1 a) $r_{Br} = r_{Br_1} + r_{Br2} + r_{Br3}$

$$r_1 = \frac{r_{Br1}}{2} = \frac{r_{Br_2 1}}{-1} \longrightarrow r_{Br_1} = 2k_1[Br_2] - 2k_{-1}[Br]^2$$

$$\boxed{r_{Br} = 2k_1[Br_2] - 2k_{-1}[Br]^2 - k_2[Br][H_2] + k_{-2}[H][HBr] + k_3[H][Br_2]} \quad \text{I}$$

$r_H = r_{H1} + r_{H2} + r_{H3}$

$$\boxed{= k_2[Br][H_2] - k_{-2}[H][HBr] - k_3[H][Br_2]} \quad \text{II}$$

b) $r_{HBr} = k_2 \underline{\underline{[Br]}}[H_2] - k_{-2}\underline{\underline{[H]}}[HBr] + k_3 \underline{\underline{[H]}}[Br_2]$ III

To get $[Br]$ use the fact that step 1 is always QE:

$$r_1 = 0 = k_1[Br_2] - k_{-1}[Br]^2$$

$$\Downarrow$$

$$[Br] = \sqrt{\frac{k_1}{k_{-1}}}\,[Br_2]^{1/2} \quad \text{IV}$$

To get $[H]$ for the general case, apply PSSH to II:

$$r_H = 0 = -k_3[H][Br_2] - k_{-2}[H][HBr] + k_2[Br][H_2]$$

$$\Downarrow$$

$$[H] = \frac{k_2[Br][H_2]}{k_3[Br_2] + k_{-2}[HBr]} \quad \text{V}$$

combine III, IV, and V:

$$r_{HBr} = k_2\sqrt{\frac{k_1}{k_{-1}}}\,[Br_2]^{1/2}[H_2] - \frac{k_{-2}k_2\sqrt{\frac{k_1}{k_{-1}}}\,[Br_2]^{1/2}[H_2][HBr]}{k_3[Br_2] + k_{-2}[HBr]} + \frac{k_3[Br_2]^{3/2}k_2\sqrt{\frac{k_1}{k_{-1}}}\,[H_2]}{k_3[Br_2] + k_{-2}[HBr]}$$

← most common form

↓ algebra

$$\boxed{r_{HBr} = \frac{2k_2k_3\sqrt{\frac{k_1}{k_{-1}}}\,[Br_2]^{3/2}[H_2]}{k_3[Br_2] + k_{-2}[HBr]}}$$

← prettiest form

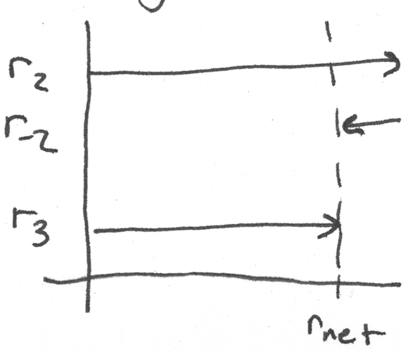
c) $$r_{HBr} = \frac{2k_2k_3\sqrt{\frac{k_1}{k_{-1}}}\,[Br_2]^{3/2}[H_2]}{k_3[Br_2] + k_{-2}[HBr]}$$

↓ step 2 equilibrated

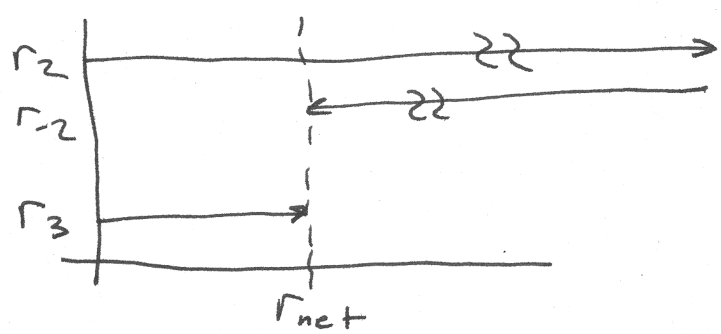
$$= \boxed{2\underbrace{\frac{k_2}{k_{-2}}}_{K_2}k_3\sqrt{\frac{k_1}{k_{-1}}}\,\frac{[Br_2]^{3/2}[H_2]}{[HBr]}}$$

