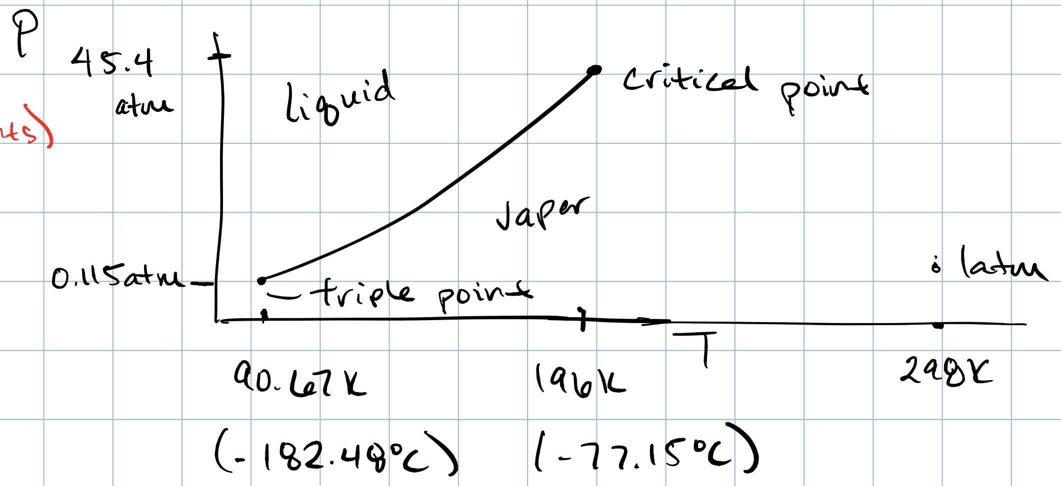
1. Natural gas storage

a.

(4 points)



+1, correct triple point and critical point

+1, general PT diagram correct

+1, liquid vaper regions correct

methane's phase, ambient conditions $(T=298K, P=1atm)$

use graph

$\boxed{\text{gas/vapor}}$ +1

b) 623,000 moles $V=500\ m^3$ $P=10atm$ limit

(5 points)

$$P = \frac{nRT}{V} = \frac{(623,000)(8.314\ J/mol\,K)(298\ K)}{500\ m^3}$$

+3, using ideal gas law

$P = 3087054\ Pa$

$\boxed{P = 30.5 \text{ atm}}$

Storage container can't be used

+1 correct answer

+1 correct conclusion

c) $T: -140°C = 133.15 \text{ K}$

i) $P = \frac{nRT}{V} = \frac{(623{,}000)(8.314 \text{ J/mol K})(133.15 \text{ K})}{500}$

+1, using ideal gas again

$P = 1379333 \text{ Pa}$

if $T = -130°C$

$P = 1482926 \text{ Pa}$

$P = 14.6 \text{ atm}$

$+\frac{1}{2}$ $\boxed{P = 13.61 \text{ atm}}$

if all vapor

$P > P_{max}$

check w/ Antoine's

+2, checking w/ Antoine's

$$P^* = 10^\wedge\left[6.34159 - \frac{342.22}{-140 + 260.221}\right]$$

$P^* = 3126 \text{ mmHg}$

$+\frac{1}{2}$, correct P^*

+1, $P = P^*$, concluding tank is good

$P^* = 4.11 \text{ atm}$

$P^* < P_{IGL}$, so vapor liquid equilibrium

single component : $P^* = P$

this tank can be used!

$$\boxed{\begin{array}{ll} \text{if } T = -130°C & P^* = 5171 \text{ mmHg} \\ & P^* = 6.80 \text{ atm} \end{array}}$$ same conclusions

ii.

$$\rho_{liquid} = 28100 \frac{mol}{m^3}$$

$$PV = nRT \qquad \frac{P}{RT} = \frac{n}{V} = \rho = \frac{(4.11\,atm)(101325\,Pa/atm)}{(8.3145\,J/molK)(133.15)}$$

$$\rho = 376.19 \frac{mol}{m^3}$$: density of vapor phase

+2, solving density of V

+1 total volume = liquid volume + vapor volume

+1 , mole balance

$$623{,}000\,moles = \left(376.19 \frac{mol}{m^3}\right) V_{vapor} + 28100 \frac{mol}{m^3} \left(V_{liquid}\right)$$

