2018-2019
M.TECH. AUTUMN (I - SEMESTER) EXAMINATION
(PETROLEUM STUDIES)
ADVANCED ENGINEERING MATHEMATICS
AM-641
Credits-04

Maximum Marks: 60
Duration: Two Hours

Answer all questions.

1(a) Define vector space. Are the following vectors (1,2,1), (2,1,4), (4,5,6), and (1,8,-3) linearly dependent? If so find the relation between them.

OR

1(a') Define a linear transformation. Let $T : R^3 \rightarrow R^1$ be defined by the rule $T(x_1 , x_2 , x_3) = (x_1^2 + x_2^2 + x_3^2)$. Show that $T$ is not linear transformation for $x = y = (1,0,0)$.

1(b) Define an inner product space and show that $|\langle x, y \rangle| \leq \|x\| \|y\|$ where $x$ and $y$ be any two vectors in an inner product space.

2(a) Prove that the matrix $A = \begin{bmatrix} 10 & 2 \\ 2 & 7 \end{bmatrix}$ is similar to the matrix $B = \begin{bmatrix} 11 & 0 \\ 0 & 6 \end{bmatrix}$ via a non-singular matrix $P = \begin{bmatrix} \frac{2}{\sqrt{5}} & \frac{1}{\sqrt{5}} \\ \frac{1}{\sqrt{5}} & \frac{2}{\sqrt{5}} \end{bmatrix}$.

2(b) (i) Find the eigen values of $3A^2 + 5A - 6A + 2I$, where $A = \begin{bmatrix} 2 & -1 & -1 \\ -1 & 2 & -1 \\ 1 & 1 & 2 \end{bmatrix}$.

(ii) $A$ and $P$ be square matrices of the same type and if $P$ be invertible, show that $A$ and $P^{-1}AP$ have the same characteristic roots.

OR

2(b') Define Rayleigh Quotient and hence use it to estimate the eigen values of the matrix $\begin{bmatrix} 5 & 4 & -4 \\ 4 & 5 & 4 \\ -4 & 4 & 5 \end{bmatrix}$.

contd...2.
3(a) Solve $u_{xx} + u_{yy} = 0$ in $0 \leq x \leq 4$, $0 \leq y \leq 4$ over the square mesh of side 4 units satisfying the following boundary conditions:

$U(0, y) = 0$, $U(4, y) = 12 + y$, $U(x, 0) = 3x$ and $U(x, 4) = x^2$.

Take $h = k = 1$ and obtain the result for one iteration.

3(b) Using Crank-Nicholson's method to solve $u_{xx} = 16u_t$, $0 < x < t$, $t > 0$,

given $U(x, 0) = 0$, $U(0, t) = 0$, $U(1, t) = 50t$. Compute $U$ for two steps in $t$

direction taking $h = \frac{1}{4}$.

OR

3(b') Consider $u_{tt} = 4u_{xx}$ with boundary conditions $U(0, t) = 0 = U(4, t)$, $U_t(x, 0) = 0$ (CO3) and $U(x, 0) = x(4 - x)$. Solve numerically.

4(a) Using Fourier integral, show that

$$\int_{0}^{\infty} \frac{1 - \cos \pi \lambda}{\lambda^2} \sin \lambda d\lambda = \begin{cases} \frac{\pi}{2} & \text{when } 0 < \xi < \pi \\ 0 & \text{when } \xi > \pi \end{cases}$$

OR

4(a') Find the Fourier transform of $f(x) = \begin{cases} 1 - x^2, & |x| \leq 1 \\ 0, & |x| > 1 \end{cases}$.

4(b) A tightly stretched flexible string has its ends fixed at $x = 0$ and $x = l$. At time $t = 0$ the string is given a shape defined by $F(x) = \mu x(l - x)$, where $\mu$ is a constant and then released. Find the displacement of any point $x$ of the string at any time $\xi > 0$. 

