B.E. CHEMICAL ENGINEERING THIRD YEAR SECOND SEMESTER EXAM 2024

3rd Year, 2nd Semester

SEPARATION PROCESSES - II

Time: 3 Hours Full Marks: 100

Answer all questions from Group A ***and*** *any One (1) question from Group B*

Group A: *Distillation [CO1+CO2+CO3+CO4]*

[2+3+4+2+4+5+3+3+12(=4+8)+9(=3+6)+10+18=75]

1. How does the heat load of a distillation column change when the column pressure is increased or decreased?
2. How would the number of plates change, in case of binary distillation, if feed is given in any plate other than the optimum one?
3. In case of binary distillation, how many types of pinch points are possible in a distillation tower? Explain with diagrams.
4. If both condenser and reboiler are partial type, explain how it will affect the theoretical number of trays.
5. If equilibrium data (x, y) are not supplied, how can you obtain the same using bubble and dew point diagrams?
6. Sketch a simplified flow diagram for an extractive distillation process. Give one major application of this process. State the major difference between extractive and azeotropic distillation.
7. If Murphy tray efficiency is assumed to be the same, say 0.7 for each tray, how would you get actual number of trays from the McCabe-Thiele diagram.
8. Mention and explain three advantages of bubble cap trays over sieve plates?
9.
   a) Starting with the general form of Rayleigh's equation, derive the modified form, as given below, for differential distillation of an ideal mixture of constant relative volatility.

$$\ln\frac{F}{W} = \frac{1}{\alpha - 1}\ln\frac{x_F(1 - x_W)}{x_W(1 - x_F)} + \ln\frac{1 - x_W}{1 - x_F}$$

   In the above equation, F is feed; W is residue; x_F is the composition of feed; x_W is the composition of residue; and α is relative volatility.

b) 100 moles of Benzene (A) and Toluene mixture containing 50% (mole) of Benzene is subjected to a differential distillation at atmospheric pressure till the composition of benzene in the residue is 33%. Calculate the total moles of the mixture distilled. Average relative volatility may be assumed as 2.16. The modified form of Rayleigh's equation, derived above, may be used. *Or, the graphical method may be used, while applying the general form of Rayleigh's equation. The equilibrium curve is plotted in the graph paper provided.*

$$\ln \frac{F}{W} = \int_{x_W}^{x_F} \frac{dx}{y^* - x}$$

The equilibrium relationship is:

$$y^* = \alpha x/[1 + x(\alpha - 1)]$$

10.

a) Derive the expression of material balance for flash calculations in terms of the mole fraction *(f)* of the feed vaporized.

b) A feed of 60 mole% hexane and 40 mole% octane is fed into a pipe still through a pressure-reducing valve and then into a flash-disengaging chamber. The vapor and liquid leaving the chamber are assumed to be in equilibrium. If the fraction of the feed converted to the vapor is 0.6, find the compositions of the top and bottom products. *The equilibrium curve is plotted in the graph paper provided.*

11. A continuous fractionating column is to be designed for separating 11,000 kg per hour of a liquid mixture containing 45 mole percent methanol and 55 mole percent water into an overhead product containing 97 mole percent methanol and a bottom product having 98 mole percent water. A mole reflux ratio of 3 is used. Calculate (i) moles of overhead product obtained per hour and (ii) number of ideal plates and location of the feed plate if the feed is at its bubble point. Use **McCabe-Thiele** method. *The equilibrium curve is plotted in the graph paper distributed.* Here x = mole fraction of methanol in liquid; and y = mole fraction of methanol in vapor.

12. 1000 kg/hr of a mixture containing 42 mole percent heptane (C_7H_{16}) and 58 mole percent ethyl benzene ($C_6H_5C_2H_5$) is to be fractionated to a distillate containing 97 mole percent heptane and a residue containing 99 mole percent ethyl benzene using a total condenser and feed at its saturated liquid condition. *The enthalpy-concentration (H-x-y) diagram and the equilibrium curve for the heptane-ethyl benzene at 1 atm pressure are plotted in two different plots in the graph paper distributed.* Using **Ponchon-Savarit** method Calculate the following:

i. Minimum reflux ratio
ii. Minimum number of stages at total reflux
iii. Number of stages at reflux ratio of 2.5
iv. Condenser duty
v. Reboiler duty

