2010-2011
M.TECH. (I SEMESTER) EXAMINATION
(PETROCHEMICAL ENGINEERING)
ADVANCED MATHEMATICS
(AM – 641)

Maximum Marks: 75
Duration: Three Hours

Note: Answer five questions, selecting at least two from each section.

SECTION – A

1 (a) Solve the system of differential equations
\[
\frac{dx}{dt} = y - t
\]
\[
\frac{dy}{dt} = x + t
\]
with \( x = 1, y = 1 \) when \( t = 0 \), taking \( \Delta t = h = 0.1 \), using fourth order Runge-Kutta method.

(b) Solve the boundary value problem \( y'' - 64y + 10 = 0 \) with \( y(0) = y(1) = 0 \), using finite difference method. Compute the value of \( y(0.5) \) only with \( h = 0.25 \).

OR

(b') Use the Runge-Kutta method, of fourth order to determine the approximate value of \( y \) at \( x = 0.1 \) if \( y \) satisfies the differential equation
\[
\frac{d^2y}{dx^2} - x^2 \frac{dy}{dx} - 2xy = 1
\]
with \( y(0) = 1 \), and \( y'(0) = 0 \). Take \( h = 0.1 \) \( \text{(8,7)} \)

2 (a) Find the solution of the parabolic equation \( \frac{\partial^2 y}{\partial x^2} - 2 \frac{\partial u}{\partial t} = 0 \) when \( u(0,t) = 0 \),
\( u(4, t) = 0 \), \( u(x,0) = x (4 - x) \) using Bender-Schmidt recurrence relation. Assume \( h = 1 \). Find the values up to \( t = 5 \).

(b) Derive the Crank-Nicolson difference scheme for the parabolic equation
\[
\frac{\partial^2 u}{\partial x^2} = a \frac{\partial u}{\partial t}
\]
with boundary conditions \( u(0, t) = T_b, u(l, t) = T_l \) and initial condition as \( u(x, 0) = f(x) \).

(c) Classify the partial differential equation:
\[
\frac{\partial^2 u}{\partial x^2} + 2x \frac{\partial u}{\partial x} + (1 - y^2) \frac{\partial^2 u}{\partial y^2} = 0
\]
\( \text{(6,6,3)} \)

3 (a) Evaluate the pivotal values of the following equation taking \( h = 1 \) and up to one half of the period of vibration

Contd.....2
\[ 16 \frac{\partial^2 u}{\partial x^2} = \frac{\partial^2 u}{\partial t^2} \]

given that \( u(0, t) = u(5, t) = 0 \);
\( u(x, 0) = x^2 (5 - x) \) and \( \left( \frac{\partial u}{\partial t} \right)_{t=0} = 0 \).

(b) Solve the Poisson's equation

\[ \frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} = -10 \left( x^2 + y^2 + 10 \right) \]

going over the square with sides \( x = 0 \), \( x = 3 \) and \( x = y \) with \( u = 0 \) on the boundary and \( \Delta = 1 \). Give four iterations only.

4  (a) Express the function

\[ f(x) = 1 \quad \text{for} \quad |x| \leq 1 \]

\[ = 0 \quad \text{for} \quad |x| > 1 \]

as a Fourier integral. Hence evaluate \( \int_0^\infty \frac{\sin x}{x} \, dx \)

(b) Using Fourier integral, show that

\[ \int_0^\infty \frac{\sin \pi \lambda \sin x \lambda}{1 - \lambda^2} \, d\lambda = \begin{cases} \frac{1}{2} \pi \sin x, & 0 \leq x \leq \pi \\ 0 & x > \pi \end{cases} \]

(c) Solve the integral equation: \( \int_0^\infty f(x) \cos \lambda x \, dx = e^{-\lambda} \) using integral transform method.

OR

(c') If \( F(s) \) and \( G(s) \) are the complex Fourier transforms of \( f(x) \) and \( g(x) \), then (5,5) show that

\[ \int_0^\infty \frac{f(s)}{G(s)} e^{-is} \, ds = \int_0^\infty g(t) f(x-t) \, dt. \]

SECTION – B

5  (a) Define a vector subspace and show that the subset defined by

\[ S = \{(x_1, x_2, x_3): \sqrt{3}x_1 = \sqrt{5}x_2 \} \] in \( \mathbb{R}^3 \) is a subspace.