(CO4)
Q1(a) Derive the equation to obtain following form of the VLE (vapour liquid equilibrium) relationship for multi component mixture used in the design of distillation column.

\[ y_i = \frac{\alpha_{ij} x_i}{1 + \sum_{i=1}^{N_c} (\alpha_{ij} - 1) x_i} \]

\( \alpha_{ij} \) = relative volatility
\( x_i \) = mole fraction of component \( i \) in liquid phase
\( y_i \) = mole fraction of component \( i \) in vapour phase
\( N_c \) = number of components present in the mixture
\( j \) = reference component

Q1(b) A closed kettle as shown in the figure below having total surface area \( A \) (m\(^2\)) is heated through this surface by condensing steam at temperature \( T \) (K). The kettle is charged with M kg of liquid of heat capacity \( C_p \) (J/Kg at a temperature of \( T_0 \) (K). If the process is controlled by heat transfer coefficient \( h \) (W/m\(^2\)K), how does the temperature of the liquid vary with time?
Q1' (b)

Explain briefly the following models and their application in chemical engineering:

(i) Linear and nonlinear model
(ii) Static and dynamic model
(iii) Lumped parameter and distributed parameter model
(iv) Fundamental and empirical model

Q2

A Newtonian fluid is in laminar flow in a narrow slit formed by two parallel walls at distance 2B apart. It is understood that B << W, so that 'edge' effects are unimportant. Make a differential momentum balance and obtain the model equations for the following situation:
(a) Momentum flux and velocity distributions:

(i) \[ \tau_{xx} = \left( \frac{P(0) - P(L)}{L} \right) x \]

(ii) \[ v_x = \left( \frac{P(0) - P(L)}{2L\mu} \right) B^2 \left[ 1 - \left( \frac{x}{B} \right)^2 \right] \]

In these expressions \( P=p+pgh=p-pgz \)
Where \( \rho = \) density of fluid

(b) Ratio of average velocity to the maximum velocity for the flow.

(c) The slit analogue of the Hagen-Poiseuille equation

OR

Q2*

In a batch reactor the content is heated to reaction temperature with saturated steam supplied to the jacket at temperature \( T_s \). The reactor is stirred at fixed rpm and cooling water is passed through coil and exothermic heat is removed and desired temperature is maintained. Following consecutive reactions that take place in the reactor:

\[ A \xrightarrow{k_1} B \xrightarrow{k_2} C \]

Assumed \( A \rightarrow B \) has second order kinetics whereas \( B \rightarrow C \) has first order kinetics. Where \( B \) is desired product and if the reaction goes on for long time the yield of undesired waste \( C \) will be high. If the reaction stops early conversion of \( A \) may be very low.

Mentioning the standard assumptions, derive the model to obtain following equations:

(i) \[ \frac{dC_A}{dt} = -k_1 C_A^2 \]

(ii) \[ \frac{dC_B}{dt} = k_1 C_A^2 - k_2 C_B \]

(iii) \[ \frac{dT}{dt} = \frac{(-\Delta H_1)}{\rho C_p} k_1 C_A^2 + \frac{(-\Delta H_2)}{\rho C_p} k_2 C_B + \frac{U_f A_f}{\rho C_p V_f} (T_s - T) - \frac{U_e A_e}{\rho C_p V_e} (T - T_e) \]

contd...
Q3 Derive the model for pH neutralization CSTR (Continuous stirred tank reactor) as shown in the following Figure.
Derive the process model and write the assumptions to obtain the following equations:

(i) \[
\frac{dx_1}{dt} = \frac{F_A}{V} (x_{1,i} - x_1) - \frac{F_{B}}{V} x_1
\]

(ii) \[
\frac{dx_2}{dt} = \frac{F_B}{V} (x_{2,i} - x_2) - \frac{F_A}{V} x_2
\]

(iii) \[
\frac{dx_3}{dt} = \frac{F_B}{V} (x_{3,i} - x_3) - \frac{F_A}{V} x_3
\]

(iv) \[
[H^+] + x_2 + x_3 - x_i - \frac{K_E}{[H^+]} x_3 + \frac{K_D[H^+]}{K_L} = 0
\]

and

\[pH = -\log_{10}[H^+]\]

Where as:

- \(F_A\) = volumetric flow rate of acidic solution
- \(x_{1,i}\) = composition of acidic solution
- \(F_B\) = volumetric flow rate of alkaline solution
- \(x_{2,i}\) = composition of alkaline solution
- \(x_3, i\) = Buffer agent
- \(HA\) = Strong Acid
- \(BOH\) = Strong Base
- \(BX\) = Buffer Agent
- \(H^+\) and \(OH^-\) = ions

Q4

Consider a non isothermal CSTR as shown in figure in which a first order exothermic irreversible chemical reaction takes place.

