Marks – 20 **Fluid Flow Laboratory Exam** **Time – 60 mins**

Part A

Answer any five from the following. [5x2]

1. For which one coefficient of discharge is smaller, venturi or orifice meter? And why?
2. What is the value of coefficient of discharge for venturi meter? Why is the pressure drop inside the and rotameter constant?
3. Draw and explain the velocity profile of packed bed and fluidized bed.
4. How pitot tube is working? Draw and explain the velocity profile inside the pitot tube.
5. What is the importance of triangular notch weirs experiment? If the coefficient of discharge value will change with discharge rate in a triangular notch weirs?
6. What is coefficient of velocity and coefficient of discharge in Hook's Gauge experiment? How are they differing from each other?
7. What are the different types of pipe fitting you studied and among them which one showed maximum and minimum pressure drop?
8. What are the different types of liquid there in viscosity meter experiment? Which pipe having more diameter than other and why?

Part B

Answer any three from the following. [3x3.33]

1. Find out the coefficient of discharge of a venturi meter if the throat diameter is 1 inch and pipe diameter is 2.067 inch. The LHS and RHS manometer reading is 15.8 cm and 14.2 cm. 6.4 litters of water was collected after 30 sec. Density of mercury is 1.6 gm/cc.

2. Find out the viscosity of water at 35 ^{O}C. Following data are available

Water collected (ml)	Time (Sec)	LHS (cm)	RHS (cm)	Pipe dia (cm)	Pipe length (cm)
350	15	7.4	9.2	1.3	186

3. Find out the coefficient of discharge of a triangular notch with a 50-degree angle. Following data are available

Water collected (ml)	Time (Sec)	H (cm)
6600	15	16.1

4. Find out the equivalent length of a T-joint having a water flow rate of 268 cm^3/s with an internal diameter of 2.54 cm. Viscosity of water is 1 cp and density of mercury and water are 1.6 gm/cc and 1 gm/cc respectively.

5. Calculate the pressure drop over unit length in a packed bed reactor of water with flow rate of 2.5 LPM. Following data are collected.

Flow rate (gm/cc)	Height diff. across orifice		Packed bed heigh difference	
	LHS (cm)	RHS (cm)	LHS (cm)	RHS (cm)
78	13.9	9.9	9.4	7.5

Viscosity of water is 0.89 cp, diameter of the packed material = 1.58 x 10^{-3}, void fraction = 0.67.

6. Find out the pitot tube coefficient of water having a flow rate of 28 LPM. In the pitot tube, mercury (density 1.6 gm/cc) in u-tube and water in pipe (3.81 cm dia). Experimental reading are as follows

Pitot tube reading (cm)	Manometer reading (cm)	Local Velocity (m/s)	U-Tube reading, y (cm)
36	1.9	0.592	1.9
30	2.4	0.665	2.4
20	2.6	0.692	2.6
15	1.7	0.560	1.7

INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR

End-Spring Semester Examination 2022-23

Date of Examination: ______ **Session: (FN/AN)** ______ **Duration: 3 hrs.** **Full Marks:** 50

Subject No.: CH21206 **Subject:** REACTION ENGINEERING

Department/Center/School: CHEMICAL ENGINEERING

Specific charts, graph paper, log book etc., required

Special Instructions (if any): ______

PART-A

Q1. **[4+4 = 8 marks]**

For the reaction system $A \rightarrow B \rightarrow C$, in a continuous reactor where each reaction is irreversible, liquid phase and possessing first order kinetics, determine,

(a) τ_{max} and Y_{Bmax} in a PFR

(b) τ_{max} and Y_{Bmax} in a CSTR

for the case when yield of B is the maximum by showing proper derivation.

Q2. **[6+6 = 12 marks]**

The elementary irreversible gas-phase reaction

$$A \rightarrow B + C$$

is carried out adiabatically in a PFR packed with a catalyst. Pure A enters the reactor at a volumetric flow rate of 20 dm^3/s at a pressure of 10 atm. pressure and a temperature of 450 K. Assume that $\Delta P = 0.0$

(a) Formulate the conversion and temperature profile down the plug-flow reactor from the starting and find the corresponding equations to be solved. Also write the initial condition.

(b) What catalyst weight is necessary to achieve 80% conversion in a CSTR?

Additional information:

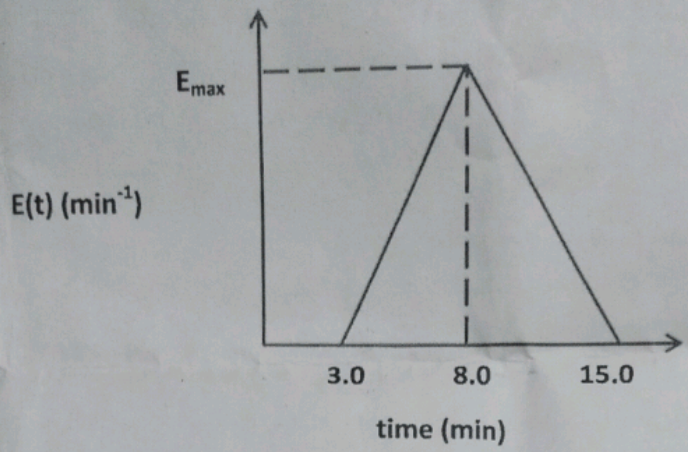
$C_{PA} = 40$ J/mol.K $\quad$ $C_{PB} = 25$ J/mol.K $\quad$ $C_{PC} = 15$ J/mol.K

$H^0_A = -70$ kJ/mol $\quad$ $H^0_B = -50$ kJ/mol $\quad$ $H^0_C = -40$ kJ/mol

All heats of formation are referenced to 273 K.

