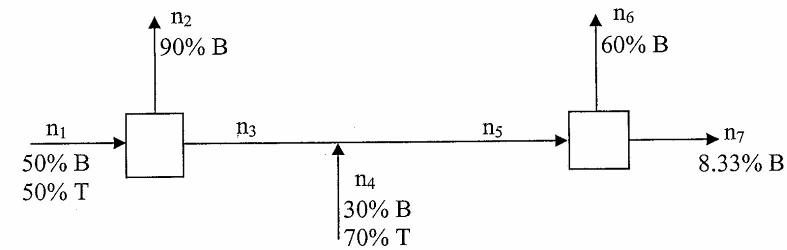
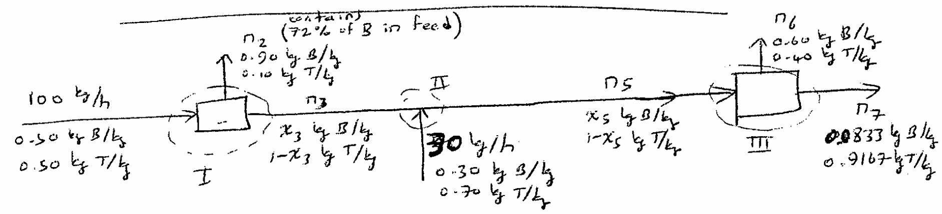
1. **(25 pts)** Consider the following flowchart. For each kg of stream n_1, 0.30 kg of stream n_4 is fed to the process. 72% of B in stream n_1 is recovered in stream n_2. For 100 kg/h of the feed stream n_1, determine the flow rates and compositions of all streams.





System I : 3 unk, 2 bal, 1 add. eq. $\Rightarrow$ DF = 0 ✓

System Overall : 3 unk, 2 bal, 1 add. eq. $\Rightarrow$ DF = 0 ✓

System II : 4 unk., 2 bal $\Rightarrow$ DF = 2 ✗

System III : 4 unk., 2 bal $\Rightarrow$ DF = 2 ✗

System I:

$(0.72)(0.50)100 = (0.90)n_2 \Rightarrow \boxed{n_2 = 40\ \text{kg/h}}$

Total Balance: $100 = \overset{40}{n_2} + n_3 \Rightarrow \boxed{n_3 = 60\ \text{kg/h}}$

B balance: $50 = (0.90)\overset{40}{n_2} + x_3(\overset{60}{n_3}) \Rightarrow \boxed{x_3 = 0.2333}$ $\boxed{1-x_3 = 0.7667}$

System II

Total: $\overset{60}{n_3} + 30 = n_5 \Rightarrow \boxed{n_5 = 90\ \text{kg/h}}$

B balance: $\overset{0.2333}{x_3}\,\overset{60}{n_3} + (0.30)30 = x_5\,\overset{90}{n_5} \Rightarrow \boxed{x_5 = 0.2555}$ $\boxed{1-x_5 = 0.7445}$

System III

Total: $\overset{90}{n_5} = n_6 + n_7$

B Balance: $\underbrace{\overset{0.2555}{x_5}\,\overset{90}{n_5}}_{22.995} = (0.60)n_6 + (0.0833)n_7$

