Answer all the questions. Assume suitable data if missing. Notations used have their usual meaning.

1(a) In MLT θ system (T being time and θ temperature), what is the dimension of thermal conductivity?

1(b) Heat transfer by combustion of wood in open air is analysed by three different cases: case1, case 2 and case3, as shown in fig. 1. Identify the major mode of heat transfer in each case.

[1.5]

![Image](image.png)

Fig1: Heat generation by burning of wood

I(c) In flow across tube banks, how does the heat transfer coefficient vary with the row number in the flow direction? How does it vary with in the transverse direction for a given row number?

I(d) The wall of the house in a new state are to be constructed using a 'cavity wall' design. This comprises an inner layer of brick (k = 0.5 W/m K and 120 mm thick), an air gap and an outer layer of brick (k = 0.3 W/m K and 120 mm thick). At the design condition the inside room temperature is 20 °C, the outside air temperature is -10 °C; the heat transfer coefficients on inside, outside and in the air gap are; 10, 40 and 6 W/m²K respectively. Calculate the heat flux through the wall.

I(e) Show that the overall heat transfer coefficient for a concentric tube heat exchanger is given by the relation:

\[ U = \left[ \frac{r_2}{k} \ln \left( \frac{r_2}{r_1} \right) + \frac{r_0}{h_i r_i} + \frac{1}{h_o} \right]^{-1} \]

[02]

[05]

[05]
(37/41)

1(e') Air at atmospheric pressure and 20 °C is flowing with a velocity of 8 m/s over a 1.5 m x 6 m flat plate whose temperature is 80 °C. Determine the rate of heat transfer from the plate if air is flowing parallel to 1.5 m long side.

The properties of air is given in Table 1.

<table>
<thead>
<tr>
<th>T (K)</th>
<th>ρ (kg/m³)</th>
<th>c_p (J/kg-K)</th>
<th>ρ (kg/m-s)</th>
<th>ν (m²/s)</th>
<th>k (W/m-K)</th>
<th>α (m²/s)</th>
<th>Pr</th>
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<tr>
<td>100</td>
<td>3.605</td>
<td>1039</td>
<td>0.711 x 10⁻³</td>
<td>0.197 x 10⁻³</td>
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<tr>
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<td>1012</td>
<td>1.035</td>
<td>0.437</td>
<td>0.01406</td>
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<td>0.745</td>
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<tr>
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<td>1007</td>
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<td>0.754</td>
<td>0.01836</td>
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<tr>
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<td>1.214</td>
<td>0.02329</td>
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<td>0.712</td>
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<tr>
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<td>0.02400</td>
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<tr>
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<td>1.475</td>
<td>0.02544</td>
<td>2.078</td>
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</tr>
<tr>
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<td>1007</td>
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<td>1.578</td>
<td>0.02623</td>
<td>2.213</td>
<td>0.713</td>
</tr>
<tr>
<td>310</td>
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<td>1.659</td>
<td>0.02684</td>
<td>2.340</td>
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<tr>
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<td>1008</td>
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<td>0.02888</td>
<td>2.821</td>
<td>0.707</td>
</tr>
</tbody>
</table>

2(a) Draw a typical pool boiling curve and level various regimes on it.

2(b) Explain Leidenfrost phenomenon in boiling.

2(c) Show various regimes in film condensation on a vertical plate. Will the heat flux be higher at the top or at the bottom of the plate and Why?

2(d) The condenser of a steam power plant operates at a pressure of 7.38 kPa. Steam at this pressure condenses on the outer surface of horizontal pipes through which cooling water circulates. The outer diameter of the pipe is 3 cm, and the outer surface of the pipes are maintained at 30 °C. Determine

i. The rate of heat transferred to the cooling water per unit length of pipe.

ii. The rate of condensation of steam per unit length of a horizontal pipe.

Given that:
Saturation Temperature at 7.38 kPa, \( T_s \) = 40 °C
Density of water (Liquid phase), \( \rho_l \) = 994 kg/m³
Density of water (Vapour phase), \( \rho_v \) = 0.05 kg/m³
Specific heat of water, \( C_p \) = 4178 J/kg.°C
Thermal conductivity of water, \( k_l \) = 4178 W/mK
Viscosity of water, \( \mu_l \) = 0.720 x 10⁻³ kg/m.s
Latent heat, \( h_{fg} \) = 2407 x 10³ J/kg

Contd....3.
2(d') Water is to be boiled at atmospheric pressure in a mechanically polished stainless steel pan placed on the top of a heating unit. The inner surface of the bottom of the pan is maintained at 108 °C. If the diameter of the bottom of the pan is 30 cm, determine:

a) The rate of heat transfer to the water
b) The rate of evaporation of water
c) Apply Rohsenow relation for boiling which is as follows:

\[ q_{\text{nuclide}} = \mu_f h_{fg} \left[ \frac{g (\rho_f - \rho_v)}{\alpha} \right]^{1/2} \left[ \frac{C_p \left( T_s - T_{\text{sat}} \right)}{C_f h_{fg} \Pr_f} \right] \]

Where, \( C_{st} = 0.0130 \) and \( n = 1.0 \)

The properties of water at this condition could be taken as given below:

- \( \rho_f = 957.9 \text{ kg/m}^3 \)
- \( h_{fg} = 2257.0 \times 10^3 \text{ J/kg} \)
- \( \rho_v = 3.6 \text{ kg/m}^3 \)
- \( \mu_f = 0.282 \times 10^{-3} \text{ kg m/s} \)
- \( Pr_f = 1.75 \)
- \( C_p = 4.17 \text{ J/kg °C} \)
- \( \sigma = 0.0589 \text{ N/m} \)

3(a) Draw temperature profile for 1-2 shell and tube heat exchanger.