This happens if $\boxed{k_{-2} \gg k_3}$

d) general:



step 2 equilibrated:



e) PFR: $\frac{dF_{Br_2}}{dV} = r_{Br_2}$

$$\longrightarrow F_{Br_2} = F_{Br_2 0}(1-X) \rightarrow dF_{Br_2} = -F_{Br_2 0}\,dX$$

$$-F_{Br_2 0}\frac{dX}{dV} = r_{Br_2} = -k' C_{Br_2}^{3/2}$$

$\hookrightarrow$ liquid phase:

$C_{Br_2} = C_{Br_2 0}(1-X)$

$$F_{Br_2 0}\frac{dX}{dV} = k' C_{Br_2 0}^{3/2}(1-X)^{3/2}$$

$$\int_0^{X_F}\frac{dX}{(1-X)^{3/2}} = \frac{k' C_{Br_2 0}^{3/2}}{F_{Br_2 0}}\int_0^V dV$$

$$V = \frac{2F_{Br_2 0}}{k' C_{Br_2 0}^{3/2}}\left[(1-X)^{-1/2}\right]_0^{0.7} = \boxed{2.05L}$$

$F_{Br_2 0} = 12\ \frac{mol}{min}$

$k' = 4.3\ \frac{L^{1/2}}{mol^{1/2}\,min}$

$C_{Br_2 0} = \frac{12\ \frac{mol}{min}}{7\ \frac{L}{min}} = \frac{12}{7}\ \frac{mol}{L}$

2.

(a) In − Out + Rxn = Accumulation

$$v_0 C_{max} - v_0 C_A + 0 = V\frac{dC_A}{dt} + C_A\left(\cancel{\frac{dV}{dt}}\right)^{\to 0} \quad \text{liquid phase}$$

$$v_0 (C_{max} - C_A) = -V\frac{d(C_{max} - C_A)}{dt}$$

$$\frac{d(C_{max} - C_A)}{C_{max} - C_A} = -\frac{v_0}{V}\,dt$$

$$\ln(C_{max} - C_A)\Big|_0^{C_A} = -\frac{v_0}{V}t$$

$$\frac{C_{max} - C_A}{C_{max}} = e^{-\frac{v_0}{V}t}$$

$$C_A = C_{max}\left(1 - e^{-\frac{v_0}{V}t}\right) \quad (t \geq 0)$$

(b) 0^{th} order rxn $r_A = -k$

In − Out + Rxn = Accumulation

$$v_0 C_{max} - v_0 C_A' - kV = V\frac{dC_A'}{dt} + C_A'\cancel{\frac{dV}{dt}}^{\to 0}$$

$$v_0\left(C_{max} - C_A' - \frac{kV}{v_0}\right) = -V\frac{d\left(C_{max} - C_A' - \frac{k}{v_0}\right)}{dt}$$

$$\ln\frac{C_{max} - C_A' - \frac{kV}{v_0}}{C_{max} - \frac{k}{v_0}} = -\frac{v_0}{V}t$$

$$C_A' = \left(C_{max} - \frac{kV}{v_0}\right)\left(1 - e^{-\frac{v_0}{V}t}\right)$$

(C)

① Without rxn, steady state CSTR

$$v_0 C_{max} - v_0 C_{A,ss} = 0 \qquad C_{A,ss} = C_{max}$$

to reach 99% of $C_{A,ss}$, then by looking at the results from part (a)

$$\left.\begin{array}{l} C_A = C_{max}\left(1 - e^{-\frac{v_0}{V}t_1}\right) \\ C_A = 0.99\, C_{max}. \end{array}\right\} \Rightarrow t_1 = \frac{2V}{v_0}\ln 10$$

