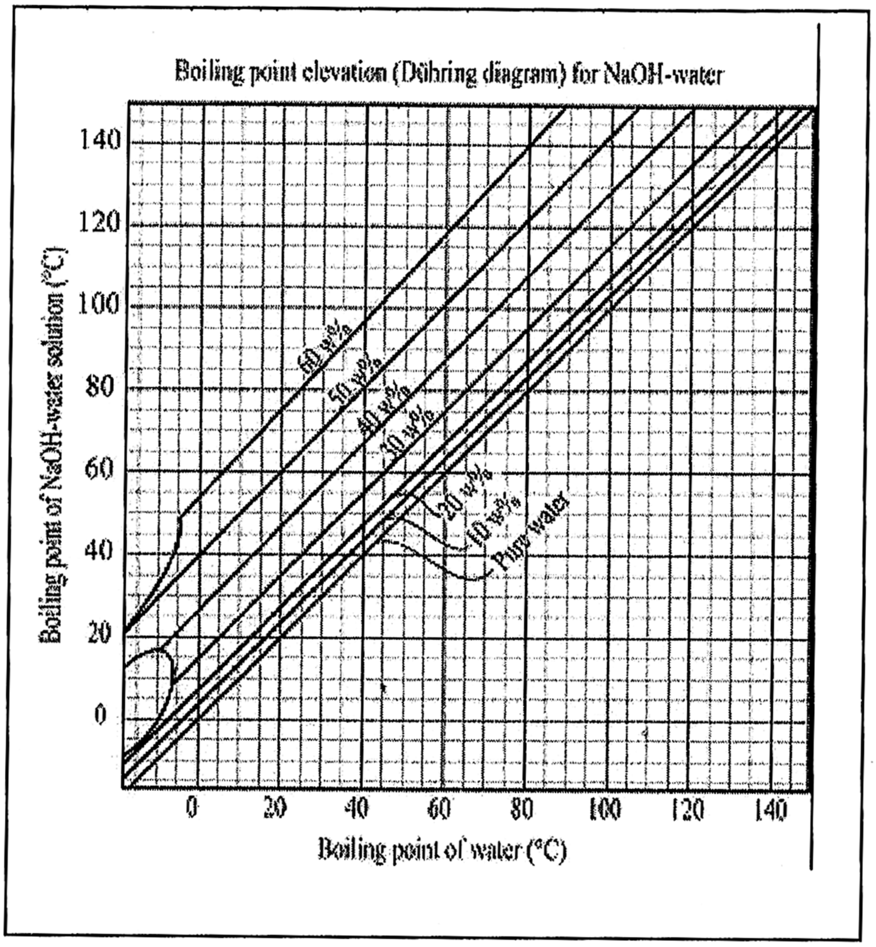
The density (ρ_l), thermal conductivity (k_l), viscosity (μ_l) of water at the film temperature may be taken to be 980 kg.m^{-3}, 0.65 Wm^{-1} °C^{-1} and 0.45x0^{-3} Pa s^{-1} respectively. The density (ρ_v) of saturated steam, latent heat of vaporization (γ) and saturation temperature at 2 atm (gauge) is 0.596 kg.m^{-3}, 2257 kJ kg^{-1} and 135 °C respectively.

Enthalpy of 20 wt% NaOH solution, 50 wt% NaOH solution and vapor at 150 mm Hg is 128 kJ.kg^{-1}, 540 kJ.kg^{-1}, and 2344.6 kJ.kg^{-1} respectively.

The average heat transfer coefficient for laminar condensation may be calculated from the following equation

$$\bar{h} = 1.13\left(\frac{\rho_l(\rho_l - \rho_v).k_l.g.\gamma}{\mu_l L(t_{sat} - t_w)}\right)^{0.25}$$

[Turn over


Boiling point elevation (Dühring diagram) for NaOH-water
Boiling point of NaOH-water solution (°C)
Boiling point of water (°C)
60 w%
50 w%
40 w%
30 w%
20 w%
10 w%
Pure water
0
20
40
60
80
100
120
140