3(b) What are advantages and limitations of U tube heat exchanger over fixed tube type?

3(c) What is meant by fouling in a heat exchanger? Write the types and economic penalties of fouling.

3(a) A 2-4 shell and tube heat exchanger is used to heat glycerine from 20 °C to 50 °C by hot water which enters the thin walled 2 cm diameter tube at 80 °C and leaves at 40 °C. The total effective length of the tubes in the exchanger is 60 m. The convective heat transfer coefficient is 25 W/(m²K) on the glycerine side and 160 W/(m²K) on water side. Determine the rate of heat transfer in the exchanger:

a) before fouling

b) After fouling, with a fouling factor of 0.0006 m²°C/W, occurs on the outer surface of the tube

\[ P = \frac{t_2 - t_1}{R} \]

\( R = \frac{T_1 - T_2}{t_2 - t_1} \)

Two-shell passes and 4, 8, 12, etc. (any multiple of 4), tube passes

Contd.....
3(d') Show that the effectiveness of a 1-1 shell and tube heat exchanger for parallel flow is given by

\[ e_{\text{parallel flow}} = \frac{1 - \exp \left( -\frac{UA}{C_r} \left( 1 + \frac{C_r}{C_h} \right) \right)}{\left( 1 + \frac{C_r}{C_h} \right) \frac{C_{\text{msc}}}{C_v}} \]

4(a) Write a short note on scrap surface heat exchangers.

4(b) How does the vortex formation in an agitated vessel affect the heat transfer rate?

4(c) What is Wein's displacement law? At what wavelength does a body at 2000 K emit maximum radiation?

4(d') A thin Aluminium sheet with an emissivity of 0.1 on both sides is placed between two very large parallel plates that are maintained at uniform temperatures \( T_1 = 800 \) K and \( T_2 = 500 \) K and have emissivities \( \varepsilon_1 = 0.2 \) and \( \varepsilon_2 = 0.7 \) respectively. Determine the net rate of radiation heat transfer between the two plates per unit surface area of the plates and compare the result to that without the shield.

OR

4(d'') Consider the 5-m \times 5-m \times 5-m cubical furnace shown in Fig. 2 whose surfaces closely approximate black surfaces. The base, top and side surfaces of the surface are maintained at uniform temperatures of 800 K, 1500 K and 500 K respectively. Determine

a) The net rate of radiation heat transfer between the base and the side surfaces.

b) The net rate of radiation heat transfer between the base and the top surfaces.

c) The net rate of radiation heat transfer from the base surfaces.

Fig 2: Radiant heat transfer from cube

View factor \( F_{1-2} = 0.2 \)
Answer all the questions.
Start each question and its part thereof from fresh page.
Notations used have their usual meaning unless otherwise specified.
Use of psychrometric chart and graph paper is allowed.

1(a) State the penetration theory of mass transfer along with the assumptions. Also write down the expression for the liquid phase mass transfer coefficient according to this theory.

1(b) A test tube, 0.015 m in diameter and 0.12 m long, has 0.0004 kg camphor in it. How long will it take for the camphor to disappear? The pressure is 1 atm and the temperature is 20 °C. The sublimation pressure of camphor at this temperature is 97.5 mm Hg, and the diffusivity of camphor at given temperature and pressure is $5.64 \times 10^{-6}$ m$^2$/s. Molecular weight of camphor is 152.03 kg/kmol.

OR

1'(a) Define the terms mass average velocity and molar average velocity. Show that the two velocities are same if the molecular weights of all species in the mixture are equal.

1'(b) A stream of nitrogen containing 7.5 mol% benzene vapor is scrubbed with a nonvolatile absorption oil in a tower at 35 °C and 1.2 bar total pressure. The gas phase mass transfer coefficient is estimated to be $k_G = 9.8 \times 10^{-4}$ kmol/m$^2$·s·bar. The mole fraction of benzene at gas-liquid interface is $y_i = 0.01$. Calculate the mass transfer coefficients $k_y$ and $k_c$. Also calculate the mass transfer flux.

2(a) The number of transfer units for absorption of three gases A, B, and C in water are 10, 4, and 15 respectively. The inlet and exit concentrations (mole fraction) of the
gas-phase and of the liquid-phase have the same values in all the cases. For which system is the average driving force for mass transfer maximum? Give detail explanation of your answer.

2(b) It is required to absorb 95% of the acetone from a mixture with nitrogen containing 1.5 mol% of acetone in a counter-current tray tower. The total gas input is 30 kmol/h and the water enters the tower at a rate of 90 kmol/h. The tower operates at 300 K and 1 atm. The equilibrium relation is \( y = 2.53x \). Determine the number of ideal trays necessary for this separation using Kremser analytical method.

OR

2(b') Sulfur dioxide is to be scrubbed from an air stream in a small packed tower by contacting with an organic amine. The feed gas contains 3% SO\(_2\) by volume, and 95% of it is to be absorbed. The total gas rate is 150 m\(^3\)/h at 20 °C and 1.1 bar absolute pressure. The liquid enters the column at a rate of 1.40 kmol/h. Given: the overall mass transfer coefficient, \( K_t = 3.2 \times 10^{-4}\) kmol/m\(^2\)-s·Δp(bar); the effective gas-liquid contact area = 105 m\(^2\) per m\(^3\) of packed volume; slope of the equilibrium line, \( m = 0.17\). Determine the overall gas-phase mass transfer units and the packed height if the column is 0.3 m in diameter.

3(a) Define the terms relative saturation and percentage saturation related to humidification operation and obtain a relationship between them. Show that the relative saturation is always greater than the percentage saturation except for the extreme conditions of dry gas (0% humidity) and saturated gas (100% humidity).

