PROBLEMS

Problem 2.1

Consider the following set of equations

$$5x_1 - x_2 + x_3 = 10$$
$$2x_1 + 4x_2 = 12$$
$$x_1 + x_2 + 5x_3 = -1$$

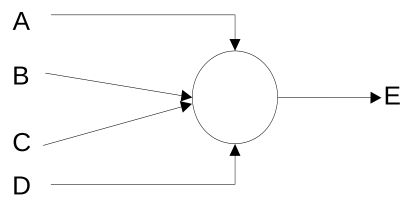
(b) Use Crout LU decomposition to solve this set of equations.

(c) Solve this system by Jacobi and Gauss-Seidel schemes, starting with (2,2,-1) as initial guess.

Problem 2.2

(a) Write a set of material balance equations for the system shown by figure below. The streams are *A,B,C,D* and *E*. The components are 1,2 and 3. The table below lists the known mass fractions.

(b) Solve the system for all the unknowns.



Data:

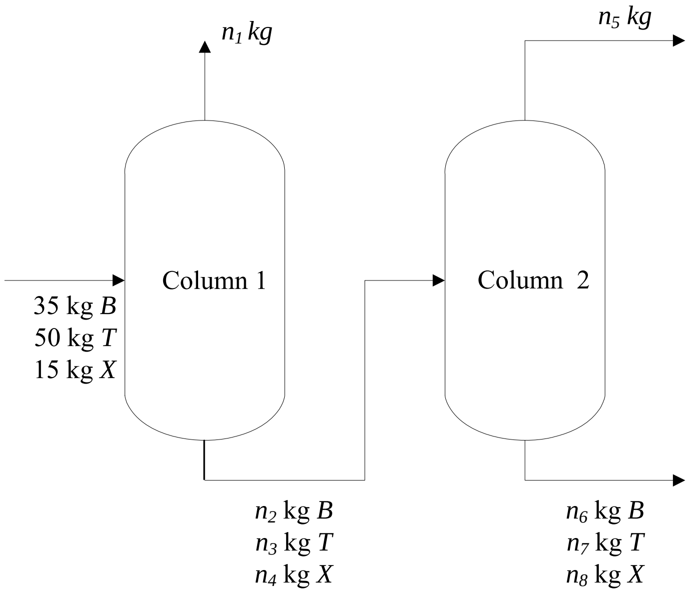
	A	B	C	D
Component 1	0.5	0.3	0.6	0.8
Component 2	0.3	0.2	0.4	0.2
Component 3	0.2	0.5		

Problem 2.3

Reconsider the equations for the three stages absorption tower given in the introduction to this chapter (Eqs. 2.5-2.7). Solve for the values of x_i and y_i , for the following data: $x_f = 0.01$, $y_f = 0.06$, $L = 40.8$ lb/min, $G = 66.7$ lb/min, a=0.72.

Problem 2.4

A stream containing 35 wt% benzene, 50% toluene, and the rest xylene is fed to a distillation column. The overhead product from the column contains 91.4 wt% benzene and 8.3% toluene. The bottom product is fed to a second column . The overhead product from the second column contains 4.25% benzene and 91.6% toulene. Of the toluene fed to the process, 10% is recovered in the bottom product from the second column, and 93.3% of the xylene fed to the process is recovered in the same stream .



(a) Show that the system equations are as given below:

Benzene: $0.914 = 35.0n_1 + n_2$

Toulene: $0.083 = 50n_1 + n_2$

Xylene: $0.003 = 15n_1 + n_4$

Benzene: $n_2 = 0.0425\, n_5 + n_6$

Tolune: $n_3 = 0.916\, n_5 + n_7$

Xylene: $n_4 = 0.0415\, n_5 + n_8$

10% toulene recovery: $n_7 = 0.1\ (50) = 5$

93.3% Xylene recovery: $n_8 = 0.933\ (15) = 14$

(b) Solve this 8×8 system of equations.