$$500 m^3 = V_{vapor} + V_{liquid} \qquad V_{vapor} = 500 - V_{liquid}$$

+1 vapor balance

+1 solving system of equations

$$623000 \text{ moles} = \left(376.19 \frac{\text{mol}}{\text{m}^3}\right)(500 - V_{liquid})$$

$$+ 28100\ V_{liquid}$$

$$623000 = 188095 - 376.19\ V_{liquid} + 28100 V_{liquid}$$

$$434905 = 27723.81\ V_{liquid}$$

$$V_{liquid} = 15.687 \text{ m}^3$$

$$V_{vapor} = 484.313 \text{ m}^3$$

$$\text{moles vapor} = 484.313 \text{ m}^3 * 376.19 \frac{\text{mol}}{\text{m}^3} = 177835 \text{ moles}$$

$$\text{moles liquid} = 15.687 \text{ m}^3 * 28100 \frac{\text{mol}}{\text{m}^3} = 440805 \text{ moles}$$

$$\boxed{\begin{array}{l} \text{mol vapor} = 178 \text{ Kmol} \\ \text{mol liquid} = 441 \text{ Kmol} \end{array}}$$

* allow some rounding error

+2 final answers

If $T = -130°C$ $P^* = 6.80\text{ atm}$

$$\frac{P}{RT} = \frac{n}{V} = \rho_{vapor} = \frac{(6.80\text{atm})(101325\ \text{Pa/atm})}{(8.314\ \text{J/molK})(143.15)}$$

$$\rho_{vapor} = 578.93\ \frac{\text{mol}}{\text{m}^3}$$

$$623000 = \left(578.93\frac{\text{mol}}{\text{m}^3}\right) V_{vapor} + 28100\ V_{liquid}$$

$$500\text{m}^3 = V_{vapor} + V_{liquid}$$

$$623000 = (578.93)(500 - V_{liquid}) + 28100\ V_{liquid}$$

$V_{liquid} = 12.12\ \text{m}^3$ $V_{vapor} = 487.88\ \text{m}^3$

mol vapor : 282 Kmols

mol liquid = 341 Kmol

* allow some rounding error

-2 if correct idea but math errors

+1 +1

iii) $T_r = \frac{133.15}{196} = 0.679$ $P_r = \frac{4.11\ \text{atm}}{45.4\ \text{atm}} = 0.091$

($\frac{1}{2}$ credit if T_r found using °C)

Use T_r and P_r to find z on graph

$z \rightarrow 0.70$ (approximately!, almost not marked)

Methane non ideal here, on the saturation line, z indicates some compressability.

An equation of state would be better to use.

+1, finding a close value of z and concluding somewhat non ideal

2.

F stream = 1000 Kmole/hr

$Z_H = 0.2$

$Z_p = 0.35$

$Z_o = 0.45$

a)

For bubble point

$\sum y_i = 1.$ +1

$x_i P_i^{sat} = y_i P_{sys}$

hep:

$P_{sat} = 10^\wedge\left(6.90253 - \frac{1267.828}{T + 216.823}\right)$ +1

Pentane:

$P_{sat} = 10^\wedge\left(6.84471 - \frac{1060.793}{T + 231.541}\right)$ +1

Oct:

$P_{sat} = 10^\wedge\left(6.91874 - \frac{1351.756}{T + 209.100}\right)$ +1

$$\frac{0.2 P_H^{sat} + 0.35 P_p^{sat} + 0.45 P_o^{sat}}{1520 \text{ mmHg}} = 1$$ +2

Solve for T.

bubble point T = 91.6 °C. +1

dew point:

$$\sum x_i = 1. \quad +1 \qquad \sum \frac{y_i P_{sys}}{P_i^{sat}} = 1$$

$$1520\left(\frac{0.2}{P_H^{sat}} + \frac{0.35}{P_P^{sat}} + \frac{0.45}{P_o^{sat}}\right) = 1. \quad +1$$

solve for T.

dew point temp = 132.0 °C

+1

b). version 1.

$T = 120°C \qquad P = 2\text{ atm} \qquad F = 1000\text{ kmol}/h$

Find y_H, y_P, y_O, D; x_H, x_P, x_O and B.