Group B: *LLE+Crystallization+(Adsorption+Leaching) [CO1+CO2+CO3+CO4]*

13. **(1+2+2+6+2+12=25)**

a) Give one example of separation processes where LLE is favored over distillation.
b) Classify ternary systems with respect to mutual miscibility behavior.
c) Sketch the Liquid-Liquid equilibrium diagram on an equilateral triangular plot for Type I miscibility [solute is miscible in both carrier liquid and extracting solvent]. Indicate the plait point, tie lines, and single and two-phase regions in the plot. Why is the equilibrium curve called 'binodal'?
d) Draw the Maloney-Schubert diagram for a liquid-liquid system using the following equilibrium data. Also, show the tie lines in the diagram.
e) Carry out the overall material balance and solute balance for a single-stage Liquid-Liquid Extractor.
f) 1200 kg of an aqueous solution containing 55% acetone is contacted with 750 kg of chloro-benzene containing 0.6 mass% acetone in a mixer settler unit, followed by separation of the extract and the raffinate phases. (i) Determine the composition of extract and raffinate phases and the fraction of acetone extracted. (ii) Calculate the amount of solvent required if 92% of acetone is to be removed. Equilibrium and tie line data are given below.

Aqueous phase (Raffinate)			Organic phase (Extract)		
Water (x_A)	**Chlorobenzene (x_B)**	**Acetone (x_C)**	**Water (y_A)**	**Chlorobenzene (y_B)**	**Acetone (y_C)**
0.9989	0.0011	0	0.0018	0.9982	0
0.8979	0.0021	0.1	0.0049	0.8872	0.1079
0.7969	0.0031	0.2	0.0079	0.7698	0.2223
0.6942	0.0058	0.3	0.0172	0.608	0.3748
0.5864	0.0136	0.4	0.0305	0.4751	0.4944
0.4628	0.0372	0.5	0.0724	0.3357	0.5919
0.2741	0.1259	0.6	0.2285	0.1508	0.6107
0.2566	0.1376	0.6058	0.2566	0.1376	0.6058

14. **(2+2+7+3+5+3+3=25)**

a) While discussing the solid-liquid phase equilibrium of crystallization, express Gibbs-Thompson equation, elaborating each term.

b) What is *Ostwald Ripening*?

c) A solution of 40 wt% $MgSO_4$ is cooled to 15.6°C. What is the yield of $MgSO_4.7H_2O$ (i) assuming no water evaporation, (ii) 6% of total water evaporation. Solubility is 24.5% (wt) at 15.6°C. The original mixture is 1200 Kg.

d) Give an expression for the rate of homogeneous primary nucleation and explain the terms.

e) What is '*secondary nucleation*'? Enumerate the major steps. What are the types of secondary nucleation? Which type is mostly practiced in the industry.

f) Starting with the rate of crystal growth, in terms of increase of mass, derive an expression for rate crystal growth in terms of characteristic length.

g) State McCabe's "ΔL" Law of crystal growth. State one major difference between this law and the Mass Transfer Theory of crystal growth.

15. **(1+6+6+4+8=25)**

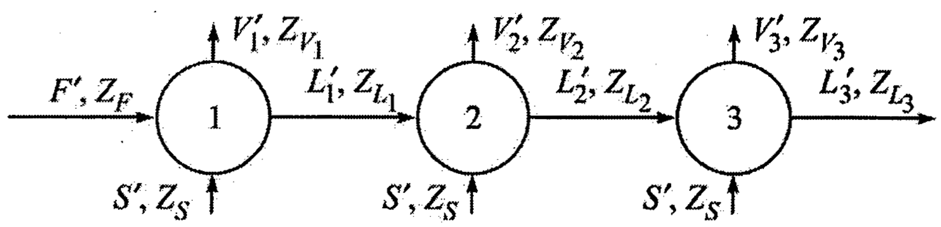
a) Represent adsorption isobar schematically.