$k = 0.133 \exp[\frac{E}{R}(\frac{1}{450} - \frac{1}{T})] \frac{dm3}{kg.cat.s}$ $with\ E = 31.4\ kJ/mol$

Q3. [2 + 3 = 5 marks]



The residence time distribution for a real reactor is shown in the above diagram.

(a) What is the value of E_{max}?

(b) What is the value of mean residence time (t_m) in min?

PART-B

Q4. [1 marks]

How can you express mass transfer co-efficient in terms of concentration difference and mole flux for a solid catalytic gas phase reaction?

Q5. [4 marks]

For solid catalytic gas phase reaction, how the rate of the reaction is dependent on the gas phase velocity and catalyst particle size? Explain with logic by proper figure showing control regimes.

Q6. [1 + 4 = 5 marks]

Define "Effective Diffusivity". Write the expression of it explaining all the terms in that.

Q7. [2 marks]

How effectiveness factor is related to Thiele modulus for various shapes of the catalyst?

Q8. [3 marks]

Make a flow diagram for determination of Effectiveness factor starting from the bulk density of the reactant gas.

Q9. [5 marks]

Why Thiele Modulus for a reversible reaction is more than an irreversible reaction?

Q10. [5 marks]

For a solid fluid non catalytic reaction, what are the reaction models you can predict? Explain them with their practicability.

INDIAN INSTITUTE OF TECHNOLOGY, KHARAGPUR

End-Spring Semester Examination, 2022-2023

Subject : Mass Transfer - I *Subject No.*: CH21202/CH31001

Date: 21.04.2023 (AN) *Time*: 3 Hrs *Full Marks*: 50

Specific charts, graph paper, log book etc., required: Normal graph paper ($\geq$3 nos. per candidate)

Instructions : (1) Use relevant equations and diagrams, wherever necessary.
(2) Any missing data may be assumed suitably giving proper justification.
(3) Answer all parts of a question at one place only.

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1. (a) What are 'Dumping' and 'Priming' of a Sieve Tray Tower?
(b) When is split flow tray preferred over cross flow tray?
(c) A tray tower is to be designed to absorb CO_2 from a flue gas stream by scrubbing into an aqueous amine solution at 25°C. Approximately, 180 m^3/h (at 25°C and 1 atm) of gas is to be processed and the CO_2 content of the gas is to be reduced from 15 mol% to 2 mol%. The scrubbing liquid, which is recycled from a stripper, will contain 0.058 mol CO_2/mol solution. Determine (i) the minimum liquid rate, kmol/h and (ii) the number of real trays required for a liquid rate 1.2 times the minimum. Assume an overall tray efficiency of 53%.

Equilibrium Data:

Mole CO_2/mole amine solution	0.058	0.060	0.062	0.064	0.066	0.068
p_{CO2} (mm Hg)	5.6	12.8	29.0	56.0	98.7	155.0

[2+1+(4+3)]

2. (a) For dilute mixtures and cases where Henry's law applies, prove that the number of overall gas phase transfer units for co-current gas absorption in packed towers is given by

$$N_{tOG} = \frac{A}{A+1} \ln\left[\frac{y_1 - mx_1}{y_2 - mx_2}\right]$$

where the notations have their usual meanings.

(b) Ammonia is to be removed from an ammonia-air mixture by water scrubbing in a 0.30 m diameter tower packed with 25 mm Berl saddles. The gas mixture is available at the rate of 150 m^3/h (at 25°C and 1 atm) with 6% ammonia by volume. Calculate the depth of the packing required for a final ammonia content of 0.05% by volume. At 25°C, ammonia-water solutions follow Henry's law up to 6 mole% ammonia in liquid and m = 1.4. The water rate is 250 kg/h and K_{Ga} is given as 265 kmol/m^3 h atm.

OR

(a) What are the factors that influence N_{tOL} and H_{tOL} of a packed desorption tower?

(b) A relatively nonvolatile hydrocarbon oil containing 3.5 mol% benzene is being stripped at a rate of 160 kmol/h by direct superheated steam in a packed tower to reduce the benzene content to 0.1%. The gas-liquid equilibrium may be represented by $y^* = 22.5\,x$, where y^* is the mole fraction of benzene in the steam and x is the mole fraction of benzene in the oil. Steam can be considered as inert gas and will not condense. Determine the height of the packing if the diameter of the tower is 1.5 m. The steam rate is 270 kg/h and $K_x a$ is 150 kmol/m^3 h (Δx^*).

[4+6]

3. (a) How is butadiene separated from C_4-stream of naphtha cracker?

(b) Why are the heat-sensitive high-boiling materials not degraded during purification by steam distillation?

