1. (a) Determine the error in Addition and Multiplication of two quantities $x_1$ and $x_2$ with approximations $x_{a1}$ and $x_{a2}$, and associated relative errors $\varepsilon_{r1}$ and $\varepsilon_{r2}$ respectively.

**OR**

(a') Consider the following Taylor Polynomial expansions.

\[
e^h = 1 + h + \frac{h^2}{2!} + \frac{h^3}{3!} + O(h^4) \quad \text{and} \quad \cos(h) = 1 - \frac{h^2}{2!} + \frac{h^4}{4!} + O(h^6)
\]

Determine the order of approximation for their Sum and Product.

1. (b) The function $h(x) = x \sin(x)$ occurs in the study of undamped oscillations. Find the value of $x$ that lies in the interval $[0,2]$, where the function takes on the value $h(x) = 1$. The function $\sin(x)$ is evaluated in radians. Use Bisection method. You may stop the iterations when the estimated error reaches below 5%. If the absolute magnitude of the error is $\frac{\varepsilon_{r}}{100} = 10^{-4}$, and $L_0 = 2$, how many iterations will you have to do to get the required accuracy in the solution?

1. (c) Write an algorithm in pseudocode to compute $e^x$ in terms of its power series. Your algorithm should compute and printout the value of $e^x$ and display the percent relative errors, as each term in the series is added, up to n terms.
2. Consider the following system of equations.

\[
\begin{align*}
3.0x_1 - 0.1x_2 - 0.2x_3 &= 7.85 \\
0.1x_1 + 7.0x_2 - 0.3x_3 &= -19.30 \\
0.3x_1 - 0.2x_2 + 10.0x_3 &= 71.40
\end{align*}
\]

Solve by:

(a) LU Decomposition Do-Little method

(b) Gauss Seidel method

2. (b) The rate of cooling of a body can be expressed as

\[
\frac{dT}{dt} = -k(T - T_a)
\]

where \( T \) = temperature of the body (°C), \( T_a \) = temperature of the surrounding medium (°C), and \( k \) = a proportionality constant (per minute). Thus, this equation (called Newton’s law of cooling) specifies that the rate of cooling is proportional to the difference in the temperatures of the body and of the surrounding medium. If a metal ball heated to 80°C is dropped into water that is held constant at \( T_a = 20°C \), the temperature of the ball changes, as in

<table>
<thead>
<tr>
<th>Time, min</th>
<th>0</th>
<th>5</th>
<th>10</th>
<th>15</th>
<th>20</th>
<th>25</th>
</tr>
</thead>
<tbody>
<tr>
<td>T, °C</td>
<td>80.0</td>
<td>44.5</td>
<td>30.0</td>
<td>19.1</td>
<td>21.7</td>
<td>20.7</td>
</tr>
</tbody>
</table>

Utilize numerical differentiation and linear regression to evaluate \( k \).

2. (c) Compare and contrast Lagrange interpolating polynomials and cubic splines for curve fitting quantitatively. Do it in terms of the characteristics of the results rather than the actual mathematical formulation.

3. (a) Derive Simpson’s 1/3 rule from Lagrange Interpolating polynomial formulas.

(a') Fully developed flow moving through a 40 cm diameter pipe has the following velocity profile:

<table>
<thead>
<tr>
<th>Radius, ( r ), cm</th>
<th>0.0</th>
<th>2.5</th>
<th>5.0</th>
<th>7.5</th>
<th>10.0</th>
<th>12.5</th>
<th>15.0</th>
<th>17.5</th>
<th>20.0</th>
</tr>
</thead>
<tbody>
<tr>
<td>Velocity, ( v ), m/s</td>
<td>0.914</td>
<td>0.890</td>
<td>0.847</td>
<td>0.795</td>
<td>0.719</td>
<td>0.543</td>
<td>0.427</td>
<td>0.204</td>
<td>0.000</td>
</tr>
</tbody>
</table>

Find the volumetric flowrate \( Q \) using the relationship \( Q = \int_0^R v(2\pi r) \, dr \), where \( r \) is the radial axis of the pipe, \( R \) is the radius of the pipe, and \( v \) is the velocity. Solve the problem using multiple application

(i) Trapezoidal rule.

(ii) Simpson’s 1/3 rule.
3. (b) Use Forward, Backward and Centered difference approximations to estimate the first derivative of
\[ f = -0.1x^4 - 0.15x^3 - 0.5x^2 - 0.25x + 1.2 \]
at \( x = 0.5 \) using step size of \( h = 0.5 \). Repeat using \( h = 0.25 \).
Use Richardson extrapolation to estimate the first derivative at \( x=0.5 \) employing step sizes of \( h_1 = 0.5 \) and \( h_2 = 0.25 \). Compute the improved estimate with Richardson extrapolation.

3. (c) Solve the following set of differential equations using Euler's Method.
\[
\frac{dx}{dt} = -0.5x \quad \frac{dy}{dt} = 4 - 0.3y - 0.1x
\]
with the initial conditions \( x(t=0)=4 \) and \( y(t=0)=6 \). Integrate to \( t=2 \) with a step size of 0.5.

4. Minimize the following function within the interval \([0.005, 0.015]\).
\[
f = \frac{50}{2\pi} \left( \ln \left( \frac{200x}{0.16} \right) + \frac{1}{20x} \right) + 280
\]
Use the following Region Elimination scheme:
(a) Fibonacci Search
(a') Golden Section Search
OR

4. (b) Minimize:
\[
f = x_1 - x_2 + 2x_1x_2 + 2x_1^2 + x_2^2
\]
using steepest descent method. Take the starting point as \( X^0 = [0, 0] \). Carry out two iterations only.