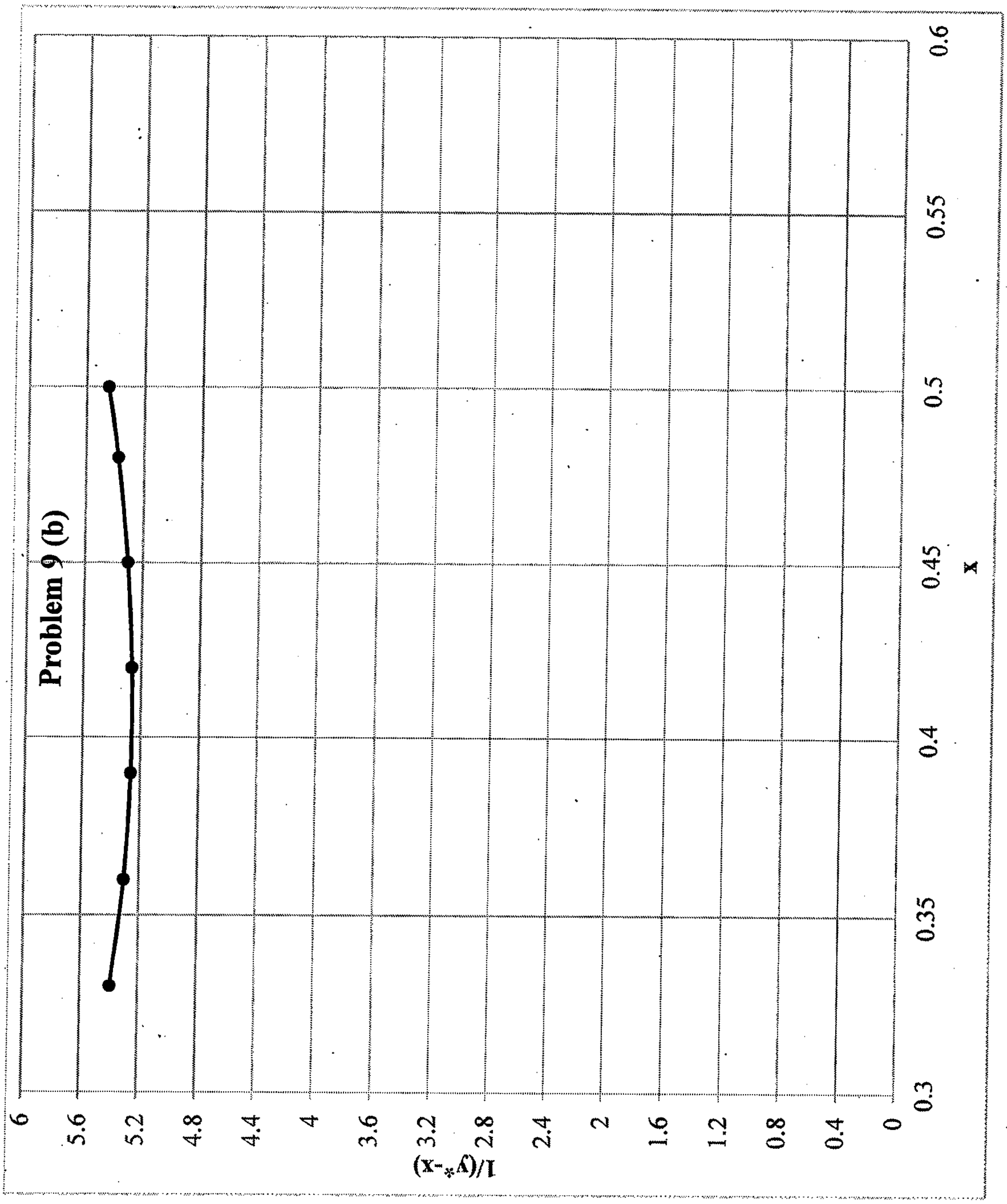
b) Represent the expression of Langmuir isotherm in terms of the fraction of surface covered by adsorbed molecules, adsorption-desorption kinetic constants, and maximum loading corresponding to complete surface coverage. What are the assumptions behind this expression. How do we fit experimental data to the linearized form of this expression.