$\boxed{n_6 = 30\ \text{kg/h}}$ $\boxed{n_7 = 60\ \text{kg/h}}$

or

Overall System

Total: $100 + 30 = \overset{40}{n_2} + n_6 + n_7 \Rightarrow 90 = n_6 + n_7$

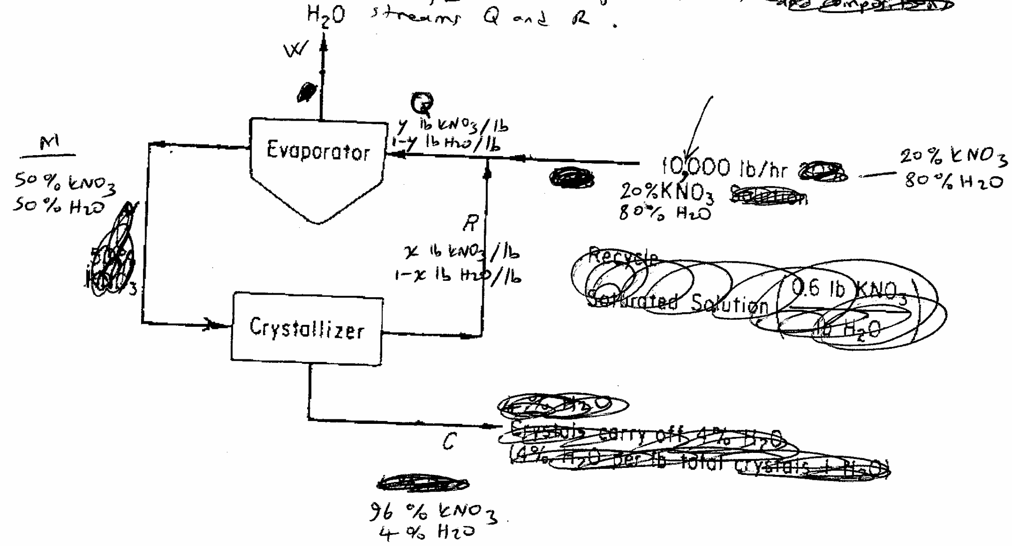
B Balance: $50 + (0.30)30 = (0.90)\overset{40}{n_2} + (0.60)n_6 + (0.0833)n_7$

$23 = (0.60)n_6 + (0.0833)n_7$

Same as above

make the necessary changes in the computer & redraw the figure.

2. **(25 pts)** Examine Figure below. KNO_3 crystals are produced through a combined evaporation and crystallization process. The recycled liquid from the crystallizer (stream R) contains 0.6 lb KNO_3/lb H_2O. Stream W is pure water, while stream M is a 50% KNO_3 solution. The crystals carry out 4% water. Calculate the ~~recycle stream in lb/hr~~. flow rates of the streams W, M, Q, R and the compositions of the streams Q and R.



Recycle : $\dfrac{x R}{(1-x) R} = 0.6 \Rightarrow \boxed{x = 0.375 \quad (37.5\% \; KNO_3)}$

Overall System: 2 unk., 2 bal. $\Rightarrow$ DF = 0 ✓

KNO_3 Bal. $(0.20)(10{,}000) = (0.96)\, C \Rightarrow \boxed{C = 2083.3 \text{ lb/h}}$

Total Bal. $10{,}000 = W + C \Rightarrow \boxed{W = 7916.7 \text{ lb/h } H_2O}$

Crystallizer : 2 unk. (M, R), 2 bal. $\Rightarrow$ DF = 0 ✓

Total : $M = \overset{2083.3}{C} + R$

KNO_3 bal. $0.5\, M = 0.96 \overset{2083.3}{C} + \overset{0.375}{x} R$

$\boxed{R = 7666.5 \text{ lb/h}}$

$\boxed{M = 9749.8 \text{ lb/h}}$

Evaporator : 2 unk., 2 bal. $\Rightarrow$ DF = 0

Total : $Q = W + M = 7916.7 + 9749.8 \Rightarrow \boxed{Q = 17666.5 \text{ lb/h}}$

KNO_3 bal. $y \overset{17666.5}{Q} = (0.50) \overset{9749.8}{M} \Rightarrow \boxed{y = 0.276 \; (27.6\%)}$