7 (c) A liquid mixture containing 50 mol% ethanol (A) and 50 mol% n-propanol (B) is subjected to differential distillation at atmospheric pressure with 50 mol% of the liquid distilled. What will be the compositions of the composited distillate and the residue? The vapour pressures of A and B at 80°C are given as 787 mm Hg and 364 mm Hg, respectively.

OR

(c) A liquid mixture containing 50 mol% ethanol (A) and 50 mol% n-propanol (B), at 80°C, is to be continuously flash vaporized at atmospheric pressure to vaporize 50 mol % of the feed. What will be the composition of the vapour and liquid if the vaporizer is an ideal one? The vapour pressures of A and B at 80°C are 787 mm Hg and 364 mm Hg, respectively.

[3+2+5]

4. (a) How does the cost of a distillation column vary with reflux ratio?

(b) A mixture of diethylamine (DEA) and triethylamine (TEA) containing 50 mol% of DEA is to be continuously fractionated at a rate of 8700 kg/h and at a total pressure of 113.3 kPa. The top product should have 98% more volatile component and the bottom product 2%. The feed will be 50 mol% vaporized before it enters the tower. A total condenser will be used and the reflux will be returned at the bubble point. Determine (i) the product rates, kg/h; (ii) the minimum reflux ratio; (iii) the number of theoretical trays required at a reflux ratio 1.5 times the minimum and (iv) the location of the feed tray.

4 The equilibrium data for the system are given below:

x	0.02	0.104	0.227	0.34	0.428	0.52	0.65	0.79	0.90	0.95
y	0.052	0.231	0.45	0.6	0.694	0.765	0.845	0.915	0.963	0.982

[2+ (2+2+3+1)]

5. (a) Draw model operating line and equilibrium line diagrams on X-Y plane for (i) co-current absorption and (ii) counter-current stripping processes.

(b) Derive the relationship between the nucleation rate, growth rate and the population density function of vanishingly small size.

(c) The crystal growth rate in an MSMPR crystallizer under a given set of condition is 5×10^{-8} m/s. The holdup of the suspension is 10 m^3 and the suspension withdrawal rate is 4 m^3/h. The zero-size population density is 5×10^{10}/cm. liter. Calculate the total number of crystals, and mass of the crystal in the size range of 0.5 mm to 1 mm per unit volume of the product. Volume shape factor and the density of the crystals can be taken as 0.6 and 2700 kg/ m^3.

3.

[2+2+6]

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Class Test 1

Time: 40 minutes

Date: 08/02/2023

Full Marks: 20

1. A 3 cm diameter sphere containing hot liquid at 180^{0}C is to be insulated to reduce the heat loss to the ambient (h=2W/m^{2}C) at 30^{0}C. If fiberglass [k=0.04 W/m(^{0}C)] is selected as the insulating material, compare the heat losses when the sphere is covered with the critical radius of insulation and when the sphere does not have an insulation. Please provide the derivation for critical radius of insulation for a sphere. **(10)**

2. Heat is generated uniformly at a rate of 500 MW/m^3 in a SS plate (k =20 W/m.°C) of thickness 1 cm. Derive an expression for the temperature profile in the plate when the two sides of the plate are maintained at 100 °C and 200 °C. Also estimate the temperature at the center of the plate. Mention all assumptions. **(10)**

The generalized heat conduction equation in Cartesian, cylindrical and spherical coordinates

$$\frac{\partial^2 T}{\partial x^2}+\frac{\partial^2 T}{\partial y^2}+\frac{\partial^2 T}{\partial z^2}+\frac{\dot{q}}{k}=\frac{1}{\alpha}\frac{\partial T}{\partial t}$$

$$\frac{\partial^2 T}{\partial r^2}+\frac{1}{r}\frac{\partial T}{\partial r}+\frac{1}{r^2}\frac{\partial^2 T}{\partial \phi^2}+\frac{\partial^2 T}{\partial z^2}+\frac{\dot{q}}{k}=\frac{1}{\alpha}\frac{\partial T}{\partial t}$$

$$\frac{1}{r^2}\frac{\partial^2 (rT)}{\partial r^2}+\frac{1}{r^2\sin\theta}\frac{\partial}{\partial \theta}\left(\sin\theta\frac{\partial T}{\partial \theta}\right)+\frac{1}{r^2\sin^2\theta}\frac{\partial^2 T}{\partial \phi^2}+\frac{\dot{q}}{k}=\frac{1}{\alpha}\frac{\partial T}{\partial t}$$

NC221-30

INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR

Mid-Autumn Semester Examination 2022-23

Date of Examination: ________ Session: (FN/AN) ______ Duration: 2 hrs. Full Marks: 30

Subject No.: CH21206 Subject: Reaction Engineering

Department/Center/School: Chemical Engineering

Specific charts, graph paper, log book etc., required No

Special Instructions (if any): Answer the questions writing in which Part those belong

PART-A

[2+2+2+3 = 9]

Q1.
The reversible isomerization $m - Xylene \rightleftharpoons$ para – Xylene follows elementary rate law kinetics. If Xe is the equilibrium conversion,

(a) Show for a batch and a PFR: $t = \tau = \frac{Xe}{k} ln \frac{Xe}{Xe-X}$

(b) Show for a CSTR: $\tau = \frac{Xe}{k}\left(\frac{Xe}{Xe-X}\right)$

(c) Determine the volume efficiency, defined as $\frac{VPFR}{VCSTR}$, for $X/Xe = 0.5$

(d) For the same $X/Xe = 0.5$, what would be the volume efficiency for two CSTRs in series with the sum of the two CSTR volumes being the same as the PFR volume?