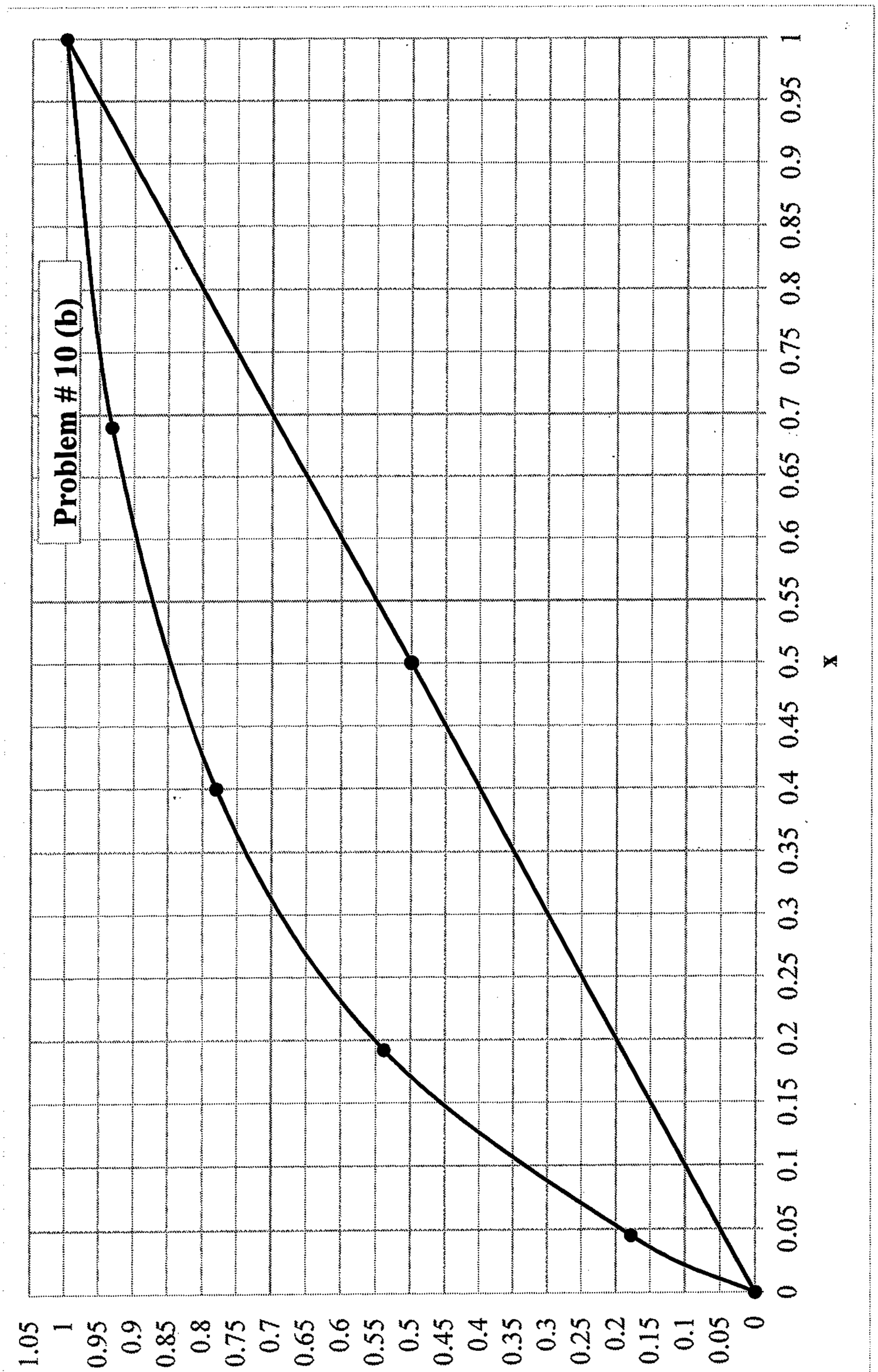
c) In the case of fixed-bed continuous adsorption, explain breakthrough time with respect to movement of the Mass Transfer Zone [MTZ] using a diagram. Show schematically the zones upstream and downstream of the stoichiometric front.