3(b) A cooling tower is to be designed to cool water from 45 °C to 30 °C by counter-current contact with air of dry-bulb temperature 30 °C and wet-bulb temperature of 25 °C. The water rate is 5500 kg/h·m\(^2\) and the air rate is 1.25 times the minimum. Determine the tower height if the overall mass transfer coefficient is \( K_t = 2500\) kg/h·m\(^3\).

OR

3(b') A horizontal spray chamber with recirculated water is to be used for the adiabatic humidification and cooling of air. The active part of the chamber is 1.5 m long. The

Contd....3.
The coefficient of heat transfer is \( h_s = 18.6 \) W/m²-K. An amount of 200 cc/min of air at 65 °C, \( Y' = 0.017 \) kg water / kg dry air, is to be blown through the spray. Determine the temperature of the exit air. For air-water system, humid heat in J/kg DA is:

\[
C_s = 1005 + 1884Y'
\]

4(a) In a laboratory drying test of a granular, hygroscopic wet solid, it took 8.5 h to dry the solid from 28% to 2% moisture with solid loading of 20 kg/m². Given \( X'_s = 0.1 \), \( X'_* = 0.005 \), and the falling rate of drying being linear in moisture content (all moistures are on dry basis), calculate the time required for drying the material from 25% to 1.5% moisture under similar drying conditions. What are the highest and the lowest drying rate?

4(b) A Swenson-Walker crystallizer is to produce 800 kg/h of FeSO₄·7H₂O crystals. The saturated solution enters the crystallizer at 49 °C and the slurry leaves at 27 °C. Cooling water enters in the jacket of the crystallizer at 25 °C and leaves at 21 °C. The overall heat transfer coefficient has been estimated to be 203.5 W/m²-K. There are 1.3 m² of cooling surface per meter of crystallizer length. Estimate the cooling water required in kg/h. Given: Saturated solution FeSO₄ at 49 °C and 27 °C contain 140 and 74 parts of FeSO₄·7H₂O per 100 parts of excess water, respectively. The average specific heat of the initial solution 2.90 kJ/kg·K, and the heat of crystallization is 66.15 kJ/kg. Molecular weights of FeSO₄ and H₂O are 151.91 and 18.02 kg/kmol respectively.
1(a) The following mechanism has been reported by Pacey & Purnell \((I\&EC \ [10] Fund. 11:233, 1972)\) for the pyrolysis of ethane.

**Initiation:**  \[ \text{C}_2\text{H}_6 \rightarrow 2\text{CH}_3^* \]  (1)

**Propagation:**  \[ \text{CH}_3^* + \text{C}_2\text{H}_6 \rightarrow \text{CH}_4 + \text{C}_2\text{H}_5^* \] (2)
\[ \text{C}_2\text{H}_5^* \rightarrow \text{C}_2\text{H}_4 + \text{H}^* \] (3)
\[ \text{H}^* + \text{C}_2\text{H}_6 \rightarrow \text{H}_2 + \text{C}_2\text{H}_5^* \] (4)

**Termination**  \[ \text{C}_2\text{H}_5^* + \text{C}_2\text{H}_5^* \rightarrow \text{n-C}_4\text{H}_{10} \] (5)
\[ \text{C}_2\text{H}_5^* + \text{C}_2\text{H}_6^* \rightarrow \text{C}_2\text{H}_6 + \text{C}_2\text{H}_4 \] (6)

**Propylene formation:**  \[ \text{C}_2\text{H}_5^* + \text{C}_2\text{H}_4 \rightarrow \text{C}_3\text{H}_6 + \text{CH}_3^* \] (7)

**Inhibition:**  \[ \text{H}^* + \text{C}_2\text{H}_4 \rightarrow \text{C}_2\text{H}_5^* \] (8)

No significant accumulation of free radicals was observed experimentally, and thus the pseudo-steady-state assumption may be used in analysis. Also, it was found experimentally that \( k_8 = 7k_6 \). Write down the expression for the rate of disappearance of ethane and the rate of appearance of ethylene based on the above mechanism. Determine the expressions for the coverage based terms, \([\text{CH}_3^*]\), \([\text{H}^*]\), and \([\text{C}_2\text{H}_5^*]\) in terms of the measurable parameters and constants.

*Contd.....2.*
1(b) Consider the reaction \( A \rightarrow R \), \( k_c = 0.02 \text{ min}^{-1} \). It is desired to produce 4572 g mol of R per 10-hr day, and 99% of A entering the reactor is to be converted. To charge the reactor and to heat it to reaction temperature requires 0.26 hr. To discharge the reactor and to prepare it for the next run takes 0.9 hr. Calculate the volume of the reactor required. Pure A with a molar density of 8 g mol/litre is charged to the reactor.

OR

1(b') A mixed flow reactor (2 m³) processes an aqueous feed (100 litre/min) containing reactant A \( (C_{A0} = 100 \text{ mmol/litre}) \). The reaction is represented by

\[
A \rightleftharpoons R, \quad -r_A = 0.04 C_A - 0.01 C_R \text{ mol/litre.min}
\]

What is the equilibrium conversion and the actual conversion in the reactor?

2(a) Reactant A decomposes with stoichiometry \( A \rightarrow R \) and with a rate dependent only on \( C_A \). The following data on this aqueous decomposition are obtained in a mixed flow reactor.