[6]

Q2.
The liquid-phase reaction A → B was carried out in a CSTR. For an entering concentration of 2 mol/dm^3, the conversion was 40%. For the same reactor volume and entering conditions as the CSTR, the expected PFR conversion is 48.6%. However, the PFR conversion was, amazingly, 50% exactly. Brainstorm reasons for the disparity. Quantitatively show how these conversions came about (i.e., the expected conversion and the actual conversion).

PART B

Q3. a) Write different steps associated with a gas phase solid catalytic reaction to form product.

The reaction is: A → B. [3.5]

b) What do you mean by active sites in a solid catalyst? How do you express its concentration? [1+1=2]

c) From the following rate equation, state the reaction, adsorption mechanism and reaction kinetics with logic. [1+2+2=5]

$$-r'_N = \frac{kP_N}{(1 + K_1P_N + K_2P_C)^2}$$

d) Derive this rate law, considering a suitable rate limiting step consistent with the given rate expression as in the question c). Keep all notations same and name the notations.

[4.5]

INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR

Mid-Spring Semester 2022-23 (closed book)

Course No.: CH21208 | **Max. Time**: 2 hrs

Course Title: Instrumentation and Process Control | **Total Marks**: 30

Answer all questions

Q1. Consider an isothermal stirred-tank blending system shown in Figure 1. Here, V denotes the liquid volume. The mass fraction of component A in the two inlet streams are x_1 and x_2, and that in the exit stream is x. The respective mass flow rates are F_1, F_2 and F.

(a) Stating suitable assumptions, develop the dynamic model.

(b) Supposing constant V, F_1, F_2 and F, develop the transfer function model in terms of gain K_p and time constant τ_p:

(i) When x_1 varies and x_2 remains constant,

(ii) When both x_1 and x_2 vary. **[2+(2+2)+(3+2)=11]**

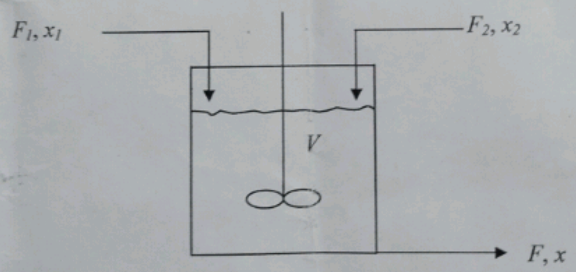


Fig. 1: A stirred-tank blending system.

(c) Consider a constant liquid holdup of 2 m^3 maintained to blend the said two streams whose densities are both approximately 900 kg/m^3. The density does not change during mixing.

(i) Assume that the process has been operating for a long period of time with flow rates of $F_1 = 500$ kg/min and $F_2 = 200$ kg/min, and the feed compositions (mass fractions) of $x_1 = 0.4$ and $x_2 = 0.75$. What is the steady state value of x?

(ii) Suppose that F_1 changes suddenly from 500 to 400 kg/min and remains at the new value. Determine an expression for $x(t)$.

Q2. (a) Why do we need to develop the mathematical model of a process we want to control?

(b) Derive the standard expression of decay ratio for an underdamped response.

(c) With an example of first-order system, show how the time constant is correlated with storage capacitance and resistance to heat flow. **[2+3+3+3+8=19]**

(d) How the system responds when the real part of its complex poles is zero? Mathematically prove it.

(e) Two noninteracting liquid tanks having the following transfer functions are connected in series (see Figure 2):

$$G_1(s) = \frac{K_1}{\tau_1 s + 1} \text{ (for Tank 1)} \qquad G_2(s) = \frac{K_2}{\tau_2 s + 1} \text{ (for Tank 2)}$$

Consider $K_1 = K_2 = 1$ and $\tau_1 = \tau_2 = 1$.

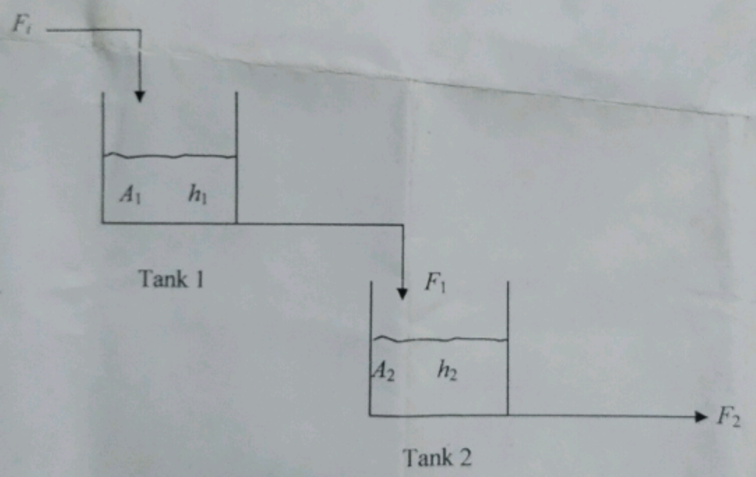


Fig. 2: Two noninteracting tanks in series.