4. (c) A refinery has available two crude oils that have the yields shown in the following table. Because of equipment and storage limitations, production of gasoline, kerosene, and fuel oil must be limited as also shown in this table. There are no plant limitations on the production of other products such as gas oils. The profit on processing crude #1 is Rs 60/bbl and on crude #2 it is Rs 42/bbl. Find the optimum daily feed rates of the two crudes to this plant by Simplex method.

<table>
<thead>
<tr>
<th>Volume percent yields</th>
<th>Maximum allowable product rate (bbl/day)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude #1</td>
<td>Crude #2</td>
</tr>
<tr>
<td>Gasoline</td>
<td>70</td>
</tr>
<tr>
<td>Kerosene</td>
<td>6</td>
</tr>
<tr>
<td>Fuel oil</td>
<td>24</td>
</tr>
</tbody>
</table>
1. Use of graph paper is allowed
2. Symbols have their usual meanings unless otherwise specified
3. Start each question and its part thereof from a new page

1(a) Explain how the reaction plane moves away from the gas-liquid interface with time for the mass transfer into semi infinite medium accompanied by an instantaneous chemical reaction. Show that at any time \( t \), its distance from the interface is \( \sqrt{4 \alpha t} \).

OR

1(a') Derive the following form of Fick’s first law

\[
\bar{J}_A = -\frac{D_{AB} \bar{\nabla} W_A}{cM_A M_B}
\]

1(b) Water (B) at 25 °C, in contact with pure CO\(_2\) (A) at 1 atm, flows as a film down a vertical wall 1 m wide and 3 m high at a Reynolds number of 25. Using the following properties, estimate the rate of absorption of CO\(_2\) in water in kmol/s.

- Diffusivity of CO\(_2\) in water at 25 °C and 1 atm = 1.96 \times 10^{-9} m^2/s
- Solubility of CO\(_2\) in water at 25 °C and 1 atm = 0.034 kmol/m^3
- Density of CO\(_2\)-water solution = 1000 kg/m^3
- Viscosity of CO\(_2\)-water solution = 8.9 \times 10^{-4} kg/m-s

OR

1(b') Solute \( A \) is diffusing at unsteady state into a semi infinite medium of pure B and undergoes a first-order reaction with B (reaction rate constant \( k_1 = 1 \times 10^{-4} \text{s}^{-1} \)). Solute \( A \) is dilute with an interfacial concentration of 1.0 kmol/m\(^3\). The diffusivity of \( A \) in \( B \) is \( D_{AB} = 1 \times 10^{-9} \text{m}^2/\text{s} \). Calculate the concentration of \( A \) at the point 5 mm away from the interface and rate of mass transfer at interface after 1 h of contact of \( A \) and \( B \).
value of error function is given in the following table.

<table>
<thead>
<tr>
<th>$x$</th>
<th>0.1</th>
<th>0.2</th>
<th>1.0</th>
<th>1.1</th>
<th>1.2</th>
<th>1.3</th>
<th>1.4</th>
<th>1.5</th>
<th>1.6</th>
</tr>
</thead>
<tbody>
<tr>
<td>$erf(x)$</td>
<td>0.1125</td>
<td>0.2227</td>
<td>0.8427</td>
<td>0.8802</td>
<td>0.9103</td>
<td>0.9340</td>
<td>0.9523</td>
<td>0.9661</td>
<td>0.9763</td>
</tr>
</tbody>
</table>

2(a) For absorption operation, derive the following expression for the number of overall gas transfer unit for dilute solution

$$N_{OG} = \frac{y_1 - y_2}{(y - y^*)_{LM}}$$

2(b) A CO₂ (B)-rich vapor contains 2 mole% ethyl alcohol (A). It is required to recover 97% of ethyl alcohol by absorption with pure water in a sieve-tray tower. The vapor enters at a flow rate of 180 kmol/h at 30°C and 110 kPa. For the water flow rate of 1.5 times the minimum at 30°C and 110 kPa, determine the number of equilibrium stages required for counter-current flow of liquid and gas, assuming isothermal, isobaric conditions in the tower. The equilibrium relationship for CO₂-ethyl alcohol at the prevailing condition is $y = 0.57x$

OR

2'(b) A soluble gas is absorbed in water using a packed tower. The equilibrium relationship may be taken as $y = 0.06x$. Terminal conditions are as follows:

<table>
<thead>
<tr>
<th></th>
<th>Top</th>
<th>Bottom</th>
</tr>
</thead>
<tbody>
<tr>
<td>$x$</td>
<td>0</td>
<td>0.08</td>
</tr>
<tr>
<td>$y$</td>
<td>0.001</td>
<td>0.009</td>
</tr>
</tbody>
</table>

If individual height of gas and liquid transfer unit are 0.36m and 0.24m respectively, what is the height of the packed section?

3(a) Define the following terms absolute humidity, relative humidity, and dew point related to vapor-gas mixture

3(b) A packed counter-current water cooling tower using a gas flow rate of 1.356 kg dry air/s.m² and a water flow rate of 1.356 kg water/s.m² is to cool water from 43.3 °C to 29.4°C. The entering air at 29.4 °C has a wet bulb temperature of 23.9 °C. The mass transfer coefficient $k_g a$ is estimated as $1.207 \times 10^{-7}$ kmol/s.m².Pa and $h_t a / k_g a M_b P_t$ is $4.187 \times 10^4$. The tower operates at a pressure of 1 atm. Calculate the height of the packed tower.
A mixture of nitrogen and acetone vapor at 800 mmHg total pressure, 25 °C, has a percentage saturation of 80%. Calculate (a) the absolute molal humidity, (b) the absolute humidity, (c) the partial pressure of acetone, (d) the relative humidity, and (e) the dew point.