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B.E. CHEMICAL ENGINEERING THIRD YEAR FIRST SEMESTER - 2025
PROCESS HEAT TRANSFER
PART-II
Marks: 50

Use separate answer scripts
Answer all questions

B.E. CHEMICAL ENGINEERING THIRD YEAR FIRST SEMESTER EXAM 2025
Subject: PROCESS HEAT TRANSFER

Year: **Semester:**
Exam Roll No.:

Signature of Invigilator:

Date:

	CO-1	CO-2	CO-3	CO-4	CO-5	CO-6	Total
Marks Allotte							
Marks Obtained							

Signature of Examiner:

Q. No	CO No.	Questions	Marks
1.	CO1	1(a). What would be your recommendations if the value of critical insulation radius is greater than the outer radius of the steam pipe and the insulation of a steam pipe is wetted? 1(b). Show the electrical analogy to heat flow. 1(c). What is the difference between Biot (Bi) number and Nusselt (Nu) number? 1(d). What do you mean by a lumped heat capacity system? 1(e). What is a Heisler Chart? 1(f). What do you mean by temperature cross? 1(g). Why is a temperature correction factor required in the case of heat exchanger design? 1(h). What are the empirical equations generally used for the determination of convective heat transfer coefficients for tube and shell-side fluids in laminar and turbulent flows? 1(i). Define the steam economy of an evaporator and why backward feed operation is used in a triple effect evaporator when the product is highly viscous. 1(j). Write the Wein's diplacement law and show that the wavelength is inversely proportional to the temperature.	1×10 =10
2.	CO2	2(a). Derive an expression for critical insulation radius on a hollow cylinder in terms of thermal conductivity of the insulating material and convective heat transfer co-efficient outside the insulation. 2(b). Steam at 230°C is flowing through a wrought-iron (k=69 W/m K) tube of ID=5 cm and OD=8 cm which is covered with 1 cm thick asbestos (k=0.2216 W/m K) insulation. If the convection heat transfer co-efficients at the inner and outer surfaces of the tube are 200 W/m^2 K and 10 W/m^2 K, respectively, and the atmospheric air is at 36°C, estimate the rate of heat losses from steam per meter length of the tube. Assume that the steam in the tube is held at a constant temperature.	5+5 =10 *P.T.O.*

3.	CO3	3(a).What do you mean by fin? 3(b).A plane wall is fitted with a copper (k= 420 W/m-K) pin fin of 1 cm diameter and 50 cm length. The fin base temperature is 350°C and the pin fin is in contact with air at 25°C. The convection heat transfer co-efficient between the fin surface and air is 25 W/m^2-K. Assuming that the fin is infinitely long, calculate the temperature at 10 cm, from the base. 3(c). Write the 11 step-wise description of the design procedure of the shell-and-tube heat exchanger.	1+4+5 =10
4.	CO4	4(a).Draw the temperature profiles for the 2-4 and 4-8 heat exchangers and explain which one is more efficient. 4(b).Two liquids are flowing in a double-pipe heat exchanger, both at the rate of 1880 kg/hr. The inner pipe of the heat exchanger has an inner diameter of 4.6 cm and a wall thickness of 0.336 cm. The inner pipe is made up of copper having thermal conductivity, k = 539 Watt/m.K. The outer pipe of the heat exchanger has an internal diameter of 6.0 cm. For simplicity, assume that both liquids have physical properties comparable with those of water. The liquid in the inner tube is being cooled from 70°C to 55°C at the expense of the liquid flowing in the outer tube, which is entering at 20°C. Calculate the length of the heat exchanger required if the liquids are flowing in a counter-current manner. Physical properties of water: Viscosity at 62.5°C = 0.425 cp Viscosity at 27.5°C = 0.840 cp Thermal conductivity at 62.5°C = 0.57 kcal/h.m^2.°C/m Thermal conductivity at 27.5°C = 0.528 kcal/h.m^2.°C/m	2+8 = 10
5.	CO5	5(a).Briefly explain the backward feed operation of the evaporator. 5(b).Discuss the different types of radiation intensity. 5(c).Briefly explain the exchange of energy between any source and any receiver.	3+3+4 =10