Obtain an expression for the response of $h_2'(t)$ (the level in the second tank as a deviation from its initial steady state value) to a unit step change in the inlet flow rate to Tank 1.

.....**END**.....

Class Test 2

Time: 45 minutes

Date: 21/03/2023 at 5 p.m.

Full Marks: 25

1. Evaluate the effectiveness of a fin (k=500 W/m K) of 5 mm diameter and 250 mm length. The fin can be assumed to adiabatic at the end and the heat-transfer coefficient is 250W/m^2K. (5)

2. Oil with flow rate of 1000 kg/hr. and temperature of 80°C is to be cooled to 50°C. A double pipe heat exchanger is used where cooling water enters the tube at 30°C and exits at 45°C. Assuming the overall heat transfer coefficient to be 0.2kW/m^2(K) and specific heat of oil and water as 2kJ/kg (K) and 4.2kJ/kg (K) respectively, estimate the percentage saving in the heat transfer area for counter w.r.t co current flow of the two liquids. (10)

3. An aluminum rod 5.0 cm in diameter and 15 cm long protrudes from the wall that is maintained at 250°C. The rod is exposed to an environment at 25°C. The convection heat-transfer coefficient is 12 W/m^2 (°C). Calculate (i) the heat lost by the rod (ii) the temperature profile in the rod. (5+5)

Assignment No. 1

A process vessel is to be designed for the maximum operating pressure of 800 kPa. The vessel has a nominal diameter (O.D.) of 1.5 m. It is made of IS: 2002-1962 grade 2B quality steel having allowable design stress of 120 MPa, at working temperature. Use weld joint efficiency of 0.85.

(i) Find the standard thickness of plate to fabricate this vessel.

(ii) Find out thickness of flat head (head is flanged and butt welded to shell).

(iii) Find out thickness of a conical head having half apex angle of 45^0.

(iv) Find out thickness of the plate required to fabricate a torispherical head for this vessel. It is assumed that there is no uncompensated opening in the head. Specifications of the head are as follows: $R_i = D_0$; $r_i = 0.05\ D_0$; $S_f = 30$ mm.

(v) Find out thickness of a standard 2:1 ellipsoidal head.

(vi) Find out thickness of hemispherical head.

Determine which head thickness is minimum.

0.75

INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR

Mid-Spring Semester Examination 2022-23

Date of Examination: ________________ **Session: (FN/AN)** ______ **Duration: 2 hrs.** **Full Marks: 30**

Subject No.: CH21202 and CH31001 **Subject: Mass Transfer 1**

Department/Center/School: Chemical Engineering

Specific charts, graph paper, log book etc., required : No

Special Instructions (if any): (1) Answer ALL Questions. (2)No queries will be entertained during the exam.
(3)Any missing data may be assumed suitably giving proper justification.
(4) Use relevant equations and diagrams, wherever necessary

1. Decomposition of N_2O_4 to NO_2 is being carried out on catalyst surface according to the following reaction
$N_2O_4 \rightarrow 2NO_2$

At one place in the apparatus, pressure is 1 atm and temperature is 200°C. The analysis of bulk gas is 33.33% N_2O_4 and rest is NO_2 by volume. The circumstances such that N_2O_4 diffuse on the catalyst surface and products after the reaction diffuses back though a 1mm thick gas film. Estimate the local rate of cracking (Moles of N_2O_4 / surface area of catalyst.s) which might be considered to occur if the reaction is diffusion-controlled (chemical reaction rate is very rapid) with the concentration of N_2O_4 at the catalyst surface equal to zero. **[6 marks]**

Diffusivity of gases can be estimated using Wilke-Lee equation:

$$D_{AM} = \frac{\left(1.084-0.249*\sqrt{1/M_A+1/M_B}\right)T^{1.5}\sqrt{1/M_A+1/M_B}}{P(\gamma_{AB})^2 f\left(\frac{kT}{\varepsilon_{AB}}\right)}$$

Where M_A and M_B are molecular weights of A and B, respectively.

P – Pressure in Pa and T – Temperature in K

Gas	γ in nm	$\frac{\varepsilon_A}{k}$ (K)
N_2O_4	0.3798	71.4
NO_2	0.2827	59.7

2. Two large vessels are connected by a tapered tube of length L. The end radii of the tubes are r1 and r2. The vessels contain mixtures of gases A and B at the same total pressure and Temperature. Derive the rate of diffusion expression through the tube at steady state if the partial pressure of A in one vessel is higher than other vessel. Assume that the compositions of gases in two vessels are fairly constant in spite of the diffusional transport occurring through the connecting tube. **[3marks]**