The vapor pressure of acetone in mmHg at any temperature in °C is given by

$$\log p^* = 7.02447 - \frac{1161.0}{t + 224}$$

A plant wishes to dry a certain type of fibreboard in sheets 1.2 m by 2 m by 12 mm. to determine the drying characteristics, a 0.3 m by 0.3 m sample of the board, with the edges sealed so that the drying took place from the two large faces only, was suspended from a balance in a laboratory cabinet drier and exposed to a current of hot, dry air. The initial moisture content was 75%. The sheet lost weight at the constant rate of $1 \times 10^{-4}$ kg/s until the moisture content fell to 60%, whereupon the drying rate fell. Measurement of the rate of drying were discontinued, but after a long period of exposure to this air it was established that the equilibrium moisture content was 10%.

The dry mass of the sample was 0.9 kg. all moisture contents are on wet basis.

Determine the time for drying the large sheets from 75% to 20% moisture under the same drying conditions.

1000 kg of hot solution of MgSO₄·7H₂O containing 30 wt% MgSO₄ is cooled to 15 °C where crystals of MgSO₄·7H₂O are precipitated. The solubility at 15 °C is 24.5 wt% anhydrous MgSO₄ in the solution. Calculate the yield of crystals obtained if 5% of the original water in the system evaporates on cooling. Molecular weights of MgSO₄ and H₂O are 120.39 and 18.02 respectively.

(Fig. Attached)
1(a) Fluidized bed coal combustors are being used in Mega Thermal Power Stations. One such giant power plant would be fed 240 tons of coal/hr (90% C, 10% H), 50% of it would burn within the battery of primary fluidized beds, the other 50% elsewhere in the system. Find the rate of reaction within the beds, based on the oxygen used.

OR

1(a') Experiment shows that the homogeneous decomposition of ozone proceeds with a rate

\[-r_{O_3} = k [O_3]^2 [O_2]^{-1}\]

Suggest a two-step mechanism (with mathematical proof) to explain this rate and state how you would further test this mechanism.

1(b) For the second-order, bimolecular second-order reaction,

\[A + B \leftrightarrow R + S\]

\[2A \leftrightarrow 2R\]

with \(C_{A0} = C_{B0}, C_{R0} = C_{S0} = 0\)

Derive the performance equation for the batch reactor,

\[
\ln \left[ \frac{1 - (2 X_{Ae} - 1) (X_A/X_{Ae})}{1 - (X_A/X_{Ae})} \right] = 2 k_1 (1/ X_{Ae} - 1) C_{A0} t
\]

2(a) Pure gaseous A at about 3 atm and 30°C (120 mmol/litre) is fed into a 1-liter mixed flow reactor at various flow rates. As it decomposes, and the exit concentration of A is measured for each flow rate. From the following data, find a rate equation to

Contd......2
represent the kinetics of the decomposition of A. Assume that reactant A alone affects the rate.

<table>
<thead>
<tr>
<th>( v_0 ), liter/min</th>
<th>0.06</th>
<th>0.48</th>
<th>1.5</th>
<th>8.1</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C_A ), mmol/liter</td>
<td>30</td>
<td>60</td>
<td>80</td>
<td>105</td>
</tr>
</tbody>
</table>

A \( \rightarrow 3R \)

2(b) Qualitatively find the optimum temperature progression to maximize \( C_S \) for the reaction scheme

\[
\begin{align*}
A & \rightarrow R \rightarrow S_{\text{desired}} \rightarrow T \\
2 & \rightarrow U \\
4 & \rightarrow V \\
6 & \rightarrow W
\end{align*}
\]

\textit{Data:} \( E_1 = 10, E_2 = 25, E_3 = 15, E_4 = 10, E_5 = 20, E_6 = 25 \)

\textit{OR}

2 (b') Liquid reactant A decomposes as follows:

\[
R \quad r_R = k_1 C_A^2, \quad k_1 = 0.4 \text{ m}^3/\text{mol.min}
\]

\[
A \quad r_S = k_2 C_A, \quad k_2 = 2 \text{ min}^{-1}
\]

A feed of aqueous A (\( C_{A0} = 40 \text{ mol/m}^3 \)) enters a reactor, decomposes, and a mixture of A, R, and S leaves. Find \( C_R \), and \( C_S \), and \( \tau \) for \( X_A = 0.9 \) in a plug flow reactor.

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 for which the results of (pulse) tracer test are given below:

<table>
<thead>
<tr>
<th>( t, s )</th>
<th>0</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
<th>10</th>
<th>12</th>
<th>14</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C, \text{ mg/L} )</td>
<td>0</td>
<td>1</td>
<td>5</td>
<td>8</td>
<td>10</td>
<td>8</td>
<td>6</td>
<td>4</td>
<td>3</td>
<td>2.2</td>
<td>1.5</td>
<td>0.60</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 \( E \). Also calculate the conversion in the real reactor and compare it with the conversion in an ideal plug flow reactor.

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:

$$k_1 = 30 \ e^{-20000/RT} \quad k = \text{[min}^{-1}]$$

$$k_2 = 1.9 \ e^{-15000/RT} \quad R = 8.314 \text{ J/mol.K}$$

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) 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>

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-1 were obtained at 750 °F in a modified differential reactor. The feed consisted of pure butanol.

n-Butanol $\xrightarrow{\text{Silica-alumina catalyst}}$ Butyne + Water

A $\rightleftharpoons$ B + C

Suggest a mechanism and rate-controlling step that is consistent with the experimental data. Write the steps to evaluate the rate law parameters.

4(b) The following kinetic data are obtained in an experimental Carberry type basket reactor using 100 gram of catalyst in the paddles and at different flow rates from run to run:

$$A \rightarrow R$$

<table>
<thead>
<tr>
<th>$F_{A0}$, mol/min</th>
<th>0.14</th>
<th>0.42</th>
<th>1.67</th>
<th>2.5</th>
<th>1.25</th>
</tr>
</thead>
</table>

$C_{A0} = 10 \text{ mol/m}^3$  $C_A$, mol/m$^3$

8 6 4 2 1

Determine the amount of catalyst needed in a packed bed reactor for 75 % conversion of 1000 mol A/min of a $C_{A0} = 8 \text{ mol/m}^3$ feed.