$\boxed{1-y = 0.724 \; (72.4\% \; H_2O)}$

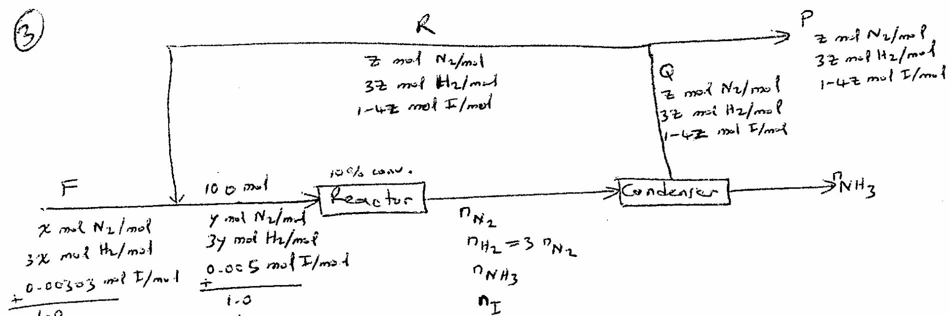
Check with mixing Point

Total : $10{,}000 + \overset{7666.5}{R} \overset{?}{=} \overset{17666.5}{Q}$

$17666.5 = 17666.5$ ✓

3. **(25 pts)** Ammonia is produced from nitrogen and hydrogen according to rxn $N_2 + 3H_2 \rightarrow 2NH_3$. The fresh feed to the process contains N_2 and H_2 in **stoichiometric ratio** and 0.303 mol% inert (I). This stream is mixed with a recycle stream to produce the feed to the reactor which contains 0.5 mol% I. The single-pass conversion in the reactor is 10%. The reactor output goes to a condenser from which two streams emerge: a liquid product stream containing all the ammonia formed in the reactor, and a gas stream containing all the N_2, H_2 and I leaving the reactor. The gas stream is split into two fractions: one is removed from the process as a purge stream, and the other is the recycle stream that combines with the fresh feed to form the feed to the reactor. Taking 100 mol of feed to the reactor as the basis, calculate the production rate of ammonia, the flow rate of fresh feed, the flow rate and composition of the purge gas, and the overall conversion.

(3)



$x = 0.24924$ $\quad$ $y = 0.24875$

$3x = 0.74773$ $\quad$ $3y = 0.74625$ $\qquad$ $N_2 + 3H_2 \longrightarrow 2NH_3$

System: Mixing Point: 3 unkn., 2 bal. (N_2 & H_2 dependent, only one of them can be used) $\Rightarrow$ DF = 1 X

Reactor: 10% conv. $\Longrightarrow (N_2)_{reacted} = (0.10)\,y\,(100) = 2.4875$ mol.

$n_{N_2} = y\,(100) - (N_2)_{reacted} = 22.3875$ mol N_2

$n_{H_2} = 3 \times n_{N_2} = 67.1625$ mol H_2

$n_{NH_3} = (N_2)_{reacted} \times \frac{2}{1} = \boxed{4.975 \text{ mol } NH_3}$

$n_I = (0.005)100 = 0.5$ mol I

Condenser: $Q = n_{N_2} + n_{H_2} + n_I = 90.05$ mol

N_2 Balance: $n_{N_2} = z\,Q \Longrightarrow \boxed{\begin{array}{l} z = 0.24861 \text{ mol } N_2/\text{mol} \\ 3z = 0.74584 \text{ mol } H_2/\text{mol} \\ 1-4z = 0.00555 \text{ mol I/mol} \end{array}}$

Overall System:

N Balance: $x\,F\,\frac{2}{1} = n_{NH_3}\,\frac{1}{1} + z\,P\,\frac{2}{1}$

$\boxed{(0.49848)\,F = 4.975 + (0.49722)\,P} \Longrightarrow \boxed{P = 11.964 \text{ mol}}$ $\boxed{F = 21.9139 \text{ mol}}$

I Balance: $\boxed{(0.00303)\,F = (0.00555)\,P}$

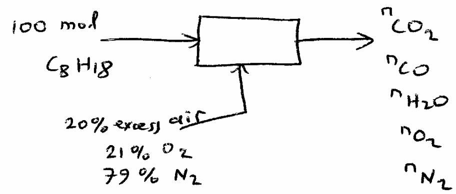
Splitter: $Q = R + P \Rightarrow R = Q - P = 78.086$ mol

Overall Conversion: $\dfrac{(N_2)_{in\,F} - (N_2)_{in\,P}}{(N_2)_{in\,F}} = \dfrac{x\,F - z\,P}{x\,F} = 0.455 \quad \boxed{(45.5\%)}$