3. (a) The molar flux from a 5 cm diameter naphthalene ball placed in stagnant air at 40°C and atmospheric pressure, is $1.47 \times 10^{-3}\ mol/m^2 \cdot s$. Assume the vapor pressure of naphthalene to be 0.15 atm at 40 °C and negligible bulk concentration of naphthalene in air. Find the value of diffusivity and mass transfer coefficient based on concentration driving force. Derive the necessary relation between diffusivity and molar flux.
(b) If air starts blowing across the surface of naphthalene ball at 3 m/s by what factor will the mass transfer rate increase, all other conditions remaining the same? For mass transfer from a single sphere into gas streams: $Sh = 2 + 0.552\ Re^{0.5}\ Sc^{0.33}$ The viscosity and density of air are $1.8 \times 10^{-5}\ kg/m{\cdot}s$ and 1.123 kg/m^3, respectively. **[8 marks]**

4. Consider the interphase mass-transfer process for the chlorine dioxide, ClO_2-air-water system. ClO_2 gas (solute A) is sparingly soluble in water. The equilibrium relationship can be described by Henry's law ($P_A^* = H\ C_A^*$)

where Henry's law constant (H) for the dilute solution of ClO_2 in water is 7.7×10^{-4}atm/(mol/m3). At the current conditions of operation, the mole fraction of ClO_2 in the bulk gas phase is $y_A = 0.040$ and the mole fraction of ClO_2 in the bulk liquid phase is $x_A = 0.00040$. The mass density of the liquid phase is 992.3 kg/m³ and is not dependent on the very small amount of ClO_2 dissolved in it. The total system pressure is 1.5 atm. **[8 marks]**

(a) Is the process gas absorption or liquid stripping?

(b) If the ClO_2 partial pressure in the bulk gas phase is maintained at 0.06 atm, what is the maximum possible dissolved ClO_2 concentration, mol/m3, in the liquid?

(c) If $k_x = 1.0$ mol/(m²·s) and k_G= 0.010 mol/(m²·s·atm), what is K_y, the overall mass-transfer coefficient based upon the overall gas phase driving force?

(d) Calculate overall mass transfer resistance based upon the overall gas phase driving force and contribution of the liquid phase and gas phase resistance to the overall mass transfer resistance.

(e) Based upon the bulk gas and liquid phase compositions, what is the mass transfer flux for ClO_2 in unit mol/(m ²·s)?

5. Answer the following questions: **[5x1 mark]**

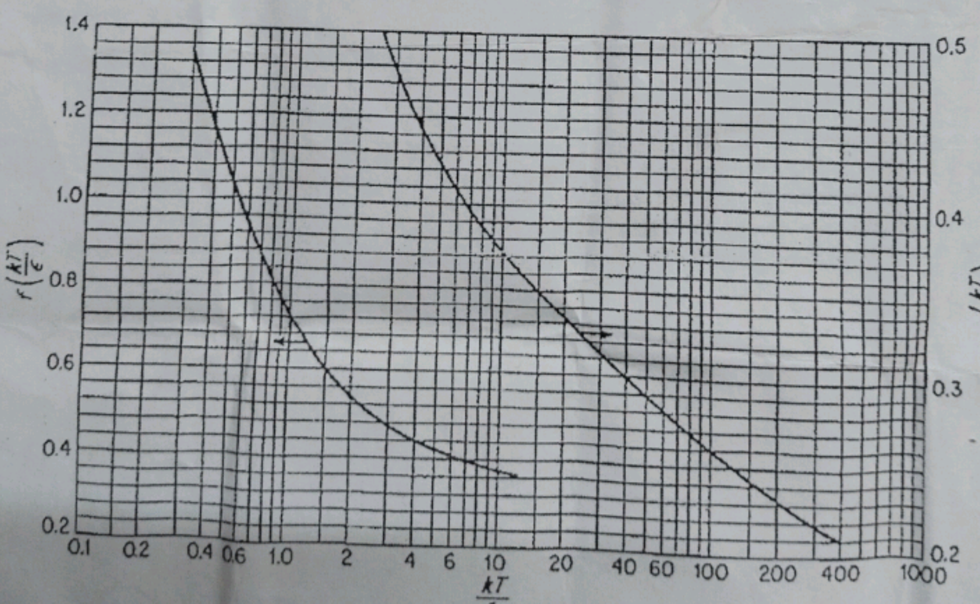
(i) If a Stefan tube experiment is carried out at few degrees lower than the boiling point temperature of the liquid, can the pseudo-steady state approximation is valid in this case? Why?

(ii) A 10 cm diameter bubble of pure gas A rises through a quiescent liquid at a steady velocity of 25 cm/s and the average mass transfer coefficient found to be 0.013 cm/s. What would be the mass transfer coefficient if bubble of 5cm diameter rises through the liquid at a velocity of 10 cm/s?

(iii) Under what conditions, Knudsen and surface diffusion is prevalent?

(iv) Write the analogous equations for heat, mass and momentum transport

(v) State the drawbacks of penetration theory.



INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR

Mid-Spring Semester Examination 2022-23

Date of Examination: 22/02/2023. _ Session: (FN/AN) AN. Duration: 2 hrs. Full Marks: 30

Subject No.: CH21204 Subject: Heat Transfer

Department/~~Center/School~~: Chemical Engineering

Specific charts, graph paper, log book etc., required: NIL

Special Instructions (if any):

All questions are compulsory

Assume any missing data, if necessary, with proper justification.

Answer all questions in a part together

Please mention the part number you are answering

Also answer all parts of a question together.