OR

Contd...... 4
4 (b') Calculate the time needed to burn to completion particles of graphite \( R_c = 5 \text{ mm}, \rho_B = 2.2 \text{ gm/cm}^3, k'' = 20 \text{ cm/sec} \) 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.

Figure 1

Initial rate, \( r_{Ao} \) (lb mol (h)/(lb catalyst)) vs. \( P_{Ao} \) (atm)
2(a) A specific enzyme acts as catalyst in the fermentation of reactant A. At a given enzyme concentration in the aqueous feed stream (25 liter/min) find the volume of plug flow reactor needed for 95% conversion of reactant A ($C_{A0} = 2$ mol/liter). The kinetics of the fermentation at this enzyme concentration is given by:

$$-r_A = \frac{0.1 C_A}{1 + 0.5 C_A} \text{ mol L.min}^{-1}$$

OR

Contd......2
2 (a') Substance A in a liquid reacts to produce R and S as follows:

\[ \begin{align*}
\text{A} & \quad \text{(first order)} \\
& \quad \text{R} \\
& \quad \text{S} \quad \text{(first order)} \\
\end{align*} \]

A feed \((C_{A0} = 1, C_{R0} = 0, C_{S0} = 0)\) enters two mixed flow reactors in series, \((\tau_1 = 2.5 \text{ min}, \tau_2 = 5 \text{ min})\). Knowing the composition in the first reactor \((C_{A1} = 0.4, C_{R1} = 0.4, C_{S1} = 0.2)\), find the composition leaving the second reactor.

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) Pure A \((C_{A0} = 100)\) is fed to a mixed flow reactor, R and S are formed, and the following outlet concentrations are recorded. Find a kinetic scheme to fit this data.

<table>
<thead>
<tr>
<th>Run</th>
<th>(C_A)</th>
<th>(C_R)</th>
<th>(C_S)</th>
<th>(t, \text{ min})</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>50</td>
<td>40</td>
<td>10</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>40</td>
<td>40</td>
<td>20</td>
</tr>
</tbody>
</table>

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:

\[ \begin{align*}
A & \xrightarrow{k_1 = 30 \ e^{-20,000 / RT}} 1 \\
& \xrightarrow{k_2 = 1.9 \ e^{-15,000 / RT}} 2 \\
R & \quad \text{S} \\
R = 8.314 \text{ J/mol.K} \\
\end{align*} \]

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

Contd.......3
Show that the most favourable product distribution is obtained when the temperature satisfies the following condition

$$\frac{1}{T_{\text{opt}}} = \frac{R}{E_3 - E_2} \ln \left[ \frac{E_3 - E_1 \cdot k_{30}}{E_4 - E_2 \cdot k_{20}} \right]$$

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>
<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>

OR

4 (a') Derive the conversion-time expression for the reaction of a spherical particle with a fluid when diffusion through ash layer 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>$t$ (min)</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>
B.TECH. (AUTUMN SEMESTER) EXAMINATION
CHEMICAL
EQUILIBRIUM STAGE PROCESSES
CH-322

Maximum Marks: 60       Credits: 04       Duration: Three Hours

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

1(a) Discuss the effect of feed conditions in terms of “q” and optimum reflux ratio in case of distillation with reflux. [04]

1(b) Explain Batch distillation briefly. [03]

1(c) Derive the equation for the rectifying section in Ponchan Savarit Method. [08]

OR

1(e') An enriching section tower is fed 100 kg mol/hr of a saturated feed containing 40 mol % benzene (A) and 60 mol % toluene (B) at 101.32 kPa abs. The distillate is to contain 90 mol% benzene. The reflux ratio is set at 4:1. Calculate kg mol/hr distillate D and bottoms W and their compositions. Also calculate the number of theoretical plates required and minimum reflux ratio (Rm). Use equilibrium data given. [08]

2(a) Enumerate the different types of tray efficiencies encountered in distillation tower briefly. [05]

OR

2(a') Discuss briefly condensers and reboilers in distillation tower. [05]

2(b) A liquid feed to a distillation tower at 405.3 kPa abs is fed to a distillation tower. The composition in mole fraction is as follows: n-butane \( x_A = 0.3 \), n-pentane \( x_B = 0.25 \), n-hexane \( x_C = 0.25 \) and n-heptane \( x_D = 0.2 \). This feed is to be fractionated so that 90% of the n-hentanc (B) is recovered in the distillate and 90% of the n-hexane (C) in the bottoms. Calculate
(a) Moles per hour and composition of distillate and bottoms.
(b) Top Temperature (dew point) and boiling point of bottoms.
(c) Minimum stages for total reflux.

3 (a) Pure isopropyl ether \( V_{N+1} = 450 \text{ Kg/hr} \) is being used to extract an aqueous solution of 150 kg/hr with 30 wt % acetic acid (A) by counter current multistage extraction. The exit acid concentration in the aqueous phase is 10 wt%. Calculate the composition and amounts of the ether extract \( V_1 \) and the aqueous raffinate \( L_N \) and number of stages required. Use equilibrium data given.

3(b) In a single stage leaching of soyabeans oil from flaked soyabean with hexane, 100 kg of soyabean containing 20 wt % oil is leached with 100 kg of fresh solvent hexane. The value of \( N \) for the slurry underflow is essentially constant at 1.5 kg insoluble solid/kg solution retained. Calculate the amounts and composition of the overflow \( V_1 \) and the slurry \( L_1 \) leaving the stage.

4(a) Explain the principles of ion exchange method in reference with its industrial applications.