A \(\rightarrow\) B

Reactant A is continuously supplied to reactor with a volumetric flow rate \(F_i\) a molar concentration \(C_{Af}\) and Temperature \(T_f\). An exit stream which contains a mixture of both reactant A and product B, is withdrawn from the reactor with a volumetric flow rate \(F_o\), composition \(C_A\) and temperature \(T\). A coolant stream with volumetric flow rate \(F_j\) and an inlet temperature \(T_{in}\) (<T) continuously takes out the heat to maintain the desired reaction temperature.
Mentioning the standard assumptions, derive the model to obtain following equations:

(i) \[ \frac{dC_A}{dt} = \frac{F_i}{A_c h} (C_{A_f} - C_A) - \alpha \exp \left( -\frac{E}{RT} \right) C_A \]  

(ii) \[ \frac{dT}{dt} = \frac{F_i}{A_c h} (T_f - T) + \left( \frac{-\Delta H}{\rho C_p} \right) \alpha \exp \left( -\frac{E}{RT} \right) C_A - \frac{U_i A_h}{\rho C_p A_c h} (T - T_j) \]  

\( U_i \) = Overall heat transfer coefficient  
\( \rho \) = mixture density  
\( C_p \) = heat capacity  
\( T_j \) = Jacket temperature  
\( A_c \) = Cross sectional area of reactor  
\( h \) = height of reactor liquid  
\( A_h \) = Heat transfer area  
\( \Delta H \) = heat of reaction  
\( \alpha \) = frequency factor  
\( E \) = activation energy

[CO-4]
Derive the momentum transfer equations for x, y and z components in a flow field in a rectangular co-ordinate system and apply the same for calculating the average velocity for a fluid flowing with a stream velocity Us, in one direction (one dimensional flow) between two large parallel plates separated by a distance “b”. The fluid flow is in steady state and the lower plate is stationary.

OR

A mixture of Air and water flows through a pipe of internal diameter 0.015m at a steady flow rate of 1.5 kg/s. The dynamic viscosities of Air (gas) and Water (liquid) are 1.5 x 10⁻⁵ Ns/m² and 2.5 x 10⁻³ Ns/m² respectively. The densities of gas and liquid are 80 kg/m³ and 1000 kg/m³ respectively. The wt. fraction of air is 0.149. Calculate the pressure gradient in the pipe using Lockhart – Martinelli’s Correlation. The two - phase correction factor, Φ, can be calculated by the following Chisholm equation:

\[ \Phi^2 = 1 + \frac{C}{X + 1/X^2}, \]

where the value of “C” can be obtained from the table,

<table>
<thead>
<tr>
<th>Liquid</th>
<th>Gas</th>
<th>C</th>
</tr>
</thead>
<tbody>
<tr>
<td>Turbulent</td>
<td>Turbulent</td>
<td>20</td>
</tr>
<tr>
<td>Laminar</td>
<td>Turbulent</td>
<td>12</td>
</tr>
<tr>
<td>Turbulent</td>
<td>Laminar</td>
<td>10</td>
</tr>
<tr>
<td>Laminar</td>
<td>Laminar</td>
<td>05</td>
</tr>
</tbody>
</table>

Where \( X = \left( \frac{1-x}{x} \right)^{0.9} \left( \frac{\mu_L}{\mu_G} \right)^{0.5} \left( \frac{\rho_G}{\rho_L} \right)^{0.1} \), when both phases are in turbulent flow.

Where \( X = \left[ \left( \frac{1-x}{x} \right) \left( \frac{\rho_G}{\rho_L} \right) \left( \frac{\mu_L}{\mu_G} \right) \right]^{0.5} \), when both phases are in laminar flow.

and \( f = 16/\text{Re} \) for laminar flow

and \( f = 0.306/\text{Re}^{0.2} \) for turbulent flow

1(b)

Explain the various flow patterns observed for a gas and liquid mixture flowing co-currently in a horizontal pipe with the help of diagrams, if the gas flow rate is increased slowly.

2(a)

In a integrated petrochemical unit exhaust steam at low temperature is available in abundance. This exhaust steam is of limited value as its saturation temperature is low. It has been decided to utilize this steam by employing two heat exchangers in series. Develop an equation to calculate the intermediate temperature to be maintained so that exhaust steam in utilized optimally. Drive the equation used. What may be the other option?