② With 0^{th} order rxn, steady state CSTR

$$v_0 C_{max} - v_0 C'_{A,ss} - kV = 0$$

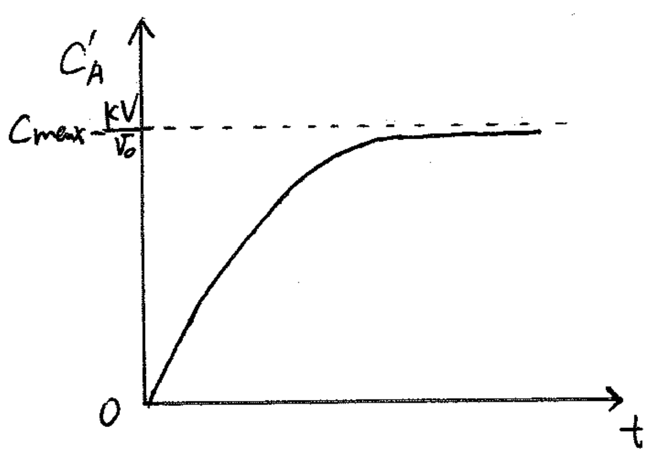
$$C'_{A,ss} = \frac{-kV + v_0 C_{max}}{v_0} = C_{max} - \frac{kV}{v_0}$$

To reach 99% of $C'_{A,ss}$, by looking at the results from part (b)

$$\left.\begin{array}{l} C'_A = \left(C_{max} - \frac{Vk}{v_0}\right)\left(1 - e^{-\frac{v_0}{V}t_2}\right) \\ C'_A = 0.99\left(C_{max} - \frac{kV}{v_0}\right) \end{array}\right\} \Rightarrow t_2 = \frac{2V}{v_0}\ln 10$$

The reaction doesn't change the time

(d)



3.a) Stoichiometric Table

Species	In	~~Out~~ Change	Out before condensation	Out after condensation
A	F_{A0}	$-F_{A0}X_A$	$F_{A0}(1-X_A)$	$F_{A0}(1-X_A)$
B	0	$\frac{1}{2}F_{A0}X_A$	$\frac{1}{2}F_{A0}X_A$	$y_B F_T'$
C	0	$\frac{1}{2}F_{A0}X_A$	$\frac{1}{2}F_{A0}X_A$	$\frac{1}{2}F_{A0}X_A$
I	$F_{I0}=F_{A0}$	0	$F_{I0}=F_{A0}$	$F_{I0}=F_{A0}$
			$F_T = 2F_{A0}$	$F_T' = F_{A0}(2-\frac{1}{2}X_A) + y_B F_T'$

$$\Rightarrow F_T' = \frac{F_{A0}(2-\frac{1}{2}X_A)}{1-y_B}$$

b) Condensation begins when $F_T = F_T'$

$$\therefore 2F_{A0} = \frac{F_{A0}(2-\frac{1}{2}X_A)}{1-\underbrace{y_B}_{\to 0.2}}$$

$$\Rightarrow 1.6 = 2 - 0.5X_A.$$

$$\Rightarrow \boxed{X_A = 0.8}$$

c) Before condensation: $2A(g) \longrightarrow B(g) + C(g)$

$\delta = 0,\ \varepsilon = 0.$

$r_A = -2k\,C_A^2$, $C_A = C_{A0}\dfrac{(1-X_A)}{(1+\varepsilon X_A)}$

or, $r_A = -2\,C_{A0}^2\,(1-X_A)^2$

$$C_{A0} = \frac{F_{Total,0} \times y_{A0}}{v} = \frac{10 \times 0.5}{1}\ \text{mol/litre} = 5\ \text{mol/litre}$$

$$\therefore \boxed{r_A = -50(1-X_A)^2}\quad (\text{mol/litre-min})$$

After condensation,

$$C_A = \frac{F_A}{\vartheta}.$$

$$\vartheta = \vartheta_0 \cdot \frac{F_T'}{F_{Total,0}} = \vartheta_0 \times \frac{F_{A0}\frac{(2-\frac{1}{2}X_A)}{(1-y_B)}}{2F_{A0}} = \frac{\vartheta_0(1-\frac{1}{4}X_A)}{(1-y_B)}$$

$$\therefore C_A = \frac{F_{A0}(1-X_A)(1-y_B)}{\vartheta_0(1-\frac{1}{4}X_A)} = \underset{\downarrow\,5}{C_{A0}} \frac{(1-X_A)(1-\overset{0.2}{y_B})}{(1-\frac{1}{4}X_A)}$$