(b) Define an orthogonal basis and hence express the vector \((4,5,6)\) in terms of the orthogonal basis \{(1,2,3), (3,-3,1), (-11,-8,9)\} in \( \mathbb{R}^3 \).

OR

(b') Discuss Gram-Schmidt orthogonalization process and hence obtain an orthonormal set from the linearly independent set of vectors \((1,2,3)^t, (2,1,3)^t, (4,3,6)^t\) in \( \mathbb{R}^3 \).

Contd……
6 (a) Define a linear transformation. Is $T : \mathbb{R}^3 \to \mathbb{R}$ defined by $T(x_1, x_2, x_3) = x_1^2 + x_2^2 + x_3^2$ a linear transformation? Construct a linear transformation $T : \mathbb{R}^2 \to \mathbb{R}^3$ such that $T(1,2) = (1,2,5)$ and $T(2,3) = (0,0,6)$.

(b) Show that the eigen vectors of a real symmetric matrix $A$ are orthogonal to each other where

$$A = \begin{bmatrix} 3 & -1 & 0 \\ -1 & 2 & -1 \\ 0 & -1 & 3 \end{bmatrix}$$

OR

(b') Define Rayleigh Quotient and hence use it to estimate the eigen values of matrix:

$$\begin{bmatrix} 5 & 4 & -4 \\ -4 & 5 & 4 \\ -4 & 4 & 5 \end{bmatrix}$$

7 (a) Define biorthogonality. Find the biorthogonal sets of eigen vectors for matrix:

$$A = \begin{bmatrix} 2 & 0 & 0 \\ 5 & 4 & 0 \\ 3 & 6 & 1 \end{bmatrix}$$

OR

(a') The eigen vector $u^i$ of a real matrix $A$ corresponding to eigen value $\lambda_i$ is orthogonal to the complex conjugate of every eigen vector $V^j$ of $A^*$ corresponding to an eigen value $\lambda_j$ different from $\lambda_i$. Verify this fact for the matrix:

$$\begin{bmatrix} 4 & -20 & -10 \\ -2 & 10 & 4 \\ 6 & -30 & -13 \end{bmatrix}$$

(b) State Fredholm solvability conditions. Check whether $Au = (2,4,7)'$ has a solution for matrix

$$A = \begin{bmatrix} 2 & 1 & -3 \\ 1 & -3 & 2 \\ -3 & 2 & 1 \end{bmatrix}$$

(8,7)
Maximum Marks: 75

Note: Answer the following questions

1. (a) Explain the industrial significance and the effectiveness of the extended surfaces (fins).

(b) Derive the steady state one dimensional energy equation for a variable cross-sectional fin. State the assumptions clearly.

(c) A thin fin of length \( L \) has its two ends attached to large parallel plates which are maintained at temperatures \( T_1 \) and \( T_2 \). The ambient air which is at a temperature \( T_a \) surrounds the fin. Show that the temperature distribution along the length of the fin is given by

\[
T = \frac{(T_1 - T_a) \sin h \frac{m}{L}(L - x) + (T_2 - T_a) \sin h \frac{m}{L}x}{\sin h \frac{m}{L}L}
\]

Where \( m = \sqrt{\frac{2h_s}{k_t}} \) and \( h_s \) = heat transfer coefficient
\( k \) = thermal conductivity of the fin
\( t \) = thickness of the fin

start from the equation developed in question 1 (b)

OR

1' (a) Derive the modified Navier-Stokes equations in rectangular co-ordinate system and use them for calculating average velocity for a fluid flowing with a stream velocity \( u_s \), in one direction, between two large parallel plates separated by a distance \( b \).

2 (a) A heated sphere of radius \( R \) is suspended in a large motion less body of fluid. It is desired to study the heat conduction in the fluid surrounding the sphere. Show that the temperature distribution \( T_r \) corresponding to any radius, \( r \) in the sphere is

\[
\frac{(T_r - T_a)}{(T_R - T_a)} = \frac{R}{r}
\]

and the heat transfer coefficient expressed as Nusselt Number, \( N_u \), in dimensionless form is \( N_u = 2 \)

Contd.......2
Where $T_R =$ Surface temperature and $T_a =$ Fluid temperature at infinite radius from the centre of the sphere. Steady state heat conduction equation through the sphere is 

$$\frac{1}{r^2} \frac{d}{dr} \left( r^2 \frac{dT}{dr} \right) = 0.$$ 

(b) Explain the importance of optimum outlet water temperature to be employed in a process heat exchanger.

c) The temperature distribution through a large wall 50 cm thick, heated from one side, at a certain time, $t$, is found to be given by

$$T = 90 - 80x + 16x^2 + 32x^3 - 25x^4$$

where $x$ is in meter and $T$ is in °C. If the area of wall is 10m$^2$, compute:

(i) the heat entering and leaving the wall in unit time.