<table>
<thead>
<tr>
<th>( \tau ), sec</th>
<th>14</th>
<th>25</th>
<th>29</th>
<th>30</th>
<th>29</th>
<th>27</th>
<th>24</th>
<th>19</th>
<th>15</th>
<th>12</th>
<th>10</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C_{A0} )</td>
<td>200</td>
<td>190</td>
<td>180</td>
<td>170</td>
<td>160</td>
<td>150</td>
<td>140</td>
<td>130</td>
<td>120</td>
<td>110</td>
<td>101</td>
</tr>
<tr>
<td>( C_A )</td>
<td>100</td>
<td>90</td>
<td>80</td>
<td>70</td>
<td>60</td>
<td>50</td>
<td>40</td>
<td>30</td>
<td>20</td>
<td>10</td>
<td>1</td>
</tr>
</tbody>
</table>

Determine which setup, plug flow, mixed flow, or any two-reactor combination gives minimum \( \tau \) for 90% conversion of a feed consisting of \( C_{A0} = 100 \). Also find this \( \tau \) minimum.

Contd.....3.
2(b) Consider the parallel decompositions of \( A \), \( C_{A0} = 2 \text{ mol/litre} \)

\[
\begin{align*}
A & \rightarrow R & r_R &= 1, \text{ mol/litre.s} \\
A & \rightarrow S & r_S &= 2C_A, \text{ mol/litre.s} \\
A & \rightarrow T & r_T &= C_A^2, \text{ mol/litre.s}
\end{align*}
\]

Determine the arrangement of two reactors which would produce most \( S \) in a flow system where recycle and separation of unreacted feed is not possible. Find the \( C_{\text{Stotal}} \) and the size of the two reactors for a flow rate of 100 litre/second.

**OR**

2(b') We want to produce \( R \) from \( A \) in a batch reactor with a run time no greater than 2 hours and at a temperature somewhere between 5 and 90 °C. The kinetics of this liquid first-order reaction system is as follows:

\[
A \rightarrow R \rightarrow S,
\]

\[
\begin{align*}
k_1 &= 30 \text{ e}^{-20000/RT} & k &= [\text{min}^{-1}] \\
k_2 &= 1.9 \text{ e}^{-15000/RT} & R &= 8.314 \text{ J/mol.K}
\end{align*}
\]

Determine the optimum temperature (to give \( C_{R_{\text{max}}} \)) and run time to use, and the corresponding conversion of \( A \) to \( R \).

3 A first order liquid phase reaction

\[-r_A = k C_A, \quad k = 0.25 \text{ min}^{-1}\]

is carried out in a reactor (flow through = 10 dm\(^3\)/min) for which the results of pulse tracer test are given below:

<table>
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<th>0</th>
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<th>1.0</th>
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<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>8</th>
<th>10</th>
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<tbody>
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<td>( C \times 10^5 ), mg/dm(^3)</td>
<td>0</td>
<td>329</td>
<td>622</td>
<td>812</td>
<td>831</td>
<td>785</td>
<td>720</td>
<td>650</td>
<td>523</td>
<td>418</td>
</tr>
<tr>
<td>( t, \text{min} )</td>
<td>15</td>
<td>20</td>
<td>25</td>
<td>30</td>
<td>35</td>
<td>40</td>
<td>45</td>
<td>50</td>
<td>60</td>
<td>65</td>
</tr>
<tr>
<td>( C \times 10^5 ), mg/dm(^3)</td>
<td>238</td>
<td>136</td>
<td>77</td>
<td>44</td>
<td>25</td>
<td>14</td>
<td>8</td>
<td>5</td>
<td>1</td>
<td>0</td>
</tr>
</tbody>
</table>

Calculate the mean residence time of fluid in the vessel, the variance, and tabulate and plot the exit age distribution \( E \). What kind of

*Contd.....4.*
compartment model is suggested by the resulting E curve? Also calculate the conversion in the real reactor and compare it with the conversion in an ideal plug flow reactor.

3' Consider the elementary liquid reaction,

\[
A \rightarrow R
\]

\[
\Delta G^\circ_{298} = -14,130 \text{ J/mol}
\]

\[
\Delta H^\circ_{298} = -75,300 \text{ J/mol}
\]

\[
C_{pA} = C_{pR} = \text{Constant} = 1000 \text{ cal/kg.K}
\]

\[
1 \text{ cal} = 4.1842 \text{ J, } 1 \text{ W} = 0.239 \text{ cal/s}
\]

Based on kinetic experiments in a batch reactor, the conversion-temperature chart with reaction rate as parameter has been prepared along with equilibrium conversion. The result for \( C_{Ao} = 1 \text{ mol/litre} \) and \( C_{Ro} = 0 \) is presented in Figure 1. Using the locus of maximum rates, determine the volume of the mixed flow reactor needed for 80% conversion of a feed of \( F_{Ao} = 1000 \text{ mol/min} \), \( C_{Ao} = 1 \text{ mol/litre} \). What is the heat duty if the feed enters at 25°C and the product is to be withdrawn at the same temperature? Density of the reaction mixture may be assumed to be equal to that of water.

4(a) The dehydration of n-butyl alcohol (n-butanol) over an alumina-silica catalyst was investigated by J. F. Maurer (Ph.D. thesis, University of Michigan). The data shown in Figure 2 were obtained at 750 °F in a modified differential reactor. The feed consisted of pure n-butanol.

\[
\text{Silica-alumina} \quad \xrightarrow{\text{catalyst}} \quad \text{n-Butanol} \rightarrow \text{Butene + Water}
\]

Suggest a mechanism and rate-controlling step that is consistent with the experimental data. Write the steps (only) involved to evaluate the rate law parameters.
4(b) The second-order reaction \( A \rightarrow R \) is studied in a recycle reactor with very large recycle ratio, and the following data are recorded:

Void volume of reactor: 1 litre
Weight of catalyst used: 3 gram
Feed to the reactor: \( C_{A0} = 2 \text{ mol/litre} \)
\( \dot{V}_0 = 1 \text{ litre/hr} \)
Exit stream: \( C_{A\text{out}} = 0.5 \text{ mol/litre} \)

(i) Find the rate constant for this reaction giving proper units.
(ii) How much catalyst is needed in a packed-bed reactor for 80% conversion of 1000 litre/hr of feed, \( C_{A0} = 1 \text{ mol/litre} \).