Rachford-Rice eq.

$$x_i = \frac{z_i}{1+\left(\frac{V}{F}\right)\left(\frac{P_i^{sat}}{P_{sys}} - 1\right)}$$

$$\sum x_i = \sum \frac{z_i}{1+\frac{V}{F}\left(\frac{P_i^{sat}}{P_{sys}} - 1\right)} = 1.$$

$$P_H^{sat} = 10^\wedge\left(6.90253 - \frac{1267.828}{120+216.823}\right) = 1375.473\text{ mmHg} \quad +1$$

$$P_P^{sat} = 10^\wedge\left(6.84471 - \frac{1060.793}{120+231.541}\right) = 6716.743\text{ mmHg} \quad +1$$

$$P_O^{sat} = 10^\wedge\left(6.91874 - \frac{1351.756}{120+209.1}\right) = 647.611\text{ mmHg} \quad +1$$

$$1 = \left(\frac{0.2}{1+\frac{V}{1000}\left(\frac{1375.437}{1520}-1\right)} + \frac{0.35}{1+\frac{V}{1000}\left(\frac{6716.743}{1520}-1\right)} + \frac{0.45}{1+\frac{V}{1000}\left(\frac{647.6011}{1520}-1\right)} \right) \quad +2$$

Solve for V.

$D = V = 572.60$ kmol/hr. +2 $B = 1000 - 572.60 = 427.40$ kmol/h. +2

now solve for x_i using Rachford-Rice eq.

$$x_h = \frac{0.2}{1+\frac{572.60}{1000}\left(\frac{1375.437}{1520}-1\right)} = 0.211 \quad +1$$

$$x_p = \frac{0.35}{1+\frac{572.60}{1000}\left(\frac{6716.743}{1520}-1\right)} = 0.118 \quad +1$$

$$x_o = \frac{0.45}{1+\frac{572.60}{1000}\left(\frac{647.6011}{1520}-1\right)} = 0.671 \quad +1$$

$$y_h = \frac{(x_h)(P_h^{sat})}{1520} = 0.191 \quad +1$$

$$y_p = \frac{(x_p)(P_p^{sat})}{1520} = 0.523 \quad +1$$

$$y_o = \frac{(x_o)(P_o^{sat})}{1520} = 0.286 \quad +1$$

For incorrect answers due to errors from a prior calculation but with correct work, only deduct 0.5 points per answer

B) version 2.

$B = 500\ \text{kmol}/h \qquad P = 2\ \text{atm}.$

Find $T,\ y_H, y_p, y_o.$

$$p_H^{sat} = 10^\wedge\left(6.90253 - \frac{1267.828}{T + 216.823}\right) \quad +1$$

$$p_p^{sat} = 10^\wedge\left(6.84471 - \frac{1060.793}{T + 231.541}\right) \quad +1$$

$$p_o^{sat} = 10^\wedge\left(6.91874 - \frac{1351.756}{T + 209.1}\right) \quad +1$$

Rachford-Rice eq

$$\sum X_i = \sum \frac{z_i}{1 + \frac{V}{F}\left(\frac{p_i^{sat}}{P_{sys}} - 1\right)} = 1.$$

$$1 = \frac{0.2}{1 + \frac{1}{2}\left(\frac{p_H^{sat}}{1520} - 1\right)} + \frac{0.35}{1 + \frac{1}{2}\left(\frac{p_P^{sat}}{1520} - 1\right)} + \frac{0.45}{1 + \frac{1}{2}\left(\frac{p_o^{sat}}{1520} - 1\right)} \quad +3$$

Solve for T.

$T = 117.05$ +2 $\qquad y_i = \dfrac{x_i p_i^{sat}}{P_{sys}}$ +1

$$x_H = \frac{0.2}{1 + \frac{1}{2}\left(\frac{1274.04}{1520} - 1\right)} = 0.2176 \quad +1 \qquad y_H = 0.182 \quad +1$$

$$x_p = \frac{0.35}{1 + \frac{1}{2}\left(\frac{6333.257}{1520} - 1\right)} = 0.1355 \quad +1 \qquad y_p = 0.565 \quad +1$$

$$x_o = \frac{0.45}{1 + \frac{1}{2}\left(\frac{594.5156}{1520} - 1\right)} = 0.6469 \quad +1 \qquad y_o = 0.253 \quad +1$$

For incorrect answers due to errors from a prior calculation but with correct work, only deduct 0.5 points per answer