2(b)

Explain the signification of Pinch Technology and its application with the help of an example (heat exchanger(s)) to conserve energy in a Refinery.
<table>
<thead>
<tr>
<th></th>
<th>Question</th>
<th>CO1</th>
<th>CO2</th>
<th>CO3</th>
</tr>
</thead>
<tbody>
<tr>
<td>3(a)</td>
<td>A heated surface of Radius R is suspended in a large motionless body of fluid. It is desired to study the heat conduction in the fluid surrounding the sphere. Show that temperture distribution, T_r, corresponding to and radius r in the sphere is; ( \frac{T_r - T_\infty}{T_R - T_\infty} = \frac{R}{r} ) where T_R = Surface temperature &amp; T_\infty = Fluid temperature at infinite radius from the centre of the sphere. Steady state heat conduction equation through the sphere is; ( \frac{1}{r^2} \frac{d}{dr} \left( r^2 \frac{dT}{dr} \right) = 0 )</td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>OR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3(a)'</td>
<td>Explain the various modes of heat transfer to boiling liquid with the help of boiling curves. Why the process heat transfer equipments are not designed in the film boiling temperature range? Explain the subcooled and saturated boiling.</td>
<td></td>
<td></td>
<td>7</td>
</tr>
<tr>
<td>3(b)</td>
<td>For turbulent flow in a tube, the heat transfer coefficient is obtained from Dittus-Boelter correlation. If the tube diameter is halved and the flow rate is doubled, calculate the factor by which the heat transfer coefficient will change.</td>
<td></td>
<td></td>
<td>3</td>
</tr>
<tr>
<td>3(c)</td>
<td>Draw the Wilson plot for calculating the heat transfer coefficient starting with overall heat transfer coefficient.</td>
<td></td>
<td></td>
<td>2.5</td>
</tr>
<tr>
<td>OR</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3(c)'</td>
<td>In a counter-current heat exchanger which has been in service for some time, due to formation of scale, the heat transfer rate is reduced to 85% of its original value based on clean surface. Assuming that the terminal temperatures of fluids are same in both cases, and the effective heat transfer area does not change appreciably due to scale formation, determine the overall fouling factor if clean overall heat transfer coefficient is 500 W/m².K</td>
<td></td>
<td></td>
<td>2.5</td>
</tr>
<tr>
<td>3(d)</td>
<td>A plant has a water tank mounted on the top of a 27 m platform. The tank is 10 m high. Calculate the height of water in the tank if a pressure gauge on the second floor at a height of 5.0 m from the ground reads 2.7 bar.</td>
<td></td>
<td></td>
<td>2.5</td>
</tr>
<tr>
<td>4(a)</td>
<td>Show / derive an equation, for a fluid flowing in laminar flow in a pipe / tube, to calculate the friction factor.</td>
<td></td>
<td></td>
<td>4</td>
</tr>
<tr>
<td>4(b)</td>
<td>Explain qualitatively the significance of optimum outlet water temperature and the need of the optimizations with the help of governing parameters (LMTD, Area etc).</td>
<td></td>
<td></td>
<td>2</td>
</tr>
<tr>
<td>4(c)</td>
<td>A fluid is flowing, through the pipes made of mild steel, stainless steel &amp; copper respectively with different roughness factor, in laminar flow. Whether the friction factor will be same in all the pipes or different?</td>
<td></td>
<td></td>
<td>1.5</td>
</tr>
<tr>
<td>4(d)</td>
<td>Explain the limitations of a double pipe and floating head type heat exchangers.</td>
<td></td>
<td></td>
<td>1.5</td>
</tr>
<tr>
<td>4(e)</td>
<td>Explain the significance of Von-Karmann integral equation for the boundary layer flow of a Newtonian liquid over a horizontal flat plate with zero pressure gradient.</td>
<td></td>
<td></td>
<td>1.0</td>
</tr>
<tr>
<td>4(f)</td>
<td>Explain the potential flow and its important characteristics.</td>
<td></td>
<td></td>
<td>1.0</td>
</tr>
<tr>
<td>4(g)</td>
<td>Explain the term NPSH &amp; the characteristics of a centrifugal pump. Why the centrifugal pumps are designed for a specific flow rate?</td>
<td></td>
<td></td>
<td>2.5</td>
</tr>
<tr>
<td>4(h)</td>
<td>When a heat exchanger is called as a compact heat exchanger? list the various types of compact heat exchangers.</td>
<td></td>
<td></td>
<td>1.5</td>
</tr>
</tbody>
</table>
Maximum Marks: 60
Credits: 04
Duration: Two Hours