(ii) the heat energy stored in the wall in unit time.

Given: $k$ (thermal conductivity) = 5.8 W/m.k and $\alpha = 0.02 m^2/\text{hr}$

One dimensional unsteady state conduction without heat generation is

$$\frac{\partial^2 T}{\partial x^2} = \frac{1}{\alpha} \frac{\partial T}{\partial t}$$

(b) Explain homogenous, separated and Lockhart Martinellis’ parameter and its significance for two-phase flow of a gas and liquid mixture.

2' (b) Derive the Lockhart-Martinelli’s parameter when both the phases are in turbulent flow and flowing co-currently in a pipe.

$$X_{TT} = \left[ \left( \frac{1-x}{x} \right)^{0.9} \left( \frac{\rho_G}{\rho_L} \right)^{0.5} \left( \frac{H_L}{H_G} \right)^{0.1} \right]$$

where $x$ is the quality

Given $f = 16/Re$ for laminar flow and $f = 0.316/Re^{0.2}$ for turbulent flow.

2' (c) A mixture of gas and liquid flows through a pipe of internal diameter 0.026m at a steady total flow rate of 0.5 kg/s. The dynamic viscosities of gas and liquid are $1.5 \times 10^{-5}$ Ns/m$^2$ and $2.5 \times 10^{-3}$ Ns/m$^2$ respectively. The density of the gas and liquid are 80 kg/m$^3$ and 1200 kg/m$^3$ respectively. The wt.fraction of the gas is 0.149. Calculate the pressure gradient in the pipe using Lockhart-Martinelli correlation.

<table>
<thead>
<tr>
<th>$X_{TT}$</th>
<th>$\phi$</th>
<th>$X_{TT}$</th>
<th>$\phi$</th>
</tr>
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<tr>
<td>0.01</td>
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<td>2.00</td>
<td>3.10</td>
</tr>
<tr>
<td>0.02</td>
<td>68.4</td>
<td>4.00</td>
<td>2.38</td>
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<td>7.00</td>
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<td>18.5</td>
<td>20.00</td>
<td>1.48</td>
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<td>11.2</td>
<td>40.00</td>
<td>1.29</td>
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<td>70.00</td>
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<td>100.00</td>
<td>1.11</td>
</tr>
<tr>
<td>1.00</td>
<td>4.20</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>$\phi$</th>
<th>$\rho$</th>
<th>$\mu$</th>
</tr>
</thead>
</table>

| Given: | $1000 \rho = 1 \text{ Ns/m}^2$ |

Contd...
3 (a) Nitrogen at atmosphere pressure and 30°C temperature flows steadily over a horizontal flat plate with a stream velocity of 60.2 m/s. Calculate the boundary layer thickness in meters at a distance of 4.2m along the plate from the initial point of impact of the nitrogen stream with the plate. Derive the equation used. Assume that the nitrogen gas behave as the ideal gas at the abovementioned conditions.

Velocity distribution in the boundary layer may be approximate by

\[ \frac{u_z}{u_s} = \left[ \frac{3}{2} \left( \frac{Z}{\delta} \right) - \frac{1}{2} \left( \frac{Z}{\delta} \right)^3 \right] \] if the flow is laminar and \[ \frac{u_z}{u_s} = \left[ \frac{Z}{\delta} \right]^{1/7} \] if the flow is turbulent. \( \delta = \text{boundary layer thickness} \)

![Diagram of boundary layer](image)

Given: (i) Dynamic Viscosity of air = 0.188 x 10^{-5} Ns/m²
(ii) Gas constant, \( R = 82.06 \) (atm)(cm³)/mol/(°K)
(iii) 1000°C, \( p = 1.0 \) Ns/m²

(b) Draw a schematic diagramme of 1-4 shell and tube heat exchanger and its temperature profile.

(c) List the various types of industrial furnaces and compact heat exchanges. Explain the limitations of double pipe heat exchanger.