OR

4 (a') Explain the process of adsorption and various adsorption isotherms

4 (b) An aqueous solution containing a valuable solute is colored by small amounts of an impurity. Before crystallization, the impurity is removed by adsorption on a decolorizing carbon which adsorbs only insignificant amounts of the principal solute. Following data is obtained after laboratory test and the color intensity is measured on an arbitrary scale, proportional to the concentration of the colored substance. It is desired to reduce the color to 10% of its original value, 9.6. Determine the quantity of fresh carbon required per 1000 kg of solution for a single stage operation and for a two stage countercurrent operation using minimum total amount of carbon. The Freundlich equation is:

\[
Y^* = 8.191 \times 10^{-5} X^{1.66}
\]

Contd......3

FIGURES ENCLOSED
Data to be used:

<table>
<thead>
<tr>
<th>Kg carbon/kg soln</th>
<th>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>8.1</td>
<td>6.3</td>
<td>4.3</td>
<td>1.7</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Figure 1 Equilibrium K-values for light hydrocarbons systems at 405.3 kPa
### A.3-24 Acetic Acid–Water–Isopropyl Ether System, Liquid–Liquid Equilibria at 293 K or 20°C

<table>
<thead>
<tr>
<th>Water Layer (wt %)</th>
<th>Isopropyl Ether Layer (wt %)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Acetic Acid</strong></td>
<td><strong>Water</strong></td>
</tr>
<tr>
<td>0</td>
<td>98.8</td>
</tr>
<tr>
<td>0.69</td>
<td>98.1</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>
<tr>
<td>13.30</td>
<td>84.4</td>
</tr>
<tr>
<td>25.50</td>
<td>71.1</td>
</tr>
<tr>
<td>36.70</td>
<td>58.9</td>
</tr>
<tr>
<td>44.30</td>
<td>45.1</td>
</tr>
<tr>
<td>46.40</td>
<td>37.1</td>
</tr>
</tbody>
</table>


### TABLE 11.1-1. Vapor-Pressure and Equilibrium-Mole-Fraction Data for Benzene–Toluene System

#### Vapor Pressure

<table>
<thead>
<tr>
<th>Temperature</th>
<th>Benzene</th>
<th></th>
<th>Toluene</th>
<th></th>
<th>Mole Fraction Benzene at 101.325 kPa</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>K</td>
<td>°C</td>
<td>kPa</td>
<td>mm Hg</td>
<td>kPa</td>
</tr>
<tr>
<td>353.3</td>
<td>80.1</td>
<td>101.32</td>
<td>760</td>
<td></td>
<td>46.0</td>
</tr>
<tr>
<td>358.2</td>
<td>85</td>
<td>116.9</td>
<td>877</td>
<td></td>
<td>54.0</td>
</tr>
<tr>
<td>363.2</td>
<td>90</td>
<td>135.5</td>
<td>1016</td>
<td></td>
<td>63.3</td>
</tr>
<tr>
<td>368.2</td>
<td>95</td>
<td>155.7</td>
<td>1168</td>
<td></td>
<td>74.3</td>
</tr>
<tr>
<td>373.2</td>
<td>100</td>
<td>179.2</td>
<td>1344</td>
<td></td>
<td>86.0</td>
</tr>
<tr>
<td>378.2</td>
<td>105</td>
<td>204.2</td>
<td>1532</td>
<td></td>
<td>101.32</td>
</tr>
<tr>
<td>383.8</td>
<td>110.6</td>
<td>240.0</td>
<td>1800</td>
<td></td>
<td>0</td>
</tr>
</tbody>
</table>
### Question

<table>
<thead>
<tr>
<th>Q.No.</th>
<th>Question</th>
<th>M.M.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1(a)</td>
<td>Explain the difference in the growth of bacteria, yeast and mould</td>
<td>[06]</td>
</tr>
<tr>
<td>1(b)</td>
<td>Discuss two important phases of a typical batch growth curve of an industrial bacteria with the help of a neat diagram</td>
<td>[06]</td>
</tr>
<tr>
<td>1(c)</td>
<td>How will you measure the microbial growth? Explain it clearly.</td>
<td>[3]</td>
</tr>
</tbody>
</table>

**OR**

<table>
<thead>
<tr>
<th>Q.No.</th>
<th>Question</th>
<th>M.M.</th>
</tr>
</thead>
<tbody>
<tr>
<td>1'(a)</td>
<td>Discuss the methods of medium preparation and its preservation with example.</td>
<td>[5]</td>
</tr>
<tr>
<td>1'(b)</td>
<td>Show that the lactic acid bacteria can behave as growth associated and non-growth associated as well.</td>
<td>[5]</td>
</tr>
<tr>
<td>1'(c)</td>
<td>Describe the process of inoculums preparation for microbial cultivation.</td>
<td>[5]</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Q.No.</th>
<th>Question</th>
<th>M.M.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2(a)</td>
<td>Derive an equation to determine the rate of an enzyme catalysed reaction with non-competitive inhibition</td>
<td>[8]</td>
</tr>
<tr>
<td>2(b)</td>
<td>Explain Covalent bonding and adsorption as method of cell immobilisation.</td>
<td>[7]</td>
</tr>
</tbody>
</table>

**OR**

<table>
<thead>
<tr>
<th>Q.No.</th>
<th>Question</th>
<th>M.M.</th>
</tr>
</thead>
<tbody>
<tr>
<td>2'(a)</td>
<td>What is effect of substrate conc., temperature, and pH at the rate of enzymatic reaction? Explain them with suitable examples.</td>
<td>[6]</td>
</tr>
<tr>
<td>2'(b)</td>
<td>Discuss the advantages of immobilized enzymes? Explain any two methods of immobilization of enzymes</td>
<td>[9]</td>
</tr>
</tbody>
</table>
3(a) Write down the mathematical equations for the following important parameters:
   i) $P_g$  ii) $N_p$ and iii) $N_a$

3(b) Explain clearly the mechanism of sterilization of the medium in bioprocess industries.