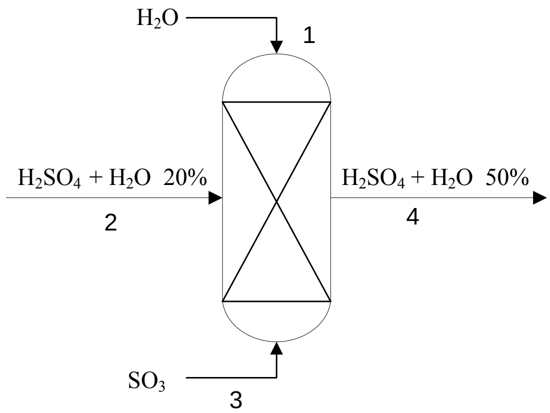
Problem 2.5

For the gas phase oxidation given below, calculate the equilibrium composition for the case where the products are not present initially. Assuming that initially the number of moles of A is 1, the problem equations have the form:

Reactions		Mass balances
$A \xleftrightarrow{k_1} R,$	$k_1 = 4$	$y_2/(1 - y_2 - y_3) = 4$
$A \xleftrightarrow{k_2} S,$	$k_2 = 1$	$y_1 + y_2 + y_3 = 1$
		$y_3/(1 - y_2 - y_3) = 1$

Problem 2.6

Sulfuric acid can be prepared by absorbing SO_3 in water as shown by figure below. Suppose a weak sulfuric acid stream (20% H_2SO_4) and a water stream are used to absorb a stream of SO_3. In what proportions should the streams be mixed if a 50% H_2SO_4 solution is to be produced?. Show first that for a basis of 100 mol of product, the elements balances can be simplified to:



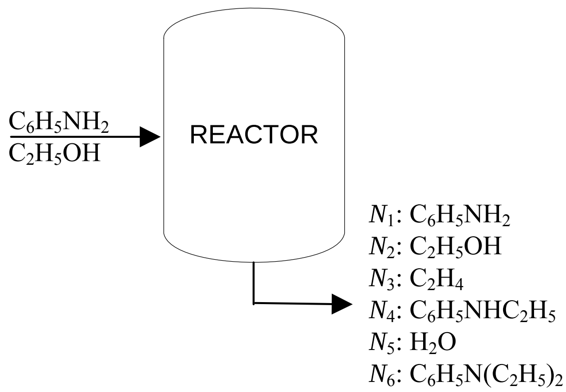
$$0.2\,N_2 + N_3 = 50$$

$$N_1 + 1.6N_2 + 3\,N_3 = 250$$

$$2\,N_1 + 2N_2 = 200$$

Problem 2.7

N-ethylaniline is produced industrially by vapor-phase catalytic reaction of aniline and ethanol. In a given plant, as shown by figure below, a reactant mixture of 6000 mol/h of ethanol (C_2H_5OH), and 3000 mol/h (C_6H_5NH2) is reacted until two thirds of the aniline and one half of the ethanol are converted. The product is a mixture of aniline, ethanol, *N*-ethylaniline ($C_6H_5NNHC_2H_5$), diethylaniline ($C_6H_5N(C_2H_5)_2$), water and 1% ethylene .



(a) Show that the atomic balances give the following linear equations:

$$N_4^{out} + N_6^{out} = 2000$$

$$N_5^{out} = 3000$$

$$2N_3^{out} + 8N_4^{out} + 10N_6^{out} = 18000$$

$$0.99N_3^{out} - 0.01N_4^{out} - 0.01N_5^{out} - 0.01N_6^{out} = 40$$

(b) Solve the given system for all unknowns

Problem 2.8

Chlorination of benzene produces a mixture of mono-, di-, tri- and quadrosubstitued products via the reaction chain

$$C_6H_6 + Cl_2 \rightarrow C_6H_5Cl + HCl$$
$$C_6H_5Cl + Cl_2 \rightarrow C_6H_4Cl_2 + HCl$$
$$C_6H_4Cl_2 + Cl_2 \rightarrow C_6H_3Cl_3 + HCl$$
$$C_6H_3Cl_3 + Cl_2 \rightarrow C_6H_2Cl_4 + HCl$$

Suppose that 100 mol/h benzene and 360 mol/h chlorine are fed to the reactor. The flowsheet of this problem is shown in Figure below. Show that, the mass balance equations for this system are:

