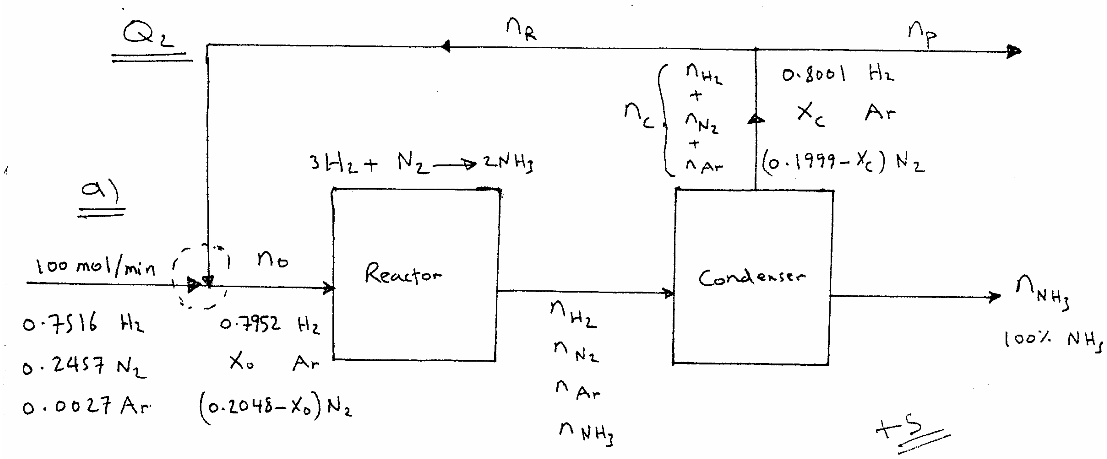
An Old Exam Question from Ch.4

The ammonia (NH_3) synthesis process consists mainly of two major units: a reactor, and an ammonia condenser. The flow rate of the fresh feed to the process is 100 mol/min and its molar composition is 75.16% H_2, 24.57% N_2, and 0.27% Ar (Inert). The fresh feed is mixed with the recycle gas before it enters the reactor; the gas entering the reactor is 79.52 mole % H_2. The reactor effluent is fed to the ammonia condenser where all the ammonia formed is condensed. The gas leaving the condenser contains 80.01 mole % H_2 and no ammonia. The product ammonia contains no dissolved gases. Part of the gas stream leaving the condenser is purged to prevent the argon from building up in the process while the remaining is recycled.

a) Draw a flow chart of the process and label all the unknowns.
b) Calculate the molar flow rates of the recycled and purged streams.
c) Calculate the single pass conversion of hydrogen.



b) 1) Overall Process:

Unknowns: $\begin{cases} n_P \\ X_C \\ n_{NH_3} \end{cases}$ equations: $\begin{cases} \text{Ar - balance} \\ \text{H - balance} \\ \text{N - balance} \end{cases}$ $\Rightarrow n_{df} = 0$

Ar - balance: $0.27 = n_P X_C$ (1)

H - balance: $2 * 75.16 = 3\, n_{NH_3} + 2 * 0.8001\, n_P$ (2)

N - balance: $2 * 24.57 = n_{NH_3} + 2 * (0.1999 - X_C)\, n_P$ (3)

+5

From (2): $n_{NH_3} = 50.01 - 0.5334\, n_P$ (4)

(1) in (3): $49.14 = n_{NH_3} + 0.3998\, n_P - 2 * 0.27$ (5)

(4) in (5): $49.14 = 50.01 - 0.5334\, n_P + 0.3998\, n_P - 0.54$

$\Rightarrow$ $\boxed{n_P = 2.47 \text{ mol/min}}$

$\Rightarrow$ $\boxed{n_{NH_3} = 48.69 \text{ mol/min}}$

$\Rightarrow$ $X_C = 0.1093$ mol Ar/mol

2) Mixing point

Unknowns: $\begin{cases} n_R \\ n_o \\ X_o \end{cases}$, equations $\begin{cases} H_2 \text{ balance} \\ N_2 \text{ balance} \\ Ar \text{ balance} \end{cases} \Rightarrow n_{df} = 0$

Ar balance: $0.1093\, n_R + 0.27 = X_o n_o$ (1)

N_2 balance: $0.0906\, n_R + 24.57 = 0.2048\, n_o - X_o n_o$ (2)

H_2 balance: $0.8001\, n_R + 75.16 = 0.7952\, n_o$ (3)

From (3) $n_o = 1.006\, n_R + 94.52$ (4)

(4) and (1) in (2):

$\Rightarrow 0.0906\, n_R + 24.57 = 0.2060\, n_R + 19.36 - 0.27 - 0.1093\, n_R$

$\Rightarrow$ $n_R = 898.36$ mol/min

$\Rightarrow$ $n_o = 998.27$ mol/min

$\Rightarrow$ $X_o = 0.0986$ mol Ar/mol

3) Splitting point $n_c = n_R + n_p$

$\Rightarrow$ $n_c = 900.83$ mol/min

4) Condenser: unknowns $\begin{cases} n_{H_2} \\ n_{N_2} \\ n_{Ar} \end{cases}$, equations $\begin{cases} N_2 \text{ balance} \\ H_2 \text{ balance} \\ Ar \text{ balance} \end{cases}$

Ar - balance :

$$n_{Ar} = X_c n_c = 0.1093 * 900.83 = 98.46 \text{ mol Ar/min}$$

$$n_{N_2} = (0.1999 - X_c) n_c = 81.62 \text{ mol } N_2\text{/min}$$

$$n_{H_2} = 0.8001 \; n_c = 720.75 \text{ mol } H_2\text{/min}$$

$\therefore$ moles purged $= n_p = 2.47$ mol/min   +5

moles recycled $= n_R = 898.36$ mol/min

c) Single pass conversion of $H_2 = \dfrac{n_o * 0.7952 - n_{H_2}}{n_o * 0.7952} = 0.0920$

$= 9.2\%$ +5