4 (a) A large plate of thickness ‘L’ has a uniform temperature distribution 2T₀ initially. The temperature at both surfaces is suddenly changed to T₀ and held constant thereafter. Derive a relationship for the temperature as a function of time, distance and thermal properties. Neglect edge effects.

(b) In a refinery, exhaust steam at low pressure is available in abundance. The exhaust steam is of limited process value as its saturation temperature is low. However from various estimates the cost of the exhaust steam is from \( 1/4 \) to \( 1/8 \) of the line process steam. In view of this it has been decided to use this steam by employing two heat exchanges in series. Frame only the equation to calculate the intermediate temperature to be maintained so that exhaust steam is utilized optimally.

**OR**

(b’) (i) Draw the Sankey’s energy diagramme for a commercial plant and indicate the potential areas wherein energy conservation measures may be adopted/required.

(ii) Define sub cooled and saturated boiling.
2010-2011
M. Tech (I Semester) Examination
Petroleum Processing and Petrochemical Engineering
Petroleum Processing
PK-602

Max Marks: 75

Duration: Three hours

NOTE: Answer ALL questions.

1(a) Describe briefly different theories of origin and formation of petroleum. What is the Modern theory for its formation?  

OR

(a') Write an explanatory note on the historical development of Indian Petroleum Industry.  

(b) Give brief accounts of: i) Kerogen ii) Resins and asphaltenes iii) Heavy and extra heavy crude oils  

(c) What are the non-hydrocarbon constituents of crude oil? Give classification of sulfur compounds present in the crude oil along with its adverse effects.  

OR

(c') Describe briefly various methods for the classification of crude oil. Which method do you feel better and convenient?  

2(a) A sample of oil has specific gravity 0.895 and a kinematic viscosity of 2.5 at 37.8 °C. Calculate its VGC value.  

(b) Give briefly the differences between ASTM D 86 and TBP 15/5 distillation. Describe briefly the different sequences followed for the operation of a TBP distillation.  

OR

(b') Explain the method of operation of a multidraw atmospheric distillation column. How does it differ from conventional distillation? Give the different products of crude oil distillation mentioning their boiling range, carbon range and their uses.  

(c) How pour point, cloud point and CFPP differ from each other?  

(d) Give a comparative account of the compositions of LPG, gasoline, Kerosene and diesel.  

3(a) What do you mean by Octane number? How do the Motor and Research methods differ from each other?  

(b) What do you understand by the term, Nelson Complexity Index? If for a refinery the complexity index is high, what does it signifies?  

(c) Why is an upper limit for aromatic content prescribed for aviation turbine fuels?  

Contd.........2
(d) Why a certain amount of hydrochloric acid is added into the reactor in reforming process. Draw a neat process flow sheet of semi regenerative catalytic reforming process for the enhancement of octane number of gasoline and describe it with the help of its reaction mechanism and reasons of using more than one reactor.

4(a) Who started the first exploration activity in India and when? How many sedimentary basins are discovered and explored in India till now?

OR

(a') Explain briefly the method of conducting seismic surveys for finding petroleum reservoirs.

(b) What are different basic types of rigs? Differentiate between Kelly and Top Drive Systems and explain their operations.

OR

(b') Which component is used to prevent kick and blowouts? Explain the different parts of it in detail

(c) Name different drill string components. Explain clearly the function of each.

5(a) Differentiate between Roller cone bit and Fixed cutter bit. When the lower bottom hole assembly becomes stuck which tool can be used to free it and how?

OR

(a') Name different types of drill fluids and describe their functions. Why crew members put additives in drill fluids?

(b) Discuss briefly different techniques of enhanced oil recovery. Explain three approaches of microbial injection.
Maximum Marks: 75

Duration: Three Hours

Answer any FIVE questions. Assume suitable values of required data, if any.

1. (a) Discuss the factors that are considered for the selection of feasible and optimum separation process(es).
(b) Derive Fenske equation for minimum number of stages. State assumptions, if any.

2. For the debutanizer shown in figure-1, calculate the minimum number of stages. Also calculate the distribution of any one non-key component (Use figure-2 for required data)

3. 100 kgmol/hr of three component bubble point mixture, to be separated by distillation, has the following composition:

<table>
<thead>
<tr>
<th>Component</th>
<th>Mole Fraction</th>
<th>Relative Volatility</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>0.4</td>
<td>5</td>
</tr>
<tr>
<td>B</td>
<td>0.2</td>
<td>3</td>
</tr>
<tr>
<td>C</td>
<td>0.4</td>
<td>1</td>
</tr>
</tbody>
</table>

(a) Calculate distillate and bottom composition for a distillate rate of 60 kgmol/hr, five theoretical stages and at total reflux.
(b) Using separation in part (a) for components B and C, determine the minimum reflux ratio and minimum boilup ratio.
(c) For an operating reflux ratio of 1.2 times the minimum, determine the number of theoretical stages and the feed stage location.

