

IV B.Tech II Semester Regular Examinations, Apr/May 2008
OPTIMIZATION OF CHEMICAL PROCESS
(Chemical Engineering)

Time: 3 hours**Max Marks: 80**

Answer any FIVE Questions
All Questions carry equal marks

1. Explain the scope and hierarchy of optimization. [16]
2. Explain the consideration of the time value of money with reference to future worth and present worth. [16]
3. Consider the following objective functions: is it convex ? use eigen values in the analysis $f(x) = 2x_1^2 + 2x_1x_2 + 1.5x_2^2 + 7x_1 + 8x_2 + 24$ [16]
4. A confectioner manufacturer two kinds of candy bars Ergies and Nergies. Ergies sell at a profit of 50 paise per box while Nergies have a profit of 60 paise per box. The candy is processed in three main operations blending and cooking and packaging. The following table records the average time in minutes required by each box of candy for each of the three activities.

	<i>Blending</i>	<i>cooking</i>	<i>packaging</i>
Ergies	1	5	3
Nergies	2	4	1

During each production run, the blending equipment is available for a maximum of 14 machines hours, the cooking equipment for atmost 40 machines hours and the packaging equipment for 15 machine hours. If each machine can be allocated to the making of either type of candy at all times that is available for production, determine how many boxes of each kind of candy the confectioner should make in order to realize the maximum profit. Use a graphical technique. [16]

5. For a waste heat recovery system the following data are given: Cost per unit area of exchanger, $C_A = \text{Rs.}20/\text{ft}^2$
 Value of power, incorporating necessary conversion factors to have a consistent set of units, $C_H = 1.76 \times 10^{-5}$
 Average overall heat transfer coefficient, $U = 100 \text{ Btu}/(\text{h})(^\circ\text{F})(\text{ft}^2)$
 Number of hours per year of operation, $y = 8760 \text{ h/year}$
 Annualization factor for capital investment, $r = 0.365$
 Efficiency of overall system, $\eta = 0.7$
 Condensing temperature, $T_2 = 600^\circ\text{R}$
 Average hot fluid temperature, $T_s = 790^\circ\text{R}$
 Calculate the optimum value of the working fluid temperature, T_H . [16]
6. Explain the procedure involved for determining the optimum reflux ratio for a staged distillation column applying the one dimensional search technique of optimization. [16]

7. The annual costs of transporting a fluid through a pipe line depends on the diameter of the of the pipe line. The objective function for the annual costs C is a sum of annualized investment charges C_{inv} and pump operating costs C_{op} , which are expressed as

$$C_{inv} = C_1 D^{0.3} L$$

$$C_{op} = C_0 m_D P / \rho \eta$$

where C_0 and C_1 are cost coefficients, m and r are mass flow rate and density of fluid, h is pump efficiency and L is the length of pipe line. The objective function C includes four variables the pipe diameter D , the velocity v , the pressure drop Δp and the friction factor f . Three of these variables have the following correlations:

$$\Delta p = 2f \rho v^2 L / D$$

$$m = (\rho \pi D^2 / 4) v$$

$$f = (0.046 \mu^{0.2}) / (D^{0.2} v^{0.2} r^{0.2})$$

Formulate the objective function by eliminating Δp , v and f , and obtain an expression for the optimal pipe diameter D considering it as the independent variable.

[16]

8. The steady state dependence of chemostat variables, namely, cell mass concentration x and substrate concentration s are expressed by the following equations:

$$x = y_{x/s} \left[S_f - \frac{DK_s}{\mu_{max} - D} \right]$$

$$s = \frac{DK_s}{\mu_{max} - D}$$

where D is the dilution rate. The parameter values are: maximum specific growth rate $\mu_{max} = 1.0 \text{ h}^{-1}$, yield factor $Y_{x/s} = 0.5$, substrate growth rate constant $K_s = 0.2 \text{ g/lit}$ and substrate feed concentration $s_f = 10.0 \text{ g/lit}$. The rate of cell mass production per unit reactor volume is Dx . Show that the system exhibits washout condition at $D = \mu_{max}$.

[16]

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1. The total cost (dollars per year) for pipe line installation/operation for an incompressible fluid can be expressed by:

$$C = C_1 D^{1.5} L + C_2 m \Delta p / \rho$$

where ? C_1 is the installed cost of the pipe per foot length computed on an annual basis ($C_1 D^{1.5}$ is expressed in dollars per year per foot length), C_2 is based on \$ 0.05 / kWh, 365 days/year and 60 per cent pump efficiency.; D is the diameter to be optimized; L is the length of the pipe line = 100 miles; m is the mass flow rate = 200,000 lb/h; $\Delta p = 2 \rho v^2 L / (D g_c)$ f = pressure drop in psi; ρ is the density = 60 lb/ft³; v is the velocity = (4m) / $(\rho \pi D^2)$; f = friction factor = $(0.046 m^{0.2}) / (D^{opt} \text{ and } v^{opt} C^{opt})$; μ is the viscosity = 1 cP.

(a) Find general expressions for D^{opt} , v^{opt} and C^{opt} .