Benzene balance

$$0.01\ N_4 = N_1 - r_1$$

C_6H_5Cl ,

$$0.07\ N_4 = r_1 - r_2$$

$C_6H_4Cl_2$balance,

$$0.12\ N_4 = r_2 - r_3$$

$C_6H_3Cl_3$balance,

$$0.75\ N_4 = r_3 - r_4$$

$C_6H_2Cl_4$ balance,

$$0.05\ N_4 = r_4$$

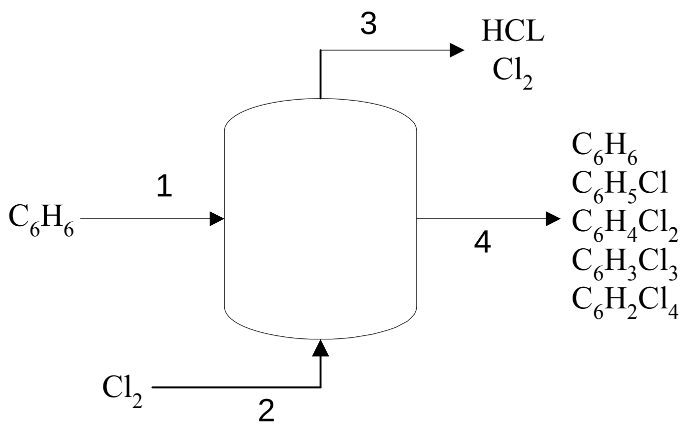
Cl_2 balance,

$$N3Cl_2 = N_2 - r_1 - r_2 - r_3 - r_4$$

HCl balance,

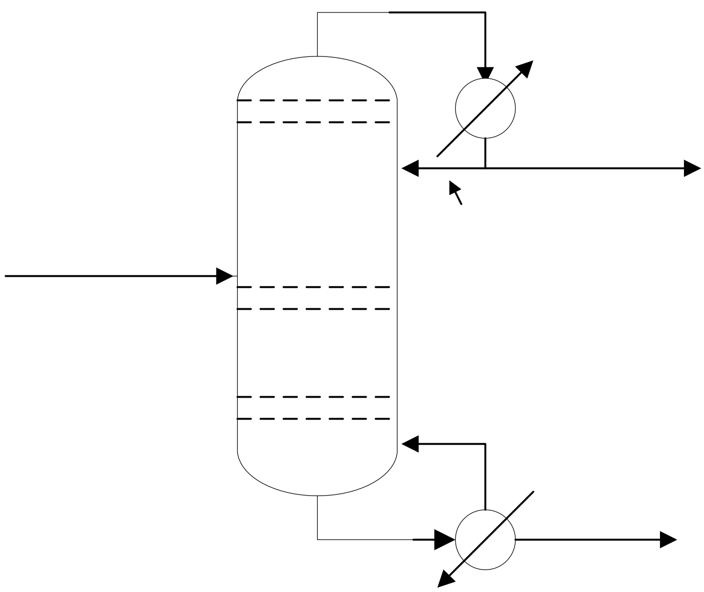
$$N_{3HCl} = r_1 + r_2 + r_3 + r_4$$

r_i represent the reaction rates in the order in which the chemical reaction equations are given. Determine all unknowns.



Problem 2.9

A mixture containing 65% mol acetone (*A*) and acetic acid (*B*) is separated in a continuous distillation column at 1 atm. A flowchart of this operation is shown in Figure below. The overhead vapor drawn of the column passes through a condenser. The condensed liquid is divided into two equal streams: the distillate and the reflux. The liquid bottom stream is partially vaporized in a rebolier. The liquid stream emerging from the reboilier is taken off as the bottom product, and the vapor is returned to the column as boilup. Negligible heat is lost from the column so that the only places where external heat transfer takes place are the condenser (Q_c) and the reboiler (Q_b)



Stream Data:

Feed-1 :	liquid $F_{A1} = 65$ mol/min, $F_{B1} = 35$ mol/min, $T_1 = 65^oC$
Overhead-2:	vapor $F_{A2}\}$, $F_{B2}\}$, $T_2 = 63^oC$
Reflux-3:	liquid $\{F_{A3}/F_{B3} = 49$, $T_3 = 56.8^oC$
Distillate-4 :	liquid $\{F_{A4}/F_{B4} = 49$, $T_4 = 56.8^oC$
Bottom -5:	liquid $\{F_{5A}/F_{5B} = 5.4$, $T_5 = 98.7^oC$
Boliup-6:	liquid $F_{A6}\}$, $F_{B6}\}$, $T_6 = 98.7^oC$

Thermodynamic data:

$T(^oC)$	$A(l)\,\hat{H}$ (kJ/mol)	$A(v)\,\hat{H}$ (kJ/mol)	$B(l)\,\hat{H}$ (kJ/mol)	$B(v)\,\hat{H}$
56.8	0	7205	0	5723
63	205	7322	194	6807
67.5	354	7403	335	6884
98.7	1385	7946	1312	7420