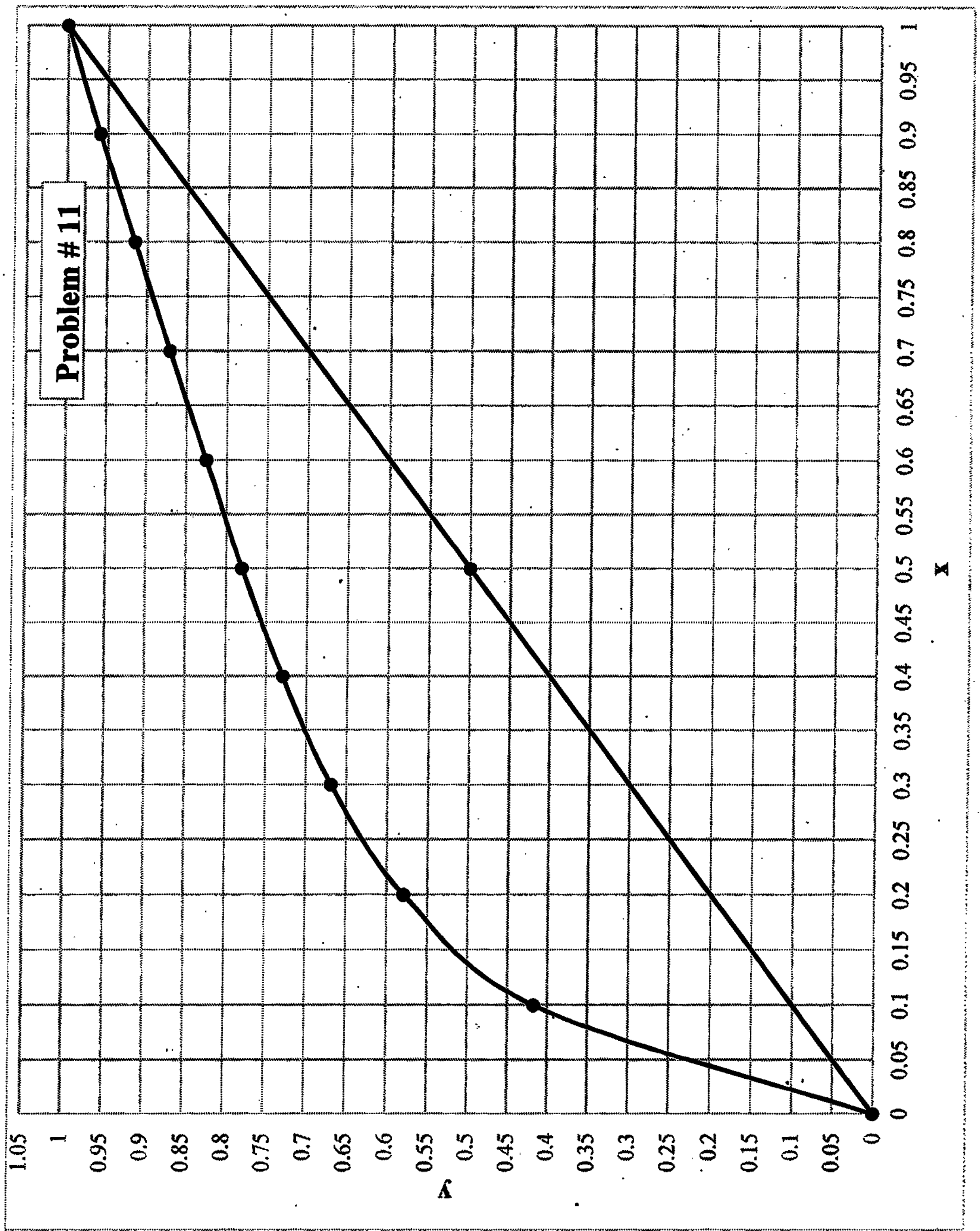
d) Choosing suitable coordinates represent solid-liquid equilibrium data on a Ponchon-Savarit diagram, indicating the equilibrium curves for overflow, underflow, and tie lines.