or, $$C_A = 4\frac{(1-X_A)}{(1-\frac{1}{4}X_A)} \text{ mol / litre}.$$

$$\therefore r_A = -2kC_A^2.$$

$$\boxed{r_A = -32\frac{(1-X_A)^2}{(1-\frac{1}{4}X_A)^2}} \text{ (mol/ litre - min)}$$

d) $X_A = 0.95$, condensation of B

$$\therefore V = \frac{F_{A0}X_A}{-r_A|_{exit}} = \frac{5\times0.95}{32\frac{(1-0.95)^2}{(1-\frac{1}{4}\times0.95)^2}} \text{ litre}$$

$$= 34.5 \text{ litre}.$$

e) $F_A = 5(1-0.95)$ mol /min $= 0.25$ mol/ min

$F_T' = \frac{5(2-0.5\times0.95)}{1-0.2} = 9.53125$ mol/min, $F_B = y_B F_T' = 1.90625$ mol/min

$F_C = \frac{1}{2}\times5\times0.95 = 2.375$ mol/min, $F_I = 5$ mol/min

$\therefore$ mole fraction $y_i = F_i/F_T'$.

$\therefore y_A = 0.026$, $F_B = 0.2$, $F_C = 0.249$, $F_I = 0.524$

4. a) Total material balance.

Accumulation = ~~In~~ - Out + Generation

$$\frac{d(V\rho)}{dt} = -v \cdot \rho \Rightarrow \boxed{\frac{dV}{dt} = -v} \quad (1)$$

ρ constant, $V = A_c \cdot z$

$$A_c \frac{dz}{dt} = -a\sqrt{2gz}.$$

$$\frac{dz}{\sqrt{z}} = \alpha\, dt, \quad \alpha = \frac{-a\sqrt{2g}}{A_c}, \quad \alpha < 0.$$

at $t=0$, $z = z_0$.

$$\therefore 2\left(\sqrt{z} - \sqrt{z_0}\right) = \alpha t.$$

$$\therefore z = \left(\sqrt{z_0} + \frac{\alpha t}{2}\right)^2.$$

$$\therefore \boxed{V = A_c \cdot z = A_c\left(\sqrt{z_0} + \beta t\right)^2} \quad \text{where } \beta = \frac{\alpha}{2} = -\frac{a}{A_c}\sqrt{\frac{g}{2}}.$$

(2)

b) General mole balance

$\underset{0}{\cancel{In}}$ - Out + Gen = Acc.

$$-C_A \cdot v + r_A \cdot V = \frac{d(N_A)}{dt}$$

$$-C_A \cdot v - kC_A \cdot V = \frac{d(C_A V)}{dt} = V\frac{dC_A}{dt} + C_A\frac{dV}{dt}.$$

$$\Rightarrow -\cancel{C_A v} - kC_A \cdot V = V\frac{dC_A}{dt} - \cancel{C_A \cdot v} \quad \left[\frac{dV}{dt} = -v \text{ from } (1)\right]$$

$$\Rightarrow \boxed{\frac{dC_A}{dt} = -kC_A}$$

c) at $t=0$, $C_A = C_{A0}$. Integrating.

$$\therefore \boxed{C_A = C_{A0}e^{-kt}}$$

Same as for a batch reactor.

We are taking out the contents, uniformly without any selectivity, for any particular reactant and conc^n is indenpendent of the volume of liquid in the reactor, because it is uniformly mixed reactor.

d) $$N_A(t) = C_A(t)\cdot V(t)$$

$$= C_{A0}e^{-kt}\cdot A_c\cdot(\sqrt{z_0}+\beta t)^2$$

e) $$\frac{N_B|_{leak}}{N_B|_{without\ leak}} = \frac{(C_{A0}-C_A).V(t)}{(C_{A0}-C_A)\cdot V_0} \qquad [C_B = C_{A0} - C_A]$$

$$= \frac{A_c\cdot z}{A_c\cdot z_0} = \frac{z}{z_0}$$

$$= \frac{\left(\sqrt{z_0}+\frac{\alpha t}{2}\right)^2}{z_0}$$