1-1/2

Part 2, version 1 and 2: only difference is pt. D

a. highest conversion? Dictated by equilibrium, when $r_A = 0$ (+2)

$$0 = -kP_A + kP_B \rightarrow \underline{P_A = P_B \text{ at equilibrium}}^{(+1)} \rightarrow P_A + P_B = P \text{ and } y_i P = P_i$$

$$2P_A = P$$

$$\text{so } y_A(2P_A) = P_A \rightarrow \underline{y_A = 0.5 \text{ at equilibrium}}$$

Species A balance around reactor: $0 = I - C$

$$n_{A,0} = y_{A,0}\underbrace{\dot{n}_0 = y_{A,0}\dot{n}_1}_{\substack{\text{Total mol} \\ \text{balance } (I=0) \\ \dot{n}_0 = \dot{n}_1}} = \dot{n}_1 - \dot{n}_1 f_A \rightarrow y_{A,0} = 1 - f_A$$

(+2) so $\boxed{f_A = 0.5}$

b. $r_A = -kP_A + kP_B$

$\rightarrow y_A P = P_A,\ y_B P = P_B$

so, $r_A = kP(y_B - y_A)$ (+1)

$\rightarrow y_B + y_A = 1 \rightarrow y_B = 1 - y_A$ (+1)

(+1)

so, $r_A = kP(1 - y_A - y_A) = \boxed{kP(1 - 2y_A) = r_A}$

c.

$$\frac{df_A}{dV} = \frac{-r_A}{\dot{n}_1} = \frac{-kP}{\dot{n}_1}(1 - 2y_A) \quad (+2)$$

relate y_A to f_A: $y_A = \dfrac{\dot{n}_{A,0}}{\dot{n}_1}$ (+1)

# of moles does not change in reactor

$$\dot{n}_{A,0} = \dot{n}_1 - \dot{n}_1 f_A = \dot{n}_1(1 - f_A)$$

So $\underline{y_A = (1 - f_A)}$ (+2) $\rightarrow$ plug into PFR design eqn:

$$\frac{df_A}{dV} = \frac{-kP}{\dot{n}_1}(1 - 2(1 - f_A)) = -\frac{kP}{n_1}(2f_A - 1) = \frac{kP}{n_1}(1 - 2f_A)$$

Rearrange:

$$\int \frac{df_A}{1 - 2f_A} = \frac{kP}{n_1}\int dV \rightarrow -\frac{1}{2}\ln(1 - 2f_A) = \frac{kP}{n_1} \cdot V + C \quad (+1)$$

2-½

1c.(cont): @ $V = 0\,L,\ f_A = 0 \rightarrow -\frac{1}{2}\ln(1-2(0)) = \frac{kP}{n_1}(0) + C \rightarrow C = 0$ (+1)

so $\ln(1-2f_A) = -2\frac{kP}{n_1}V$

$$\boxed{\begin{array}{c} f_A = \frac{1}{2} - \frac{1}{2}\exp\left(-2\frac{kP}{n_1}V\right) \\ \text{or} \\ V = -\frac{1}{2}\frac{n_1}{kP}\cdot\ln(1-2f_A) \end{array}}$$ (+1)

d. (version 1) V needed to achieve $f_A = 0.25$, w/ $n_1 = 100\,\frac{mol}{s}$, $k = \frac{0.01\,mol}{L\,s\,atm}$, $P = 10\,atm$

$$V = -\frac{1}{2}\frac{100\,\frac{mol}{s}}{0.01\,\frac{mol}{L\,s\,atm}\cdot 10\,atm}\ln(1-2\cdot 0.25) = \boxed{347L = V}$$

(+2) (+2) (-2 for incorrect answer)

d(version 2) f_A if $V = 500L$, $n_1 = 100\,\frac{mol}{s}$, $k = 0.01\,\frac{mol}{L\,s\,atm}$, $P = 10\,atm$

$$f = \frac{1}{2} - \frac{1}{2}\exp\left(-2\frac{(0.01)(10)}{100}(500)\right) = \boxed{0.316 = f_A}$$

(+2) (+2) (-2 for incorrect answer)

e. $\dot{n}_2$ and $\dot{n}_3$ in terms of $\dot{n}_1$?