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

Q.No.          Question                                                                                      CO   M.M.  
1(a)  Explain the most widely accepted theory for the formation of petroleum. (CO1)  [04]
1(b)  What do you understand by porosity and permeability? Discuss the migration of oil and gas with the help of a neat sketch. (CO1)  [04]
1(c)  Differentiate between sedimentary and igneous rocks. Discuss the formation of petroleum inside the earth. (CO1)  [07]

OR

1(c') What are the three type of traps? Discuss them in detail. (CO1)  [07]

2(a)  What are drilling rigs? Give two examples. Write in brief about offshore drilling process. (CO2)  [04]
2(b)  What are the steps involved in the completion of crude oil well? Briefly explain them. (CO2)  [04]
2(c) What do you understand by Enhanced oil recovery? Explain gas injection, chemical injection and microbial injection?

OR

2(c') What are drilling fluids? Give examples. Mention the properties of an ideal drilling fluid.

3(a) What do you understand by API Gravity? How is it different from specific gravity? Mention the advantages of using API gravity.

3(b) What are the four basic classification of crude oil? Briefly explain them.

OR

3(b') Write an overview on Refining of petroleum.

4(a) What do you understand by octane number of gasoline? How can it be improved?

4(b) What are the process variables of Reforming process? Mention the significance of these variables in efficiently carrying out the reforming process.

OR

4(b') Describe catalytic cracking process with a neat flow-sheet.
Answer all questions.
Assume suitable data if missing.
Notations and symbols used have their usual meaning.

Q.No. Question CO M.M.

1(a) Mention at least five differences between distillation and extraction. (CO1) [05]

1(b) The following feed n-hexane \( (x_A=0.33) \), n-heptane \( (x_B=0.37) \) and n-octane \( (x_C=0.30) \) is subjected to flash distillation.

(a) Find the Bubble Point and Dew point.

This mixture is subjected to flash distillation at 1.2 atm pressure and 60% of the feed is vaporized.

(b) Find the temperature of the flash and the composition of the liquid and vapor products.

OR

1'(a) The following feed of 100 mol/hr at the boiling point and 405.3 kPa pressure is fed to a fractionating tower: n-butane \( (x_A=0.35) \), n-pentane \( (x_B=0.25) \), n-hexane \( (x_C=0.25) \) and n-heptane \( (x_D=0.15) \). This feed is distilled so that 90% of the n-pentane is recovered in the distillate and 90% of the n-hexane in the bottom. Top and bottom temperature of tower is 65°C and 135°C respectively. Calculate the following using \( R_m = 0.5 \).

1. Mole per hour and composition of distillate and bottoms.
2. Minimum stages for total reflux and distribution of other components in the distillates and bottoms.
3. Number of theoretical stages at an operating reflux ratio of 1.3 times the minimum using Erbar-Maddox correlation.
4. Location of the feed tray using the Kirkbride method

1'(b) Answer the following:

(i) The effectiveness of a solvent can be measured by the

(A) Distribution coefficients
(B) Selectivity
(C) Both (A) and (B)
(D) Diffusivity

Cont...
(ii) For the extraction operation, the selectivity should be:
   (A) > 1  
   (B) < 1  
   (C) 1  
   (D) Zero

(iii) In fractional distillation, a mixture of liquids is separated based on their:
   (A) boiling point  
   (B) solubility  
   (C) density  
   (D) chemical composition

(iv) Fractional distillation can not be used to:
   (A) Separate the components of liquid air  
   (B) Refine crude oil  
   (C) Test purity of a substance  
   (D) Separate methanol and water

(v) Distillation can be used to separate:
   (A) A soluble solid from a solution  
   (B) A liquid from a solution  
   (C) A solid from a solid  
   (D) An insoluble solid from a solution

2. For the distillation column shown in Figure 1, use the Tridiagonal Matrix procedure (CO2) [15] to compute $x_{i,j}$ for components nC5 (3). Use composition independent K-values from the Table 1.