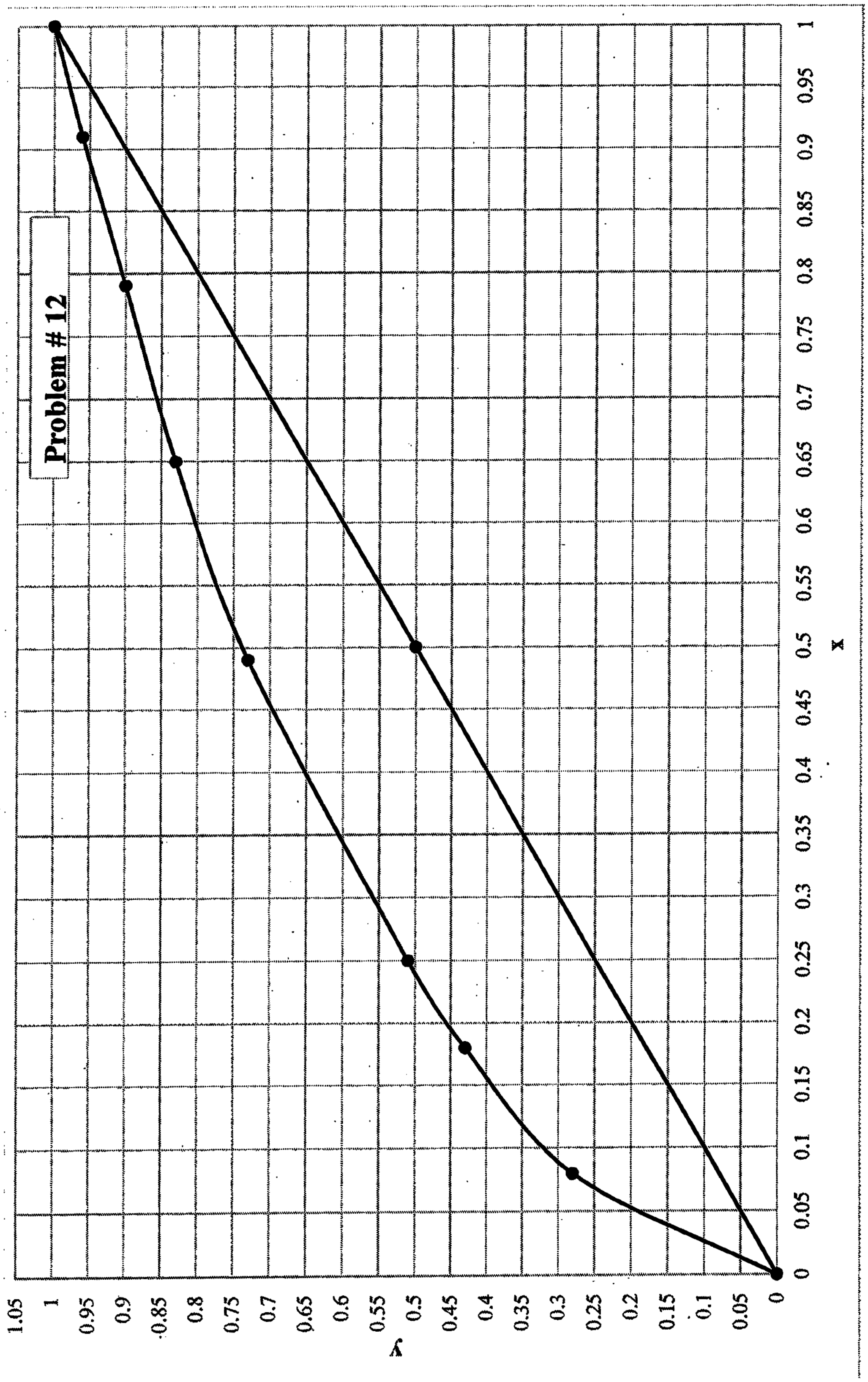
e) Carry out an overall material and solute balance in case of the following three-stage crosscurrent leaching set-up. Standard nomenclature is followed.