Balance around reactor: $I = 0 \rightarrow \dot{n}_2 = \dot{n}_3$ (+1)

split balance: $I = 0$: $\dot{n}_3 = \dot{n}_4 + \dot{n}_5 = 2\dot{n}_4$ (+1)

mix balance: $I = 0$: $\dot{n}_1 + \dot{n}_4 = \dot{n}_2$ (+1)

Combine reactor and split: $\dot{n}_2 = \dot{n}_3 = 2\dot{n}_4$ (+2)

$$\dot{n}_1 + \dot{n}_4 = \dot{n}_2 = \dot{n}_1 + \frac{\dot{n}_2}{2} = n_2 \rightarrow \boxed{\dot{n}_2 = 2\dot{n}_1 = \dot{n}_3}$$

3-½

f. $\dot{n}_{2,A} = f(\dot{n}_1 \text{ and } f_A)$?

Reactor balance: $\dot{n}_{3,A} = \dot{n}_{2,A} - \dot{n}_{2,A} f_A = \dot{n}_{2,A}(1-f_A)$ (+1) $(O = I - C)$

Split balance: $\dot{n}_{3,A} = \dot{n}_{4,A} + \dot{n}_{5,A} = 2\dot{n}_{4,A}$ $(I=O)$ (+1)

mix balance: $\dot{n}_1 + \dot{n}_{4,A} = \dot{n}_{2,A}$ $(I=O)$ (+1)

combine Reactor and split: $2\dot{n}_{4,A} = \dot{n}_{2,A}(1-f_A)$ [1]

Combine [1] and mix: $\dot{n}_1 + \frac{1}{2}\dot{n}_{2,A}(1-f_A) = \dot{n}_{2,A}$ (+2)

Rearrange to solve for $\dot{n}_{2,A}$: $\boxed{\dot{n}_{2,A} = \frac{2\dot{n}_1}{(1+f_A)}}$

g. $y_{A,3} = \frac{\dot{n}_{3,A}}{\dot{n}_3}$ (+2)

from e), $\dot{n}_3 = 2\dot{n}_1$

$\dot{n}_{3A} = \dot{n}_{2A}(1-f_A)$ and $\dot{n}_{2A} = \frac{2\dot{n}_1}{1+f_A}$ from f)

(+3)

so: $y_{A,3} = \frac{\dot{n}_{3A}}{\dot{n}_3} = \frac{\dot{n}_{2A}(1-f_A)}{2\dot{n}_1} = \frac{2\dot{n}_1(1-f_A)}{2\dot{n}_1(1+f_A)} = \boxed{\frac{(1-f_A)}{(1+f_A)} = y_{A,3}}$

h. $\frac{df_A}{dV} = \frac{-r_A}{\dot{n}_{2,A}}$ (+1) $\quad r_A = kP(1-2y_A)$ (+1), so: $\frac{df_A}{dV} = \frac{-kP\left(1-2\frac{(1-f_A)}{(1+f_A)}\right)\cdot(1+f_A)}{2\dot{n}_1}$

$\hookrightarrow \dot{n}_{2,A} = \frac{2\dot{n}_1}{(1+f_A)}$

(−2) for incorrect form

(+5) for correct form

$\frac{df_A}{dV} = \frac{-kP}{2\dot{n}_1}\left(1+f_A - 2(1-f_A)\right) = -\frac{kP}{2\dot{n}_1}(3f_A - 1) = \frac{df_A}{dV}$

or

$\int \frac{df_A}{1-3f_A} = \frac{kP}{2\dot{n}_1}\int dV$

$\hookrightarrow -\frac{1}{3}\ln(1-3f_A) = \frac{kP}{2\dot{n}_1}V + C$

$f_A = 0$ when $V = 0$ L, so $C = 0$ (+1)

$\therefore \boxed{V = -\frac{2}{3}\frac{\dot{n}_1}{kP}\ln(1-3f_A)}$ (+2)

1-3/4

Part 2, version 3 and 4: only difference is pt. D, 3/4 have a different rate expression than 1/2 ($r_A = -kP_A + \frac{1}{2}kP_B$ vs $r_A = -kP_A + kP_B$)

a) highest conversion dictated by equilibrium: $r_A = 0$ (+2)

$0 = -kP_A + \frac{k}{2}P_B \rightarrow 2P_A = P_B$ at equilibrium (+1) $\rightarrow P_A + P_B = P$, so $P_A + 2P_A = P$