4(b') Calculate the time needed to burn to completion particles of graphite (\( R_0 = 5 \text{ mm} \), \( \rho_B = 2.2 \text{ gm/cm}^3 \), \( k'' = 20 \text{ cm/sec} \)) in an 8% oxygen stream. For the high gas velocity used assume that film diffusion does not offer any resistance to transfer and reaction. Reaction temperature = 900 °C.

![Graph](image-url)

Figure - 2
Figure 1

- $r_A = 0.001$
- $r_A = 0.002$
- $r_A = 0.003$
- $r_A = 0.005$
- $r_A = 0.01$
- $r_A = 0.02$
- $r_A = 0.03$
- $r_A = 0.05$

Time in minutes
$C_{NO} = 1$ mol/liter
For other $C_{NO}$ change $r_A$ accordingly

Temperature, °C

Conversion

11/19/2014
Q.No. | Question | M.M. |
---|---|---|
1(a) | Show that the reaction: \( H_2 + Br_2 \rightarrow 2HBr \) with the experimental rate \[ \frac{\frac{k_1[H_2][Br_2]}{k_2 + [HBr]/[Br_2]}}{1/2} \] can be explained by the free radical chain reaction mechanism which introduces and involves the intermediates \( H^* \) and \( Br^* \)  
\[ \begin{align*} 
& Br_2 \quad \quad \rightarrow \quad 2Br^* \quad \quad \text{Initiation and Termination} \\
& Br^* + H_2 \quad \rightarrow \quad HBr + H^* \quad \quad \text{Propagation} \\
& H^* + Br_2 \quad \rightarrow \quad HBr + Br^* \quad \quad \text{Propagation} 
\end{align*} \] | [10] |
1(b) | The pyrolysis of ethane proceeds with an activation energy of about 300 kJ/mol. How much faster is the decomposition at 650 °C than at 500 °C? | [05] |
2(a) | Enzyme E catalyzes the fermentation of substrate \( A \) to product \( R \). Find the size of mixed flow reactor needed for 95% conversion of reactant in a feed stream (25 liter/min) of reactant \( (C_{A0} = 2 \text{ mol/liter}) \) and enzyme. The kinetics of the fermentation at this enzyme concentration are given by:  
\[ -r_A = \frac{0.1 \cdot C_A}{1 + 0.5 \cdot C_A} \text{ mol/L.min} \] | [09] |
2 (a) We wish to explore various reactor setups for the transformation of A into R which takes place by means of the elementary reaction with $k = 1$ liter/mol.min.

$$A + R \rightarrow R + R$$

The feed contains 99% A, 1% R; the desired product is to consist of 10% A, 90% R. The concentration of active materials is

$$C_{A0} + C_{R0} = C_A + C_R = C_0 = 1 \text{ mol/liter}$$

throughout.

What reactor holding time will yield a product in which $C_R = 0.9 \text{ mol/liter}$ (a) in a plug flow reactor, (b) in a mixed flow reactor, and (c) in a minimum size setup without recycle.

2 (b) For the consecutive unimolecular-type first-order reaction

$$A \xrightarrow{k_1} R \xrightarrow{k_2} S$$

The expression for the changing concentration of the intermediate R is

$$C_R = C_{A0} k_1 \left( e^{k_1 t} / (k_2 - k_1) + e^{k_2 t} / (k_1 - k_2) \right)$$

Find the maximum concentration of R and the time at which it occurs.

3(a) Chemical X, a powdered solid, is slowly and continuously fed for half an hour into a well-mixed vat of water. The solid quickly dissolves and hydrolyses to Y, which the slowly decomposes to Z as follows

$$Y \rightarrow Z, \quad -r_y = k C_y, \quad k = 1.5 \text{ hr}^{-1}$$

The volume of liquid in the vat stays close to 3 m$^3$ throughout this operation, and if no reaction of Y to Z occurred, the concentration of Y in the tank would be 100 mol / m$^3$ at the end of the half-hour addition of X.

(i) What is the maximum concentration of Y in the vat and at what time is this maximum reached?

(ii) What is the concentration of product Z in the vat after 1 hour?

OR

Contd......3.
3 (a') We want to produce R from A in a batch reactor with a run time no greater than 2 hours and at a temperature somewhere between 5 and 90 °C. The kinetics of this liquid first-order reaction system is as follows:

\[
\begin{align*}
    &1 & \quad 2 & \quad 3 \\
    \text{A} & \rightarrow & \text{R} & \rightarrow \text{S}, \\
    k_1 &= 30 \ e^{20.603 \cdot RT} & \quad k = \text{[min}^{-1}] \\
    k_2 &= 1.9 \ e^{15.000 \cdot RT} & \quad R = 8.314 \ \text{J/mol.K}
\end{align*}
\]

Determine the optimum temperature (to give \(C_{R_{\text{max}}}\)) and run time to use, and the corresponding conversion of A to R.