(b) For $C_1 = 0.3$ (D expressed in inches for installed cost), calculate D^{opt} and v^{opt} for the following values of μ and ρ . $\mu = 0.2, 1 \text{ and } 10 \text{ cP}$ $\rho = 50, 60 \text{ and } 80 \text{ lb/ft}^3$ [16]

2. An extruder is to be purchased for manufacturing plastic widgets. The capital investment is \$24,000 and the equipment has a life of five years, after which the salvage value is \$ 4000. The income from the machine is expected to be \$ 12,000 the first year and \$ 15000 per year thereafter. As the equipment ages, its operating and maintenance costs increase. The table below (line B) shows the expense profile. Assume a tax rate of 50%

with no investment tax credit. Compute the internal rate of return for:

(a) 100 % equity financing

(b) 50% debt / 50% equity. Use straight line depreciation; for debt financing, assume equal annual payments (principal plus interest) to the lender.

Year	1	2	3	4	5
A.Income	\$12,000	\$ 15000	\$ 15,000	\$ 15,000	\$ 15,000
B.Expenses	\$2,000	\$ 3,000	\$ 5,000	\$ 7000	\$8 ,000

[16]

3. Does the following set of constraints that form a closed region a convex region
 $-x_1^2 + x_2 \geq 1$ $x_1 - x_2 - 2$ [8+8]
4. Examine the following problem
 maximize $y = 3x_1 + x_2 + x_3$

subject to $x_1 - 2x_2 + x_3 \leq 11$

$-4x_1 + x_2 + 2x_3 \geq 3$

$2x_1 - x_3 = -1$

$x_1, x_2, x_3 \geq 0$

is there a basic feasible solution in the problem? Answer Yes or No and explain. [16]

5. Mention the variables that must be considered by an engineer while making an analysis for the selection of optimal evaporation equipment. [16]

6. (a) What are the categories into which optimization problems for steady state distillation are classified in general? Discuss briefly.

(b) With the help of a schematic diagram, formulate the equality constraints for optimal design and operation of a conventional staged distillation column. [8+8]

7. The cost function C representing the annual costs of a pipe line transporting a fluid is given by $C = C_1 D^{1.3} L + 0.142(C_0/\eta) m^{2.8} m^{0.2} \rho^{-2.0} D^{-4.8} L$ where the cost coefficients are considered as $C_0 = \text{Rs. } 0.59$ and $C_1 = \text{Rs. } 5.7$. The mass flow rate of fluid $m = 25 \text{ kg/s}$, density $\rho = 1000 \text{ kg/m}^3$, $\mu = 1.08 \times 10^{-3} \text{ N/s m}^2$, the pumping efficiency $\eta = 0.60$ and the pipe length $L = 10 \text{ m}$. The fluid velocity is correlated by $v = 4m/(\rho \pi D^2)$ Find the optimal pipe diameter D_{opt} and optimal fluid velocity v_{opt} . [16]

8. The dynamic model of a continuous flow biological chemostat is given by

$$\dot{e} = \gamma k_2 c - D e$$

$$\dot{c} = -k_1 s(e - c) + (k_2 + k_3)c - D c$$

$$\dot{s} = -k_1 s(e - c) + (k_3 c + D(s^o - S))$$

where e , c and s are biomass, metabolic and substrate concentrations in gmol/lit , respectively. The values of rate constants k_1 , k_2 and k_3 are 0.9 lit/mol.h , 0.7 h^{-1} and

0.0 , respectively. The limiting feed substrate concentration $s^o = 10.0 \text{ mol/lit}$ and

the parameter $g = 0.09$. The dilution rate D is an independent variable. The objective is to maximize the steady state production of biomass given by $f = D e$. Obtain the steady state responses of e , c and s as a function of D and show that the system exhibits washout condition at $D = 0.553$. [16]

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1. (a) Discuss the problem of optimization of economic insulation thickness. [6]
 (b) Assume that the bare surface of a vessel is at 700°F with an ambient temperature of 70°F . The surface heat loss is $4000 \text{ Btu}/(\text{h})(\text{ft}^2)$. Add one inch of calcium silicate insulation and the loss will drop to $250 \text{ Btu}/(\text{h})(\text{ft}^2)$. At an installed cost of \$ 4/ (ft^2) and a cost of energy at \$ 5/106 Btu, a saving of \$ 164 per year (8760 hours of operation) per square foot would be realized. Calculate the pay back period and mention the approach to determine the optimum insulation thickness. [10]
2. Discuss the parameters normally considered in the financial evaluation of chemical Processes. [16]
3. Determine the convexity or concavity of the following objective functions
 - (a) $f(x_1, x_2) = (x_1 - x_2)^2 + x_2^2$
 - (b) $f(x_1, x_2, x_3) = x_1^2 + x_2^2 + x_3^2$
 - (c) $f(x_1, x_2) = e^{x_1} + e^{x_2}$ [4+6+6]
4. Describe in detail the basic concepts involved in linear programming? [16]
5. What are the variables that an engineer must consider in the selection of optimal evaporation equipment? Make a list of them under separate headings of ?known? and ?unknown?. Also mention the features to be determined and the utilities that may be consumed. [16]
6. (a) For the determination of the optimum reflux ratio for a staged distillation column write the equality constraints with the help of a flow sheet. (Use Eduljee correlations) [6]
 (b) Develop an expression for the objective function f which is the operating profit given the following data for separating propane and propylene:
 C_1 = Reboiler heat cost
 C_2 = Condenser cooling cost
 C_B = Value of propylene in bottoms