![Figure 1](image-url)
Table 1

<table>
<thead>
<tr>
<th>Stage</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
</tr>
</thead>
<tbody>
<tr>
<td>C₃(1)</td>
<td>1.23</td>
<td>1.63</td>
<td>2.17</td>
<td>2.70</td>
<td>3.33</td>
</tr>
<tr>
<td>nC₄(2)</td>
<td>0.33</td>
<td>0.50</td>
<td>0.71</td>
<td>0.95</td>
<td>1.25</td>
</tr>
<tr>
<td>nC₅(3)</td>
<td>0.103</td>
<td>0.166</td>
<td>0.255</td>
<td>0.36</td>
<td>0.49</td>
</tr>
</tbody>
</table>

3(a) When the feed and solvent are fully miscible, is extraction still possible? If yes, (CO1) [01]
(b) What will change if a co-current extraction column has to be used instead of a cross-current column? (CO1) [01]
(c) What may be the drawback of the extraction process? (CO1) [01]
(d) What are the advantages of extraction processes compared with other separation processes? (CO1) [02]
(e) Mention various equipment for Extraction. Explain any one type in brief. (CO3) [05]
(f) A single stage extraction is performed in which 400 kg of a solution containing 35 wt% acetic acid in water is contacted with 400 kg of pure isopropyl ether. Calculate the amounts and compositions of the extract and raffinate layers. Solve for the amounts both algebraically and by the lever-arm rule. What percent of acetic acid is removed? Use equilibrium data from Figure 5.

OR

3'. Pure methylisopropyl ketone of 500 kg/h is being used to extract an aqueous solution of 200 kg/h with 20 wt% acetone by countercurrent multistage extraction. The exit acetone concentration in aqueous phase is 7.0%. Calculate the number of stages required. Use equilibrium data from Table 2.
### Table 2

<table>
<thead>
<tr>
<th>MIK</th>
<th>Acetone</th>
<th>Water</th>
<th>Water Phase</th>
<th>MIK Phase</th>
</tr>
</thead>
<tbody>
<tr>
<td>98.0</td>
<td>0</td>
<td>2.00</td>
<td>2.5</td>
<td>4.5</td>
</tr>
<tr>
<td>93.2</td>
<td>4.6</td>
<td>2.33</td>
<td>5.5</td>
<td>10.0</td>
</tr>
<tr>
<td>77.3</td>
<td>18.95</td>
<td>3.86</td>
<td>7.5</td>
<td>13.5</td>
</tr>
<tr>
<td>71.0</td>
<td>24.4</td>
<td>4.66</td>
<td>10.0</td>
<td>17.5</td>
</tr>
<tr>
<td>65.5</td>
<td>28.9</td>
<td>5.53</td>
<td>12.5</td>
<td>21.3</td>
</tr>
<tr>
<td>54.7</td>
<td>37.6</td>
<td>7.82</td>
<td>15.5</td>
<td>25.5</td>
</tr>
<tr>
<td>46.2</td>
<td>43.2</td>
<td>10.7</td>
<td>17.5</td>
<td>28.2</td>
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<tr>
<td>12.4</td>
<td>42.7</td>
<td>54.0</td>
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<td>3.73</td>
<td>94.2</td>
<td>26.0</td>
<td>37.5</td>
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<tr>
<td>2.20</td>
<td>0</td>
<td>97.8</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

4(a) Write in brief about any three of the following with significance

(i) Residue Curve Maps
(ii) Extractive Distillation
(iii) Salt Distillation
(iv) Distillation Curve maps
(v) Azeotropic Distillation
(vi) Reactive Distillation

(CO4) [15]
Figure 2
Figure 3. Equilibrium $K$ values for light hydrocarbon systems at 405.3 kPa absolute.
Figure 4

Figure 5

Ether (C)

Acetic Acid (A)

$X_A \ y_A \ \text{(mass fraction)(A)}$

$X_A \ \text{Water Layer (Raffinate) composition}$
Maximum Marks: 60  Credits: 04  Duration: Two Hours

Answer all questions. Assume suitable data if missing. Notations and symbols used have their usual meaning. Use of F-table is allowed.

Q.No.  Question  CO  M.M.

1(a)  Answer the following:
   (i) Differentiate between accuracy and precision
   (ii) What is hypothesis testing?
   (iii) Significance of ‘constant error variance’ in designing of experiments.

1(b)  Answer any ONE
   (i) Differentiate between ‘General Linear Model’ and ‘Regression Models’.
   (ii) Differentiate between ‘No-Way ANOVA’ and ‘One-Way ANOVA’ with example.

1(c)  Calculate the necessary terms (source, DF, SS, MS, and F) in two-way ANOVA using excluding-the-mean method for the given data in Table 1.