4. **(25 pts)** Octane (C_8H_{18}) is burned with 100% conversion with 20% excess air and 30% of ~~the carbon~~ octane forms CO. What is the flue gas analysis?

$$C_8H_{18} + 12.5\,O_2 \longrightarrow 8\,CO_2 + 9\,H_2O$$
$$C_8H_{18} + 8.5\,O_2 \longrightarrow 8\,CO + 9\,H_2O$$

2 pts



$$(O_2)_{theoretical} = 100 \text{ mol } C_8H_{18} \frac{12.5 \text{ mol } O_2}{1 \text{ mol } C_8H_{18}} = 1250 \text{ mol}$$ 3 pts

$$(O_2)_{fed} = (1.20)(O_2)_{th.} = (1.20)(1250) = 1500 \text{ mol}$$ 3 pts

2 pts

$$(N_2)_{fed} = (O_2)_{fed} \cdot \frac{79}{21} = \boxed{5642.86 \text{ mol} = n_{N_2}}$$ 3 pts

70% of C_8H_{18} forms CO_2 $\Longrightarrow$ $n_{CO_2} = (0.70)\,100 \text{ mol } C_8H_{18} \frac{8\,CO_2}{1\,C_8H_{18}} = \boxed{560 \text{ mol}}$

30% of C_8H_{18} forms CO $\Longrightarrow$ $n_{CO} = (0.30)\,100 \text{ mol } C_8H_{18} \frac{8\,CO}{1\,C_8H_{18}} = \boxed{240 \text{ mol}}$ 3 pts

Find n_{H_2O} & n_{O_2} either by molecular balance or atomic bal.

3 pts

ATOMIC BAL.

H: $100 \text{ mol } C_8H_{18} \frac{18\,H}{1\,C_8H_{18}} = n_{H_2O} \frac{2}{1} \Rightarrow \boxed{n_{H_2O} = 900 \text{ mol}}$ 3 pts

O: $1500 \text{ mol } O_2 \frac{2\,O}{1\,O_2} = \underset{560}{n_{CO_2}} \frac{2}{1} + \underset{240}{n_{CO}} \frac{1}{1} + n_{H_2O} \frac{1}{1} + n_{O_2} \frac{2}{1} \Rightarrow \boxed{n_{O_2} = 370 \text{ mol}}$

COMPOSITION

	WET GAS mol	WET GAS fraction (%)	DRY GAS mol	DRY GAS fraction (%)
CO_2	560	0.0725 (7.25%)	560	0.082 (8.2%)
CO	240	0.0311 (3.11%)	240	0.0352 (3.52%)
O_2	370	0.0479 (4.79%)	370	0.0543 (5.43%)
N_2	5650	0.732 (73.2%)	5650	0.8285 (82.85%)
H_2O	900	0.1166 (11.66%)		
+	7720	1.0001 (100.01%)	6820	1.0000 (100.00%)

3 pts

OR

MOLECULAR BALANCE:

$$n_{H_2O} = (0.70)\,100 \text{ mol } C_8H_{18} \frac{9\,H_2O}{1\,C_8H_{18}} + (0.30)\,100 \text{ mol } C_8H_{18} \frac{9\,H_2O}{1\,C_8H_{18}} = 100 \text{ mol } C_8H_{18} \frac{9\,H_2O}{1\,C_8H_{18}} = \boxed{900 \text{ mol}}$$

$$(O_2)_{\substack{consumed\\(reacted)}} = (0.70)\,100 \text{ mol } C_8H_{18} \frac{12.5\,O_2}{1\,C_8H_{18}} + (0.30)\,100 \text{ mol } C_8H_{18} \frac{8.5\,O_2}{1\,C_8H_{18}} = 1130 \text{ mol}$$

$$n_{O_2} = (O_2)_{feed} - (O_2)_{reacted} = 1500 - 1130 = \boxed{370 \text{ mol}}$$