C'_B = Value of propane in bottoms

C_D = Value of propylene in overhead

C'_D = Value of propane in overhead

C_F = Cost per pound of propylene

C'_F = Cost per pound of propane

Q_C = Condenser load requirement

Q_R = Reboiler heat requirement

D, B, F = Distillate flow rate, Bottoms flow rate and Feed rate respectively

X_D, X_B, X_F = Mole fraction of light key in overhead, bottom and feed respectively. [10]

7. The cost function C representing the annual costs of a pipe line transporting a fluid is given by

$$C = C_1 D^{1.3} L + 0.142 (C_0 / \eta) m^{2.8} \mu^{0.2} \rho^{-2.0} D^{-4.8} L$$

where the cost coefficients are considered as C_0 = Rs. 0.59 and C_1 = Rs. 5.7. The mass flow rate of fluid $m = 25$ kg/s, density $\rho = 1000$ kg/m³, $\mu = 1.08 \times 10^{-3}$ N/sm², the pumping efficiency $\eta = 0.60$ and the pipe length $L = 10$ m. Find the optimal pipe diameter D_{opt} [16]

8. Find the maximum of the following linear programming problem representing a thermal cracker by graphical method.

The objective function :

$$f = 2.84x_1 - 0.22x_2 - 3.33x_3 + 1.09x_4 + 9.39x_5 + 9.51x_6$$

where x_1 = fresh ethane feed, x_2 = fresh propane feed, x_3 = gas oil feed, x_4 = DNG feed, x_5 = ethane recycle and x_6 = propane recycle.

The objective is subjected to the following constraints:

$$1.1x_1 + 0.9x_2 + 0.9x_3 + 1.0x_4 + 1.1x_5 + 0.9x_6 \leq 200,000$$

$$0.5x_1 + 0.35x_2 + 0.25x_3 + 0.25x_4 + 0.5x_5 + 0.35x_6 \leq 100,000$$

$$0.01x_1 + 0.15x_2 + 0.15x_3 + 0.18x_4 + 0.01x_5 + 0.15x_6 \leq 20,000$$

$$0.4x_1 + 0.06x_2 + 0.04x_3 + 0.05x_4 - 0.6x_5 + 0.06x_6 = 0$$

$$0.1x_2 + 0.041x_3 + 0.01x_4 - 0.9x_6 = 0$$

$$x_i \geq 0$$

[16]

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1. A packed tubular reactor with radial diffusion is to be optimized. Assume that a single reversible reaction takes place. To set up the problem as a non linear programming problem, write the appropriate balances (constraints) including the initial and boundary conditions using the notation given below: x = extent of the reaction, t = time,
 T = dimensionless temperature, r = dimensionless radial coordinate. [16]
 2. Describe two commonly used models of reactors along with their governing equations [16]
 3. Explain the difference between uni model and multi model functions [16]
 4. (a) What are the natural occurrence of linear constraints? [6]
 (b) Suppose three (light naphtha, heavy naphtha, and catalytic oil made in a refinery are to be blended to produce an aviation fuel. The octane number of the fuel must be at least 95. the octane numbers for the three intermediates are as follows:
- | | <i>Amount blended,</i>
bbl/day | <i>Octane No</i> |
|---------------|-----------------------------------|------------------|
| Light naphtha | x_1 | 92 |
| Heavy naphtha | x_2 | 86 |
| Catalytic Oil | x_3 | 97 |
- Write an inequality constraint on the octane No of the aviation fuel assuming a linear mixing rule. [10]
5. Write the procedure for optimizing the process design of a baffled shell- and-tube single-pass counterflow heat exchanger in which the tube fluid is in turbulent flow but there is no change of phase of fluids in the shell or tubes. [16]
 6. The feed to a distillation column is naphtha, which has a value of Rs.42/bbl. The light ends production rate is 40% of the feed rate and the bottoms production rate is 60% of the feed rate. The light ends sell at Rs.53/bbl while the bottoms are passed through a second distillation column to yield two solvents. A medium solvent comprising 50 to 70 percent of the bottoms can be sold for Rs.68/bbl, while the remaining heavy solvent (30 to 50 percent of the bottoms) can be sold for Rs.42/bbl. Another part of the plant requires 200 bbl/day of medium solvent; an additional 200 bbl/day can be sold to an external market. The maximum feed that can be processed in column 1 is 2000 bbl/day. The operational costs

(i.e., utilities) associated with each distillation column are Rs.1.25/bbl feed. The operating range for column 2 is given as the percentage split of medium and heavy solvent. Formulate the problem as a linear programming problem by developing the objective function (in terms of profit) and the constraints. Solve the linear programming problem to determine the maximum profit and the optimal values of medium solvent and heavy solvent production rates by using the Simplex method. [16]

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