4. Discuss any two of the following in detail:
(a) Reactive Distillation
(b) Pressure Swing Distillation
5. Discuss the advantages and disadvantages of different pieces of equipment employed for Liquid-Liquid Extraction. Also suggest a scheme for selecting the suitable equipment for various applications.

6. (a) Discuss, in brief, the significance of employing supercritical conditions in the extraction process, with special reference to refining and petrochemicals.

(b) Acetic acid is continuously extracted from a 3 wt% dilute solution in water with a solvent of isopropyl ether in a mixer-settler unit. The flow rates of feed and solvent are 12,400 and 24,000 liters/hour respectively. Assuming a residence time of 2 minutes in the mixer and the settling vessel capacity of 500 liters/min·cm², estimate:

(i) Diameter and height of mixing vessel if $H/D_r = 1$
(ii) Diameter and Length of a settling vessel, assuming it to be a horizontal cylindrical vessel.
(iii) Residence Time in the settling vessel

7. Furfural is to be continuously extracted from a dilute solution in water by toluene at 25 °C in an agitated vessel as shown in figure-3. The feed flow rate is 20,400 lb/hr while the solvent flow rate is 11,200 lb/hr. For a residence time of 2 min in the vessel, estimate the following for raffinate phase as the dispersed phase:

(i) The dimension of the mixing vessel and the diameter of the flat-blade turbine impeller.
(ii) The minimum rate of rotation of the impeller for complete and uniform dispersion.
(iii) The power requirement of the agitator at the minimum rotation rate.

Figures attached
Figure 1: Specifications for debutanizer.
Figure 2: Ideal $K$-values for hydrocarbons at 80 psia.
Figure 3: Agitated vessel with flat-blade turbine and baffles.
Figure 4: Power consumption of agitated vessels. (a) Typical power characteristics.
(b) Power correlation for six-bladed, flat-blade turbines with no vortex.
[From D.S. Laity and R.E. Treybal, AIChE J., 3, 176-180 (1957).]
2010-2011
M.TECH. (I SEMESTER) EXAMINATION
(CHEMICAL / PETRO-CHEMICAL ENGINEERING)
PROCESS MODELING & SIMULATION
(PK-611 / CH-615)

Maximum Marks: 75
Duration: Three Hours

1. (a) Derive and discuss (by an example) the logic flow diagram for the development of mathematical model of a system. Differentiate between various modeling techniques. (10)

(b) Define Process Flowsheeting. What are the various softwares used for flowsheeting? Discuss in general the development of such softwares and their internal components. (05)

2. (a) Derive the transient model of a real tubular reactor, operating under isothermal conditions. Assume applicability of axial dispersion model. Define initial and boundary conditions. Use it to obtain the model for transport of reactant into the single cylindrical pore of a catalyst. Solve the model for steady state situation. (15)

(b) Explain multiplicity of steady states by considering the oxidation of carbon monoxide over platinum catalyst in a fluidized bed reactor. (05)

OR

2'. (a) Derive the state space model of a plate gas absorber, used for the design of its control systems. Solve the model using analytical techniques. (15)

(b) Consider that a first order irreversible exothermic reaction is taking place in a CSTR, fitted with cooling coils. Use Van-Heerden analysis to develop the slope criteria in general form for the stability of steady states. (05)

3. Write a note on any two of the following and suggest a simulation algorithm. (10+10)

(a) Modeling of Conventional Multicomponent Distillation.

(b) Modeling of Steamed Heated Exchanger.

(c) Modeling of Catalytic Cracking Unit.
(d) Modeling of Triple Effect Evaporator.

(e) Modeling of Ammonia Synthesis Reactor.

4. (a) Corrigan and Beavers proposed a flow model of a real CSTR. By using stochastic approach, derive the expression for its RTD functions, $E(t)$ and $F(t)$.

(b) Apply population balance modeling technique to describe N-Tanks in series. How will the model equations change for N-Tanks of equal volume?