(a) Show that the material and energy balance equations for this system are:

Overall A balance

$$65 = F_{4A} + F_{5A}$$

Overall B balance

$$35 = F_{4B} + F_{4B}$$

Around the condenser

$$F_{2A} - F_{3A} - F_{4A} = 0$$
$$F_{2B} - F_{3B} - F_{4B} = 0$$

Distillate and Reflux are equal

$$F_{3A} - F_{4A} = 0$$
$$F_{3B} - F_{4B} = 90$$

Ratio of A and B in distillate and bottom:

$$F_{4A} - 49\,F_{4B} = 0$$
$$F_{5B} - 5.4\,F_{5B} = 0$$

Condenser energy balance:

$$Q_c = (F_{4A} + F_{3A}) \times H_{A,\,liq.,\,56.8oC} + (F_{4B} + F_{3B}) \times H_{B,\,liq.,\,56.8oC} - F_{2A} \times H_{A,\,vap.,\,63oC} - F_{2B} \times H_{B,\,vap.,\,63oC}$$

Distillation column energy balance:

$$Q_c + Q_b = F_{4A} \times H_{A,\,liq.,\,56.8oC} + F_{4B} \times H_{B,\,liq.,\,56.8oC} + F_{5A} \times H_{A,\,liq.,\,98.7oC} + F_{5B} \times H_{B,\,liq.,\,98.7oC} \quad -$$

$$F_{1A} \times H_{A,\ liq.,\ 65oC} - F_{1B} \times H_{A,\ liq.,\ 65oC}$$

(b) Solve these linear equations for the unknowns:

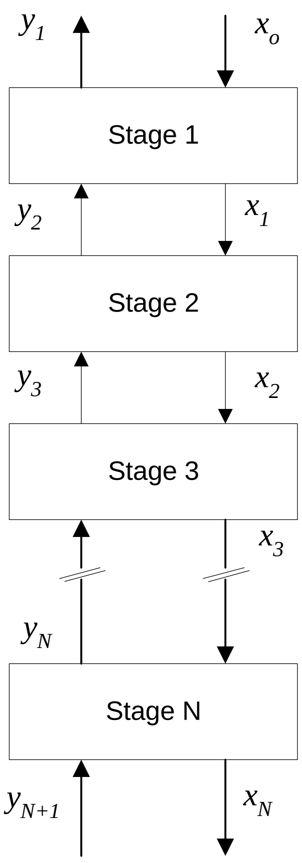
F_{2A}, F_{2B}, F_{3A}, F_{3B}, F_{4A}, F_{4B}, F_{6A}, F_{6B}, Q_c, Q_b

Problem 2.10

It is desired to absorb 90% of the acetone in a gas containing 1 mol% acetone in air in a countercurrent stage tower figure below. The total inlet gas flow to the tower is 30.0 kmol/h, and the total inlet pure water flow, to be used to absorb the acetone, is 90 kmol/h. The process is operating isothermally at 300K and a total pressure of 101.3 kPa. The gas-liquid equilibrium relation for the acetone (A) is $y_A = mx = 2.53x_A$. Using the absorption factor $A = L/mV$, the overall and component balance equations are combined to yield the following equation for each stage:

$$x_{n+1} - A\,x_n = y_{N+1}/m - Ax_N$$

Determine the number of stages required for separation.



Problem 2.11

Mass spectrometry analysis gives a series of peak height readings for various ion masses. For each peak, the height h is contributed by the various constituents. These make different contribution c_{ij} per unit concentration p_i, so that the relation

$$h_j = \sum_{i_1}^{n} c_{ij} p_i$$

holds, with n being the number of component present. The values for c_{ij} are given in the following table below.

Data

Peak number	CH_4	C_2H_4	C_2H_6	C_3H_6	C_3H_8
1	0.165	0.202	0.317	0.234	0.182
2	27.7	0.862	0.062	0.073	0.131
3		22.35	13.05	4.42	6.001
4			11.28	0	1.11
5				9.85	1.684
6					15.94

For a given sample, the measured peak heights are $h_1 = 5.2$ and $h_2 = 61.7$, $h_3 = 149.2$, $h_4 = 79.4$, $h_5 = 89.3$, and $h_6 = 69.3$. Calculate the values of p_i for each component. The total of all p_i values was 21.53 .