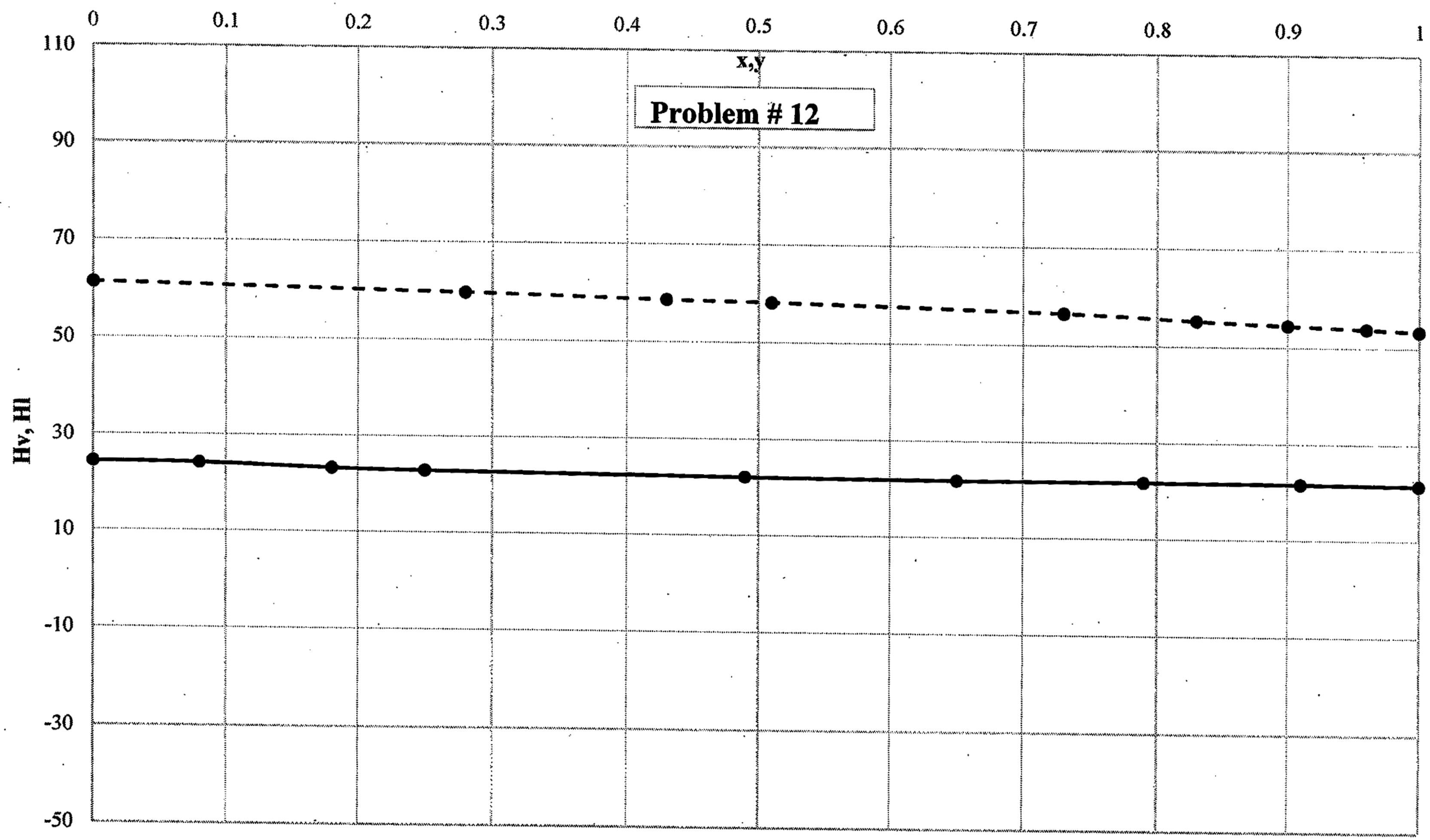

Problem 9 (b)
1/(y*-x)
6
5.6
5.2
4.8
4.4
4
3.6
3.2
2.8
2.4
2
1.6
1.2
0.8
0.4
0
0.3
0.35
0.4
0.45
0.5
0.55
0.6
x


Problem # 10 (b)
x
y
0 0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4 0.45 0.5 0.55 0.6 0.65 0.7 0.75 0.8 0.85 0.9 0.95 1
0 0.05 0.1 0.15 0.2 0.25 0.3 0.35 0.4 0.45 0.5 0.55 0.6 0.65 0.7 0.75 0.8 0.85 0.9 0.95 1 1.05


Problem # 11
x
y


Problem # 12
y
x
0
0.05
0.1
0.15
0.2
0.25
0.3
0.35
0.4
0.45
0.5
0.55
0.6
0.65
0.7
0.75
0.8
0.85
0.9
0.95
1
1.05

(a)



Problem # 12
x,y
Hv, Hl
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
110
90
70
50
30
10
-10
-30
-50

(b)