3(b) For the parallel reactions

\[
\begin{align*}
    &1 & \quad 2 & \quad 3 \\
    \text{A} & \rightarrow & \text{S} & \rightarrow \text{T}, \\
    \text{where } & E_1 > E_2, E_1 < E_3
\end{align*}
\]

Show that the most favourable product distribution is obtained when the temperature satisfies the following condition

\[
\frac{1}{T_{\text{opt}}} = \frac{R}{E_2 - E_1} \ln \left[ \frac{E_3 - E_1 \cdot k_{3\theta}}{E_1 - E_2 \cdot k_{2\theta}} \right]
\]

4(a) The concentration readings in Table-1 represent a continuous response to a pulse input into a closed vessel which is to be used as a chemical reactor. Calculate the mean residence time of fluid in the vessel \(t\), and tabulate and plot the exit age distribution \(E\).

### Table-1

<table>
<thead>
<tr>
<th>Time (t), min</th>
<th>Tracer Output Concentration, (C_{\text{pulse}}) gm/liter fluid</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>5</td>
<td>3</td>
</tr>
<tr>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>15</td>
<td>5</td>
</tr>
<tr>
<td>20</td>
<td>4</td>
</tr>
<tr>
<td>25</td>
<td>2</td>
</tr>
<tr>
<td>30</td>
<td>1</td>
</tr>
<tr>
<td>35</td>
<td>0</td>
</tr>
</tbody>
</table>
4 (a*) Derive the conversion-time expression for the reaction of a spherical particle with a fluid when diffusion through gas film controls.

\[
A (g) + bB (g) \rightarrow \text{Products}
\]

4(b) Fit the tanks-in-series model to the following mixing cup output data to a pulse input.

<table>
<thead>
<tr>
<th>t</th>
<th>0-2</th>
<th>2-4</th>
<th>4-6</th>
<th>6-8</th>
<th>8-10</th>
<th>10-12</th>
</tr>
</thead>
<tbody>
<tr>
<td>C</td>
<td>2</td>
<td>10</td>
<td>8</td>
<td>4</td>
<td>2</td>
<td>0</td>
</tr>
</tbody>
</table>
1(a) What is an equilibrium stage, explain thermal and mechanical equilibrium with respect to equilibrium stage. [02]

1(b) Discuss the characteristics of H-xy and xy diagrams. [04]

1(c) A rectification column is fed with 100kgmol/h of a mixture of 45 mol% heptane and 55mol% ethyl benzene at 101.3 kPa abs pressure. The feed is a liquid at boiling point. The distillate is to contain 90 mol% heptane and the bottoms 10mol% ethyl benzene. The reflux ratio is 4.2:1. Calculate the amounts of distillate, bottoms, and number of theoretical trays needed using McCabe-Thiele method. Equilibrium data are given below at 101.3 kPa for the mole fraction n-heptane $x_n$ and $y_n$.

<table>
<thead>
<tr>
<th>Temperature $^\circ$C</th>
<th>$x_n$</th>
<th>$y_n$</th>
<th>Temperature $^\circ$C</th>
<th>$x_n$</th>
<th>$y_n$</th>
</tr>
</thead>
<tbody>
<tr>
<td>136.1</td>
<td>0</td>
<td>0</td>
<td>110.6</td>
<td>0.485</td>
<td>0.730</td>
</tr>
<tr>
<td>129.4</td>
<td>0.08</td>
<td>0.230</td>
<td>102.8</td>
<td>0.790</td>
<td>0.904</td>
</tr>
<tr>
<td>119.4</td>
<td>0.250</td>
<td>0.514</td>
<td>98.3</td>
<td>1.000</td>
<td>1.000</td>
</tr>
</tbody>
</table>

OR

1'(a) With examples explain negative and positive deviations from ideality. [05]

1'(b) A liquid mixture of 50 mol% heptane, and 50 mol% ethyl benzene was subjected to [10]

Contd.....2.
a differential distillation at atmospheric pressure, with 60mol% of the liquid distilled. Calculate the average composition of the distillate and the composition of remaining liquid. Equilibrium data can be used from question 1(c)

2(a) Discuss in brief the working of distillation column with a neat sketch. [05]

2(b) A solution of hydrocarbons at a total pressure of 405.3 kPa has the analysis: n-buane (A) = 40, n-pentane (B) = 25, n- hexane(C) = 20, n-pentane(D) = 15 mol%.

Compute the dew point. K values are given as following:

\[ K_A = 0.0002 T^2 + 0.0066T + 0.318 \]
\[ K_B = 0.0001 T^2 - 0.0014 T + 0.125 \]
\[ K_C = 0.0001 T^2 - 0.0102 T + 0.467 \]
\[ K_D = 0.00009 T^2 - 0.0098 T + 0.3381 \]

Where \( T \) is the temperature in °C, first guess can be taken as 80 °C. [10]

3(a) What should be the characteristics of the solvent used in liquid liquid, extraction process. [05]

3(b) Explain with the help of diagram, how will you determine the number of equilibrium stages for a counter current multistage solid liquid extraction. Derive the expression used. [10]

OR

3' Pure isopropyl ether of 450kg/h is being used to extract an aqueous solution of 150 kg/h with 25wt% acetic acid by countercurrent multistage extraction. The exit acid concentration in the aqueous phase is 10wt%. Calculate the number of stages required. For acetic acid-water-isopropyl ether system, equilibrium data is given below:

<table>
<thead>
<tr>
<th>Water layer (wt%)</th>
<th>Isopropyl ether layer (wt%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>0.69</td>
<td>98.8</td>
</tr>
<tr>
<td>1.41</td>
<td>97.1</td>
</tr>
<tr>
<td>2.89</td>
<td>95.5</td>
</tr>
<tr>
<td>6.42</td>
<td>91.7</td>
</tr>
</tbody>
</table>