3(c) What is the need of sterilized air in the manufacturing of bioprocess industries? Explain one of the industrial methods of sterilized air for production of Penicillin.

4(a) Discuss production scheme of Lactic acid with the help of a neat diagram. Also mention the industrial applications of the acid.

4(b) What are concentrations of bio products in fermentation broth (cell as product itself, extra cellular and intra cellular) at the end of bio process? Suggest and briefly discuss a suitable scheme of down stream processing for production of an enzyme.
Liquid A diffuses through a stagnant liquid film onto a plane solid surface consisting of B, reacts there to produce R, according to the first-order rate given below. Product R diffuses back into the main stream.

\[-r_A = k C_A\]

Develop the overall rate expression for L/S reaction accounting for both the mass transfer and the reaction steps. Show that the resistances are additive.

Hydrogen sulphide is removed from coal gas by passing the gas through a moving bed of iron oxide particles. In the coal gas environment (consider uniform), the solids are converted from \(\text{Fe}_2\text{O}_3\) to \(\text{FeS}\) by the shrinking core model (SCM), reaction control, \(\tau = 1\) hr. Find the fractional conversion of iron oxide to iron sulphide, if the RTD of solids in the reactor is approximated by

\[E(t) = \delta (t - t_0), \quad t_0 = 45\ \text{min}.
\]

OR

At high pressure \(\text{CO}_2\) is absorbed into a solution of \(\text{NaOH}\) in a packed column. The reaction is as follows:

\[\text{CO}_2 + 2\text{NaOH} \rightarrow \text{Na}_2\text{CO}_3 + \text{H}_2\text{O}, \quad \text{with } -r_{\text{A}} = kC_A C_B\]

Let \(\text{CO}_2\) and \(\text{NaOH}\) be denoted by A and B respectively. Derive the general rate expression for the case of slow reaction with respect to mass transfer.
2(a)  t-Butyl alcohol (TBA) is an important octane enhancer that is used to replace lead additives in gasoline. TBA is produced by the liquid phase hydration of isobutene (I) by water (W) over an Amberlyst-15 catalyst. The system is normally a multiphase mixture of hydrocarbon, water and solid catalyst. However, the use of co-solvents or excess TBA can achieve reasonable miscibility. The reaction mechanism is believed to be:

\[ \begin{align*}
I & \rightleftharpoons I.S \\
W & + S \rightleftharpoons W.S \\
W.S & + I.S \rightleftharpoons TBA.S + S \\
TBA.S & \rightleftharpoons TBA + S
\end{align*} \]

Derive a rate law assuming:

(i) The surface reaction is limiting

(ii) The reaction follows Eley-Rideal kinetics, and surface reaction is limiting.

\[ \begin{align*}
I.S & + W \rightleftharpoons TBA.S
\end{align*} \]

2 (b)  The rate law for the hydrogenation (H) of ethylene (E) to for ethane (A) over a cobalt-molybdenum catalyst is

\[ r_E = \frac{KP_E P_H}{1 + K_E P_E} \]

Suggest a mechanism and rate-limiting step consistent with the rate law.

OR

2(b')  What are the different modes of catalyst deactivation? Write the general forms of the equation for catalyst activity under the above modes of deactivation

3(a)  A first-order, heterogeneous, irreversible reaction is taking place within a catalyst pore which is plated with platinum entirely along the length of the pore. The reactant concentration at the plane of symmetry (equal distance from the pore mouths) of the pore is equal to one-tenth the concentration of the pore mouth. The concentration at the pore mouth is 0.001 g mol / dm³, the pore length (2L) is 2 x 10⁻³ cm, and the diffusion coefficient is 0.1 cm²/s.

Derive the model equation along with the relevant boundary conditions describing the diffusion-reaction process. Solve the equation to arrive at the expression for effectiveness factor. What is the concentration of reactant at a distance of L/2?
3(b) Gaseous A reacts \((A \rightarrow R)\) in an experimental Carberry type basket reactor. From the following conversion data at various conditions find a rate equation to represent the reaction:

\[
v_0, \text{ m}^3/\text{hr} \quad 3 \quad 2 \quad 1.2 \quad \text{Mixed flow} \\
X_A \quad 0.2 \quad 0.3 \quad 0.5 \quad C_{A0} = 10 \text{ mol/m}^3, \ W = 4 \text{ gm}
\]

4(a) What is the significance of Thiele Modulus in heterogeneous solid catalyzed reactions? Explain Weisz-Prater criterion for internal diffusional limitations in catalytic reaction.

4(b) The catalytic hydrogenation of methyl linoleate to methyl oleate was carried out in a laboratory-scale slurry reactor in which hydrogen gas was bubbled up through the liquid containing spherical catalyst pellets. The pellet density is 2 g/cm\(^3\). The following experiments were carried out at 25\(^\circ\)C:

<table>
<thead>
<tr>
<th>Run</th>
<th>Partial Pressure of H(_2) (atm)</th>
<th>Solubility of H(_2) (g mol/dm(^3))</th>
<th>(H_2) Rate of Reaction (g mol/dm(^3) min)</th>
<th>Catalyst Charge (g/dm(^3))</th>
<th>Catalyst Particle Size ((\mu)m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>3</td>
<td>0.007</td>
<td>0.014</td>
<td>3.0</td>
<td>12</td>
</tr>
<tr>
<td>2</td>
<td>18</td>
<td>0.042</td>
<td>0.014</td>
<td>0.5</td>
<td>50</td>
</tr>
<tr>
<td>3</td>
<td>3</td>
<td>0.007</td>
<td>0.007</td>
<td>1.5</td>
<td>50</td>
</tr>
</tbody>
</table>

It has been suggested that the overall reaction rate can be enhanced by increasing the agitation, decreasing the particle size, and installing a more efficient sparger. With which, if any, of these recommendations do you agree? Support your decisions with calculations. Determine the effectiveness factor and the rate constant?