<table>
<thead>
<tr>
<th>Cu-Content</th>
<th>Mg-Content (B1)</th>
<th>Mg-Content (B2)</th>
</tr>
</thead>
<tbody>
<tr>
<td>(A1)</td>
<td>76, 78</td>
<td>77, 78</td>
</tr>
<tr>
<td>(A2)</td>
<td>73, 74</td>
<td>79, 80</td>
</tr>
</tbody>
</table>

Table 1: Hardness of cast

2(a)  Answer the TWO:
   (i) Importance of ‘Fold-over technique’
   (ii) Properties of fractional factorial designs.
   (iii) Explain the purpose of addition of centre points to \(2^k\)-factorial design.

Contd...
2(b) What do you understand by ‘Coding of the observations’? Explain with the help of examples.

OR

2(b') Rahim wants to analyze the effects of three parameters A, B, and C on filtration rate as per the given design in Table 2. But due to certain constrains, he has to confound his design. Write the designs (i) if he confounds the ABC-effect and (ii) if he confounds both AB-effect and ABC-effect together. Explain which one would be better design and why?

Table 2  
Table of Plus and Minus Signs for the $2^3$ Design

<table>
<thead>
<tr>
<th>Treatment Combination</th>
<th>$I$</th>
<th>$A$</th>
<th>$B$</th>
<th>$AB$</th>
<th>$C$</th>
<th>$AC$</th>
<th>$BC$</th>
<th>$ABC$</th>
</tr>
</thead>
<tbody>
<tr>
<td>(1)</td>
<td>+</td>
<td>-</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
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<td>+</td>
<td>-</td>
<td>-</td>
<td>-</td>
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<td>-</td>
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</tr>
<tr>
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<td>+</td>
<td>+</td>
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<td>+</td>
<td>+</td>
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</tr>
</tbody>
</table>

2(c) A factorial experiment is carried out to study the influence of four factors temperature (A), pressure (B), concentration of formaldehyde (C), and stirring rate (D) on filtration rate.
Objective is to maximize the filtration rate and reduce the formaldehyde concentration as much as possible. Discuss the results as shown in the above plots and suggest the optimum operating condition.

3(a) Answer any ONE:
(i) Statement: ‘$R^2$ (adjusted) value preferred over $R^2$ value’. Is this statement TRUE or FALSE (justify your answer)?
(ii) Statement: ‘Analysis of response data better to be carried out using a un-coded regression model’. Is this statement TRUE or FALSE (justify your answer)?

3(b) The final equation in terms of coded factors is as follows ($x_1$ and $x_2$ are effects of A and B, respectively):

$$Y = 79.94 + 0.995X_1 + 0.515X_2 - 1.376X_1^2 - 1.001X_2^2 + 0.25X_1X_2$$

What is the nature of the response surface described by the above equation? Determine the stationary point of this response surface.

3(c) A chemical engineer wants to study the effect of three parameters (A, B, & C) on the yield of an extraction process. Create (i) a Central Composite Design (CCD) with default $\alpha$ value (ii) a Box Behnken Design (BBD). Discuss which design CCD or BBD will be selected for the study and why?

OR

3(c') Explain the objective of 'the method of steepest ascent/descent'. The region of experimentation for three factors are time ($40 \leq T_1 \leq 80$ min), temperature ($200 \leq T_2 \leq 300^\circ C$), and pressure ($20 \leq P \leq 50$ psig). A first-
order model in coded variables has been fit to yield data from a \( 2^3 \) design. The model is \( y = 30 + 5T_1 + 2.5T_2 + 3.5P \).

Is this point \( T_1 = 85, T_2 = 325 \), and \( P = 60 \) on the path of steepest ascent?

4(a) Answer any TWO:
(i) What do you mean by “Quality of Product”?
(ii) Differentiate between parameter design and tolerance design.
(iii) Classification of noise factors.

4(b) Explain the importance of “Quality Loss Function” and describe the different forms of “Quadratic quality loss function”.

OR

4(b') Describe the method “Analysis of Mean (ANOM)” to estimate effects of parameter on the quality characteristics. Use L9 orthogonal array design (shown in Table 3) to explain.

4(c) A waste water treatment process is studied with three process variables (A, B, and C). L9 (3^4) orthogonal array design (see Table 3) is used for the study to minimize the impurities in treated water. The results are analyzed using ‘smaller-is-better SN ratio’ as an objective function (see figure given below). Explain the analysis results and what process condition would you select for this process and why?

<table>
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<th>Experiment No</th>
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<th>B</th>
<th>C</th>
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