Contd.....3.
4(a) Write short notes on

(i) Engineering properties of adsorbents

(ii) Ion exchange equilibria

(iii) Adsorption hysteresis

4(b) An aqueous solution containing a valuable solute is colored by small amounts of an impurity. Before crystallization the impurity is to be removed by adsorption on a decolorizing carbon which adsorbs only insignificant amounts of the principal solute. A series of laboratory tests was made by stirring various amounts of the adsorbent into batches of the original solution until equilibrium was established yielding the following data at constant temperature:

<table>
<thead>
<tr>
<th>kg carbon/kg solution</th>
<th>0.0</th>
<th>0.001</th>
<th>0.004</th>
<th>0.008</th>
<th>0.02</th>
<th>0.04</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equilibrium color</td>
<td>9.6</td>
<td>8.6</td>
<td>6.3</td>
<td>4.3</td>
<td>1.7</td>
<td>0.7</td>
</tr>
</tbody>
</table>

The color intensity was measured on an arbitrary scale, proportional to the concentration of the colored substance. It is desired to reduce the color to 10% of the original value, 9.6. Determine the quantity of fresh carbon required per 1000 kg of solution for a single stage operation.
2015-16
B.TECH. (AUTUMN SEMESTER) EXAMINATION
CHEMICAL ENGINEERING
TRANSPORT PHENOMENA
CH 323/PK323

Maximum Marks: 60
Credits: 04
Duration: Three Hours

Answer all the questions.
Assume suitable data if missing.
Notations used have their usual meaning.

Q.No.  Question                                      M.M.

1(a) Explain the two ways in which momentum can be transported. Write down the
expression for the momentum that is transported by these mechanisms (assume that
the flow that is taking place in a pipe of radius R').

How many litres per hour of water at 20°C can be delivered through a 100 m
length of a smooth pipe of 5 cm inside diameter under a pressure difference of
20x10³ N/m²?

1(b) Show that for a fluid under simple shear velocity gradient is the measure of rate of
shearing strain.

1(c) The distance between two parallel plates 0.00914 m. The upper plate is stationary
while the lower plate is being pulled at a constant velocity of 0.366 m/s. The fluid
filled between the plates is water at 24°C. Calculate the shear stress and the shear
rate.

OR

1' Distinguish between body and surface forces.

A Newtonian fluid is in a laminar flow in a narrow slit (figure on next page)
formed by two parallel walls a distance 2B apart. It is given that B ≪ W so that "end
effects" are unimportant. Flow is taking place due to gravity and pressure gradient.

Contd... 2
i) Obtain the momentum flux, \( \tau_{xz}(x) \), and distribution \( v_z(x) \).

ii) What is the ratio of average velocity to maximum velocity?

iii) Obtain the expression for the flow rate, \( Q \), as the function of \((-\Delta P)\).

Give the transport analysis and write down the assumptions made.

---

2(a) A steel pipe having inside diameter of 2.067 inch and wall thickness 0.154 inch, carrying steam is insulated with 2 inch of magnesia covered in turn with 2 inch cork. Estimate the heat loss per second per meter of pipe if the inner surface of the pipe is at 121°C and the outer surface of the cork is at 33°C. The thermal conductivities of the substances concerned are, Steel: 45.172 \( \frac{W}{m^0C} \), magnesia: 0.0692 \( \frac{W}{m^0C} \), and cork: 0.01519 \( \frac{W}{m^0C} \). Derive the expression used.

OR

2(a') A copper wire 5.2 mm in diameter, is insulated with a layer of polyvinyl chloride of thermal conductivity, \( k = 0.43 \frac{W}{m^0C} \). The wire carries current and its temperature is 60°C. The film coefficient at the outer surface of the insulation is 11.35 \( \frac{W}{m^2^0C} \). Ambient air temperature is 21°C. Calculate the critical insulation thickness and derive the expression used.

2(b) A heated sphere of radius 'R' is suspended in a large, motionless body of fluid (figure on next page). It is desired to study the heat conduction in the fluid surrounding the sphere. It is assumed that free convection effects are negligible.
i) Set up a differential equation describing the temperature 'T' in the surrounding fluid as a function of 'r' (distance from the centre of the sphere). Thermal conductivity of the fluid 'k' is constant.

ii) Obtain the temperature profile using boundary conditions:

\[ \text{BC1: at } r = R, \quad T = T_R \]
\[ \text{BC2: at } r = \infty, \quad T = T_\infty \]

iii) Develop an expression for the heat flux at the surface. Equate this result to the heat flux given by "Newton's Law of Cooling" and show that dimensionless heat transfer coefficient (known as the Nusselt Number) is given by

\[ Nu = \frac{hD}{k} = 2 \]

Where 'D' is the diameter of the sphere.

OR

2(b') An electric current of density \( I \text{ ampere/cm}^2 \) is flowing through an electric wire of uniform cross-section with radius 'R' and electrical conductivity \( k \text{ ohm}^{-1}\text{cm}^{-1} \), due to electrical dissipation some electrical energy is converted into heat energy. The rate of heat energy production per unit volume is given by \( Se = \frac{I^2}{k} \). The surface of the wire is maintained at temperature '\( T_0 \)'. Find the radial temperature distribution within the wire, along with maximum temperature and average temperature rise inside the wire cross-section.