**OR**

Disposal of industrial wastes by incineration is a feasible process if the toxic chemicals can be completely decomposed into harmless substances. One study carried out concerned the optimization and burning of a liquid stream of P0HCs. The following data gives the burning droplet diameter as a function of time.

<table>
<thead>
<tr>
<th>Time (arbitrary)</th>
<th>20</th>
<th>40</th>
<th>50</th>
<th>70</th>
<th>90</th>
<th>110</th>
</tr>
</thead>
<tbody>
<tr>
<td>Diameter (arbitrary)</td>
<td>9.7</td>
<td>8.8</td>
<td>8.4</td>
<td>7.1</td>
<td>5.6</td>
<td>4.0</td>
</tr>
</tbody>
</table>

Assuming that the combustion of the hazardous waste follows a shrinking core model, show that the combustion reaction is film diffusion controlled.
Maximum Marks: 60  Credits: 04  Duration: Three Hours

Answer all the questions. Assume suitable data if missing.

1. a. Describe the differences between consumer and producer goods/services. Why is it more difficult to estimate the demand for producer goods? 03
   b. With the help of suitable examples explain the difference between monopoly and oligopoly. 03
   c. Eight years ago, a large capacity truck was purchased for Rs. 115,000 to provide short haul earthmoving services. The company sold it today for Rs. 45,000. Operating and maintenance cost averaged Rs. 10,500 per year. A complete overhaul at the end of year 4 cost an extra Rs. 3600. Calculate the present worth of the truck at 8% per year compounded quarterly.

   OR

1'. a. What are economic indicators? Name some and discuss any one of them in detail. 06
   b. For the cash flow shown, determine the present worth, if the interest rate is 12% per year
      
      | Year | 1   | 2   | 3   | 4   | 5   | 6   | 7   | 8   | 9   | 10  |
      | Cash Flow(Rs.) | 130 | 130 | 130 | 160 | 190 | 220 | 250 | 280 | 310 |

2 a. Differentiate between
   i. Physical depreciation and functional depreciation
   ii. Book value and market value
   An asset that is depreciated over a 5 year period by straight line method has a book value of Rs. 62,000 in year 3 with a depreciation charge of Rs. 26,000 per year. Determine the first cost of the asset and the assumed salvage value.

   OR

2 a'. Two alternatives shown are under consideration for improving the security of an organisation. Determine which one should be selected on the basis of a B/C analysis, an interest rate of 7% and a 10 year study period.

Contd......2
b. Compare the following two alternatives for an interest rate of 10% pa.

<table>
<thead>
<tr>
<th></th>
<th>Alternative 1</th>
<th>Alternative 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>First cost (Rs.)</td>
<td>25000</td>
<td>130,000</td>
</tr>
<tr>
<td>Annual cost (Rs./year)</td>
<td>9000</td>
<td>2500</td>
</tr>
<tr>
<td>Salvage Value (Rs.)</td>
<td>3000</td>
<td>150,000</td>
</tr>
<tr>
<td>Life, years</td>
<td>3</td>
<td>∞</td>
</tr>
</tbody>
</table>

3. a. Differentiate between top managers, middle managers and first line managers.

b. What are the advantages and limitations of group decision making? Differentiate between Delphi group decision making and nominal group decision making techniques.

c. Calculate the expected value for the alternatives given below:

<table>
<thead>
<tr>
<th>Probability</th>
<th>First Cost (Rs.)</th>
<th>Salvage Value (Rs.)</th>
<th>Annual Operating Cost (Rs.)</th>
<th>Life (years)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>20,000</td>
<td>2,000</td>
<td>11,000</td>
<td>5</td>
</tr>
<tr>
<td>0.5</td>
<td>25,000</td>
<td>4,000</td>
<td>9000</td>
<td>5</td>
</tr>
<tr>
<td>0.3</td>
<td>28,000</td>
<td>5,000</td>
<td>5,000</td>
<td>5</td>
</tr>
</tbody>
</table>

Assume an interest rate of 10% compounded semiannually.

4. a. Define span of control. Differentiate between narrow and wide spans of control and discuss their implications.

b. Define strategic planning and discuss its basic foundation. Explain how strategic planning is related to operational planning.

4' OR

a. Define motivation and discuss the important implications of the “two factor theory” of motivation.

b. What is meant by the leadership continuum diagram? Discuss the important leadership styles on this continuum.

5. a. Differentiate between

   i. Balance sheet and income statement
   ii. Q/R inventory system and periodic inventory system

b. Discuss in detail the need and various methods used for forecasting human resource demand and supply.
2013-14
B.TECH. (AUTUMN SEMESTER) EXAMINATION
CHEMICAL/PETROCHEMICAL ENGG.
HEAT TRANSFER OPERATIONS
PK-312 N/CH-312

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) What is the driving force for (a) heat transfer (b) electric current flow (c) fluid flow (d) mass transfer. [02]
1(b) Define effectiveness of a fin. [01]
1(c) Obtain an expression for steady state one-dimensional heat transfer rate and temperature distribution in a plane wall of thickness $L$, whose thermal conductivity varies linearly in specified temperature range as $K(T)=K_0(1+\beta T)$, where $K_0$ and $\beta$ are constant. The wall surface at $x=0$ is maintained at $T_1$, while the surface at $x=L$ is maintained at $T_2$. [05]
1(d) A heat exchanger wall consists of a steel plate 2mm thick. One surface of the plate exposed to a fluid at 82°C, with heat transfer coefficient of 2100 W/m²K and the other surface exposed to a fluid at 32°C, has a heat transfer coefficient of 4500 W/m²K.
   i. Draw the electrical analogue of the 'thermal circuit'
   ii. Calculate the surface temperature of the plate
   iii. Calculate the heat flux through the plate
   iv. Determine what % improvement would be obtained in the heat flux if the 2mm thick plate was made of aluminium.
Assume the thermal conductivities for the steel and aluminium are 55 and 202 W/m.K respectively. [07]

OR

1(d') A hot steam pipe ($k = 50$ W/m.°C) having an inner diameter of 8 cm is at 250°C. The
thickness of the wall is 5.5 mm. The pipe is covered with a 90 mm layer of insulation 
(k = 0.2 W/m·°C) followed by a 40 mm layer of insulation (k = 0.3 W/m·°C). The 
outside temperature of the insulation is 20 °C. Calculate the heat loss per unit of the 
pipe length.