Part 1

1. Assume a fluid is flowing over an isothermally flat plate. If the free-stream velocity of the fluid is doubled (flow is still laminar), then estimate the change in the drag force on the plate and the rate of heat transfer between the fluid and the plate.

(3+3 = 6)

2. Air at 20 °C is flowing at 15 m/s over an isothermally heated plate (0.5 m length X 0.5 m width, $k = 0.0292$ W/m K), maintained at 110 °C. What are the average heat transfer coefficient and the total amount of transferred heat? What are h, δ_t, and δ at the trailing edge? Consider, $Pr = 0.7$, and $\nu = 0.0000195$ m^2/s of air at 65 °C.

(5)

3. In case of laminar flow over an isothermal flat plate, the local Nusselt number (Nu) for the entire range of Prandtl number (Pr) is given by:

$$\mathrm{Nu}_x = \frac{0.339\,\mathrm{Re}_x^{1/2}\,\mathrm{Pr}^{1/3}}{\left[1 + (0.0468/\mathrm{Pr})^{2/3}\right]^{1/4}}$$

Derive the expression for the average Nu for a laminar boundary layer over that plate for the identical condition.

(4)

Part 2

4. Heat flow @ 2 kW through a rectangular slab of 2.5 cm thickness and 0.2 m^2 cross-sectional area (normal to direction of heat flow) maintains a temperature of 100^0C at one side of the slab while the temperature at the other side is 30^0C. The temperature at the mid plane of the slab is 66^0C.
   (a) Obtain an expression for the thermal conductivity of the material assuming the thermal conductivity to vary linearly with temperature.
   (b) Mention the assumptions for the analysis.
   (c) Comment (rough sketch may be used) on the steady state temperature profile in the slab and compare the profile with the profile for constant thermal conductivity.
   (3+2+2)

5. A stainless steel [18% Cr, 8% Ni, k =20 W/m °C] sphere of diameter 4 cm is exposed to convection environment at 30^0C, h= 15W/m^2C. Heat is generated uniformly in the sphere at a rate of 1.0 MW/m^3. Calculate the steady state temperature at the centre of the sphere. **(3)**

6. Water flows through a stainless steel [18% Cr, 8% Ni, k =20 W/m.°C] tube of 25 mm ID and 2 mm wall thickness. The convection coefficient on the inside of the tube is 100W/m^2 (^{0}C) and on the outside is 12 W/m^2 (^{0}C). Estimate the overall heat transfer coefficient and comment on the main determining factor for U. Discuss the temperature profile in the tube.
   (3+2)

Given: The generalized heat conduction equation in cylindrical and spherical coordinates for constant thermal conductivity are -

$$\frac{\partial^2 T}{\partial r^2}+\frac{1}{r}\frac{\partial T}{\partial r}+\frac{1}{r^2}\frac{\partial^2 T}{\partial \phi^2}+\frac{\partial^2 T}{\partial z^2}+\frac{\dot{q}}{k}=\frac{1}{\alpha}\frac{\partial T}{\partial t}$$

$$\frac{1}{r^2}\frac{\partial^2 (rT)}{\partial r^2}+\frac{1}{r^2 \sin\theta}\frac{\partial}{\partial \theta}\left(\sin\theta\frac{\partial T}{\partial \theta}\right)+\frac{1}{r^2\sin^2\theta}\frac{\partial^2 T}{\partial \phi^2}+\frac{\dot{q}}{k}=\frac{1}{\alpha}\frac{\partial T}{\partial t}$$

INDIAN INSTITUTE OF TECHNOLOGY KHARAGPUR

End-Spring Semester 2022-23 (closed book)

Course No.: CH21208 — **Max. Time**: 3 hrs

Course Title: Instrumentation and Process Control — **Total Marks**: 50

Answer all questions

Q1. (a) What is derivative kick? Is there any way to overcome this problem in the feedback controller?

[2+2+2+(2+2+2)=12]

(b) Find the amplitude ratio (AR) and phase angle (ϕ) for the PID controller.

(c) What are the major limitations of Ziegler-Nichols tuning method?

(d) Consider a closed-loop process shown in Fig. 1, in which a PID controller is used to control the system.

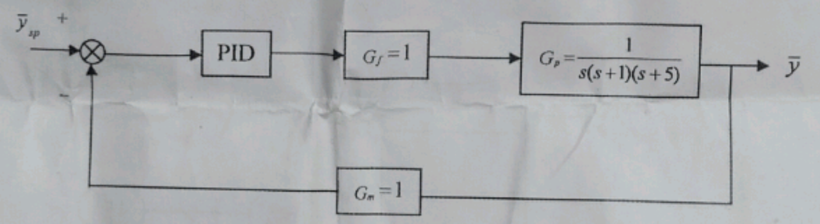


Fig. 1. A closed-loop process with PID controller.

(i) Find the ultimate gain (K_u) and ultimate period (P_u).

(ii) Use the Tyreus – Luyben recommended settings and tune the PID controller.

(iii) Find the pole(s) and zero(s) of the PID controller.