3(a) Derive the expressions:

i) \[ \bar{N}_A - \bar{X}_A (\bar{N}_A + \bar{N}_B) = CD_{AB} \bar{V} \bar{X}_A \]

ii) \[ \frac{\partial \rho A}{\partial t} = - \nabla (\rho_A \bar{V}) + \nabla (\rho D_{AB} \bar{V} \bar{W}_A) + r_A \]
iii) \( \frac{\partial C_A}{\partial t} = -\nabla \cdot (C_A \nabla V) + \nabla (CD_{AB} \nabla X_A) + R_A \)

3(b) A reaction is taking place at the catalytic surface as shown in figure below:

\[ 3A \rightarrow B \]

The reaction is not instantaneous at the catalytic surface, \( z = \delta \). Assume that the rate at which 'A' disappears at the catalyst-coated surface is proportional to the concentration of 'A' in the fluid at the interface. That is,

\[ N_{Az} = k_1 C_A \]

Where, \( k_1 \) is the rate constant for the pseudo-first order surface reaction.

i. Obtain the concentration profile for component 'A' in the above reaction.

ii. Determine the molar flux of 'A' and write down the significance of the equation obtained.

4(a) What do you understand by "hydraulically smooth tube"? A tank of radius 'r' is filled to height 'H' with a liquid of density 'p' as shown in figure below. The fluid drains from the bottom of the tank through a hole with radius 'r_0'. The flow velocity is approximated by Torricelli's Law:

\[ v = \sqrt{2gh} \]

Where 'h' is the instantaneous height. What is the total time required to empty the tank.

4(b) Show that friction factor is the function of Reynolds' Number. Derive the relation of
friction factor and Reynold's Number for laminar flow in a tube.

What are the applications of friction factor chart in a tube flow?

4(c) What do you understand by Macroscopic balance and what is its significance / importance in engineering analysis?
Maximum Marks: 60  Credits: 04  Duration: Three Hours

Answer all the questions. Assume suitable data if missing.

1. a. Differentiate between luxuries and necessities.
   
   b. What is a price demand supply relationship? Explain how the addition of supply for a given demand will establish a new and lower price.
   
   c. An engineer has two bids for an elevator to be installed in a new building. The details of the bids for the elevators are as follows:

<table>
<thead>
<tr>
<th>Bids</th>
<th>Initial cost (Rs.)</th>
<th>Service life (years)</th>
<th>Annual operations &amp; maintenance cost (Rs.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alpha Elevator Inc.</td>
<td>4,50,000</td>
<td>15</td>
<td>27,000</td>
</tr>
<tr>
<td>Beta Elevator Inc.</td>
<td>5,40,000</td>
<td>15</td>
<td>28,500</td>
</tr>
</tbody>
</table>

   Determine which bid should be accepted, based on the present worth method of comparison assuming 15% interest rate.

   OR

   1'. c'. A cement plant plans to open a new rock pit. Two plans have been devised for movement of raw material from quarry to the plant. Plan A requires the purchase of an earth mover and the construction of an unloading pad. Plan B calls for construction of a conveyor system from the quarry to the plant. The expected costs are as follows:

<table>
<thead>
<tr>
<th>PLAN A</th>
<th>PLAN B</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mover</td>
<td>Pad</td>
</tr>
<tr>
<td>Purchase Price ($)</td>
<td>45000</td>
</tr>
<tr>
<td>Annual Operating Cost ($)</td>
<td>6000</td>
</tr>
<tr>
<td>Salvage Value ($)</td>
<td>5000</td>
</tr>
<tr>
<td>Life (Years)</td>
<td>4</td>
</tr>
</tbody>
</table>

Which plan should be selected for an interest rate of 15% per year?

2. a. Differentiate between book value and market value. How does depreciation affect a company's cash flow?

   Given the data below, find the depreciation and book value in year 3, using a double declining balance method:

   First cost: Rs. 400,000
   Salvage Value: Rs. 75,000
   Life: 5 years

   OR

   Contd....2.
a. What are the various criteria for performing a cost benefit analysis? Five interdependent proposals are under consideration for a particular project. The present worth of capital requirement and benefits for each proposal are as follows:

<table>
<thead>
<tr>
<th>Alternative</th>
<th>A</th>
<th>B</th>
<th>C</th>
<th>D</th>
<th>E</th>
</tr>
</thead>
<tbody>
<tr>
<td>PW of Capital (Rs.)</td>
<td>80,000</td>
<td>50,000</td>
<td>72,000</td>
<td>43,000</td>
<td>81,000</td>
</tr>
<tr>
<td>PW of Benefits (Rs)</td>
<td>70,000</td>
<td>55,000</td>
<td>76,000</td>
<td>52,000</td>
<td>84,000</td>
</tr>
</tbody>
</table>

Develop an incremental B/C ratio analysis and select the appropriate alternative.

b. Define the terms economic life and useful life of an asset. Two years ago, a machine was purchased at a cost of Rs. 2,00,000 to be useful for eight years. Its salvage value at the end of its life is Rs. 25,000. The annual maintenance cost is Rs. 25,000. The present market value of the existing machine is Rs. 1,20,000. A new machine, with a service life of 6 years, is now available at Rs. 1,50,000. Its annual maintenance cost is Rs. 14,000. The salvage value of the new machine is Rs. 20,000. Using an interest rate of 12%, find whether it is worth replacing the present machine with the new machine.

3.

a. Discuss the social responsibilities of an organisation. What are the arguments for and against social responsibility of organisations?

b. What are the advantages of group decision making. Differentiate between Delphi and Nominal group decision making techniques.

4.

a. What do you understand by organizational planning? Differentiate among tactical and operational plans.

b. Describe the five alternatives to job specialization. What is the advantage of each, as compared to specialization?

OR

4’

a. How is leadership different from management? Give suitable example to distinguish between them.

b. What are various levels of control system in an organization? Explain the four fundamental steps of any control process.

5.

a. Describe the four basic levels of international business activity. Do you think any organization will achieve the fourth level? Why or why not?

b. Describe the processes of human resource planning, recruiting and selection.

OR

5’

a. What do you understand by marketing mix or 4P’s of marketing?

b. Explain the difference between macroeconomics and microeconomics in the context of financial management.