2(a) What is natural convection? How is it different from forced convection? In which case 
(Natural or Forced convection) heat transfer coefficient is generally high?

2(b) Do you expect the convective heat transfer coefficient in the thermally developing region 
to be higher or lower than the convective heat transfer coefficient in the fully developed 
temperature profile region? Support your answer with qualitative logic.

2(c) Define Grashoff's Number. How is it different from Reynolds's Number?

2(d) Water flowing at 2 kg/s through a 40-mm diameter tube is to be heated from 25 °C to 
75 °C by maintaining the tube surface temperature at 100 °C.

[properties of water: viscosity \( \mu = 547 \times 10^{-6} \text{N.s/m}^2 \), specific heat capacity \( c_p = 4.181 \text{kJ/kg} \) 
°C and thermal conductivity \( k = 0.643 \text{W/(m °C)} \).]

i. Is the flow laminar or turbulent?
ii. Assuming fully developed conditions, Calculate the heat transfer coefficient.
iii. Calculate the rate of heat transfer \( q \).

OR

2(d') A large vertical plate 4.0 m high is maintained at 60 °C and exposed to atmospheric air 
at 10 °C. Calculate the heat transfer if plate is 10 m wide. Air is assumed to be an ideal 
gas with properties in these temperature range as-
Thermal conductivity = 0.02685 W/(m·°C), Density = 1.1700 kg/m³
Viscosity = 1.846 \times 10^{-5} \text{kg/(m.s)} Specific heat capacity = 1.0057 \text{kJ/(kg·°C)}

Churchill and chu correlation for vertical plate is given as-

\[
\overline{Nu_D} = \left\{ 0.6 + \frac{0.387 Ra_D^{1/6}}{[1 + (0.559/Pr)^{9/16}]^{8/27}} \right\}^2
\]

Contd.....3
3(a) What are the common causes of fouling in a heat exchanger? How does fouling affect heat transfer and pressure drop? [03]

3(b) What is difference between film and drop-wise condensation? Which one has higher heat transfer coefficient? [02]

3(c) Water at the rate of 68 kg/min is heated from 35 °C to 75 °C by an oil having specific heat of 1.9 kJ/(kg.°C). The fluids are used in a counter flow double pipe heat exchanger, the oil enters the exchanger at 110 °C and leaves at 75 °C. The overall heat transfer coefficient is 320 W/(m².°C). Calculate the heat exchanger area.

3(c') Derive expression for heat transfer rate for a co-current double pipe heat exchanger.

3(d) A continuous single-effect evaporator concentrates 9072 kg/h of a 1.0 wt% salt solution entering at 311.0 K (37.8°C) to a final concentration of 1.5 wt%. The vapour space of the evaporator is at 101.325 kPa (1.0 atm abs) and the steam supplied is saturated at 143.3 kPa. The overall heat transfer coefficient is 1704 W/(m².K). Calculate the amounts of vapor and liquid product and the heat-transfer area required. Assume that, since it is dilute, the solution has the same boiling point as water. It is given that-

Specific heat of feed : 4.14 kJ/(kg.K)
Boiling point of dilute solution is assumed to be that of water at 101.32 kPa,
\[ T_1 = 373.2 \text{ K (100 °C)} \] as datum temperature.
Latent heat of water at 373.2 K is 2257 kJ/kg.
Latent heat of the steam, \( \lambda \) at 143.3 kPa (saturation temp., \( T_S = 383.2 \text{ K} \)) is 2230 kJ/kg.

4(a) If a surface emits 200 W of radiant energy at a temperature of \( T \), how much energy will it emit at a temperature of \( 2T \)? [02]

4(b) Determine the view factors from the base of the pyramid (figure 4.1) to each of its side surfaces. The base of the pyramid is a square, and its side surfaces are isosceles triangles.

Contd......4
4 (c) Determine the average emissivity of the surface and its emissive power of an opaque surface at 800 K whose spectral emissivity function at 800 K is approximated as bellow and shown in figure 4.2-

\[
\varepsilon_\lambda = \begin{cases} 
0.3, & 0 \leq \lambda \leq 3 \mu m \\
0.8, & 3 \mu m \leq \lambda \leq 7 \mu m \\
0.1, & 7 \mu m \leq \lambda \leq \infty 
\end{cases}
\]

4 (d) A refractory slab is facing a black furnace wall such that they are parallel to each other. If the furnace wall is at 1550 K and the surface of refractory slab is at 1450 K, estimate the rate of heat gain by radiation per unit surface of the refractory, if the emissivity of refractory is 0.45 and furnace is assumed to be an ideal black body.

OR

4(d') Two very large parallel planes with emissivities 0.3 and 0.8 exchange heat. Find the percentage reduction in the heat transfer when a polished-aluminium radiation shield (emissivity = 0.04) is placed between them.

<table>
<thead>
<tr>
<th>(\lambda T) (\mu m \times K)</th>
<th>(I_\lambda)</th>
<th>(\int \lambda T \frac{d\lambda}{\mu m \times K})</th>
<th>(I_\lambda)</th>
</tr>
</thead>
<tbody>
<tr>
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Figure: 4.1

Figure: 4.2