Q2 (a) Show for the following system that the AR of $G_{OL}(s)$ equals unity at cross over frequency provides oscillations in output (y) with constant amplitude:

[3+3+1+3=10]

$G_p(s) = \dfrac{e^{-0.123s}}{0.1s+1}$ $\qquad G_c = K_c \qquad G_f = G_m = 1$

(b) Investigate the stability of a closed-loop system whose characteristic equation has the following form:

$$8s^3 + 6s + 3 = 0$$

(c) What is the basic difference between the cascade and the feedforward-feedback combined control scheme in terms of their application?

(d) The transfer functions of a process with respect to manipulated variable and disturbance are given, respectively, as:

$$G_P = \frac{K_P}{(\tau_1 s+1)(\tau_2 s+1)} \qquad G_d = \frac{K_d}{(\tau_3 s+1)}$$

Design the feedforward controller that is physically realizable.

Q3. (a) Consider a liquid tank system shown in Fig. 2. The liquid level should be maintained above height h_2 to avoid cavitation at the pump.

(i) Develop the override control scheme.

(ii) Mention the action (direct/reverse) of the controllers. **[(2+2+2)+2 = 8]**

(iii) Explain how the override controller works when the level is at h_1.

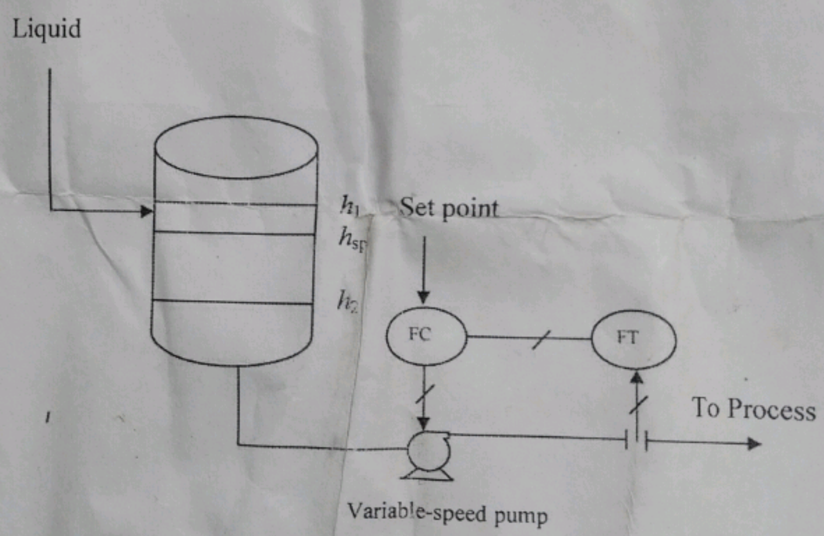


Fig. 2. The liquid tank under flow control.

(b) Discuss a suitable control scheme used to keep the ratio of fuel/air fed to a combustion chamber at its optimum value.

Q4 (a) What is the difference between a variable conversion element and variable manipulation element? Give examples. **[1.5]**

(b) What is the difference between an active and passive transducer? Give example for both kind. **[1.5]**

(c) What is the difference between null and deflection mode of measurement? Discuss the relative merits and demerits of these two methods with examples. **[1.5]**

(d) What are spurious inputs? What are different kinds of spurious inputs usually present? Give examples. **[1.5]**

Q5 (a) Sketch a flapper nozzle system and explain how it converts a displacement signal into a pneumatic signal. [2]

(b) Sketch a control valve and identify various parts of the control valve and actuator. [1.5]

(c) What is the difference between a fail open and a fail close control valve? Describe a situation where you will use a fail open control valve and another situation where you will use a fail close control valve. [1.5]

(d) What is inherent control valve characteristics and installed characteristics? Sketch various commonly encountered inherent control valve characteristics. [2]

Q6 (a) Crude oil is flowing through a pipeline of 1 m dia. What type of flowmeter is most suitable here? Justify your answer. [1]

(b) A highly viscous polymeric fluid which has large number of small trapped gas bubbles is flowing through a circular tube at a very low rate. How to obtain the flow rate of such a flow? [1]

(c) What is reference junction correction? Discuss relative merits and demerits of thermocouple and thermistors. [2]

(d) Draw symbols for process lines, pneumatic lines, safety relief valve and needle valve. How to determine if an instrument is field mounted, panel mounted or DCS display? [2]

(e) Discuss two different level monitoring methods. [1]

.....END.....

Assignment 2

Evaluation of area of compensation of a nozzle from a process vessel.

For the vessel in Assignment 1, Find out the ring pad dimensions (I.D. / O.D. and thickness).

Nozzle O.D. = 0.25 m.

Inside protrusion of nozzle: Not Desired

Length of nozzle above surface: 0.12 m.

A loose type of flange with hub needs to be designed for a shell with the following specifications:
Design pressure: 2.5 Mpa; Design temperature: 200^0C; Gasket material: Asbestos with thickness 1.6mm. Shell ID=1.5m; Allowable stress for the shell and flange material: 100Mpa; Allowable stress for the bolting material: 138 Mpa; Gasket is placed 6 mm (one side) away from the shell outer surface. Hub thickness=12mm; Gasket: $m=2.75$; $y=25.5$Mpa;

(a) Find the gasket inner, outer diameter and gasket width.

(b) Calculate the bolt circle diameter and the number of bolts required.

(c) Find flange OD.

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