$3P_A = P$

$y_A P = P_A \rightarrow y_A(3P_A) = P_A$, $y_A = \frac{1}{3}$ at equilibrium

species A balance around reactor: $0 = I - C$

$$\dot{n}_{A,0} = y_{A0}\underbrace{\dot{n}_0 = y_{A,0}\dot{n}_1}_{\substack{\text{Total mol} \\ \text{balance } (I=0) \\ n_0 = \dot{n}_1}} = \dot{n}_1 - \dot{n}_1 f_A \rightarrow y_{A0} = 1 - f_A$$

(+2) $\boxed{\text{so } f_A = 2/3 = 0.667}$

b) $r_A = -kP_A + \frac{k}{2}P_B$

$\rightarrow y_A P = P_A \quad y_B P = P_B$

so, $r_A = kP\left(\frac{1}{2}y_B - y_A\right)$ (+1)

$y_B + y_A = 1 \rightarrow y_B = 1 - y_A$ (+1)

$\rightarrow$ so, $r_A = kP\left(\frac{1-y_A}{2} - y_A\right) = \boxed{kP\left(\frac{1}{2} - \frac{3}{2}y_A\right) \text{ or } \frac{kP}{2}(1 - 3y_A) = r_A}$ (+1)

c) $\frac{df_A}{dV} = -\frac{r_A}{\dot{n}_1} = -\frac{kP}{2\dot{n}_1}(1 - 3y_A)$ (+2) need to relate y_A to f_A: $y_A = \frac{\dot{n}_{A,0}}{\dot{n}_1}$ (+1)

$\hookrightarrow$ # moles does not change in reactor

$\dot{n}_{A,0} = \dot{n}_1 - n_1 f_A = \dot{n}_1(1 - f_A)$, so $\underline{y_A = 1 - f_A}$ (+2) $\rightarrow$ plug into design eqn.

$$\frac{df_A}{dV} = -\frac{kP}{2\dot{n}_1}\left(1 - 3(1 - f_A)\right) = -\frac{kP}{2n_1}(3f_A - 2) = \frac{kP}{n_1}\left(1 - \frac{3}{2}f_A\right)$$

Rearrange: $\int \frac{df_A}{\left(1 - \frac{3}{2}f_A\right)} = \frac{kP}{n_1}\int dV \rightarrow -\frac{2}{3}\ln\left(1 - \frac{3}{2}f_A\right) = \frac{kP}{n_1}V + C$ (+1)

@ $V = 0$, $f_A = 0 \rightarrow C = 0$, (+1) so $\ln\left(1 - \frac{3}{2}f_A\right) = -\frac{3}{2}\frac{kP}{n_1}V$ (+1)

$\boxed{V = -\frac{2n_1}{3kP}\ln\left(1 - \frac{3}{2}f_A\right)}$ or $\boxed{f_A = \frac{2}{3} - \frac{2}{3}\exp\left(-\frac{3}{2}\frac{kP}{n_1}V\right)}$

2-3/4

d. (version 3) V needed to achieve $f_A = 0.25$ w/ $n_1 = 100\frac{mol}{s}$, $k = 0.01\frac{mol}{s\,L\,atm}$, $P = 10\,atm$

$$V = -\frac{2}{3}\frac{n_1}{kP}\ln\left(1-\frac{3}{2}f_A\right) = \boxed{313\,L = V}$$

(+2) (+2)

d. (version 4) $f_A = \frac{2}{3} - \frac{2}{3}\exp\left(-\frac{3}{2}\frac{kP}{n_1}V\right)$ V = 500L, all else same above

(+2)

$$\boxed{f_A = 0.352}$$

(+2)

e, f, g all same as version 1&2:

e. $\dot{n}_2 = \dot{n}_3 = 2\dot{n}_1$, f. $\dot{n}_{2,A} = \frac{2\dot{n}_1}{(1+f_A)}$ g. $y_{A,3} = \frac{(1-f_A)}{(1+f_A)}$

h. $\frac{df_A}{dV} = -\frac{r_A}{n_{2A}}$ (+1)

$\hookrightarrow = \frac{2\dot{n}_1}{(1+f_A)}$

(-2) for incorrect form

(+1)

$r_A = \frac{kP}{2}(1-3y_A)$, so $\frac{df_A}{dV} = \frac{-kP}{4\dot{n}_1}\left(1-3\left(\frac{1-f_A}{1+f_A}\right)\right)(1+f_A)$

$$\frac{df_A}{dV} = -\frac{kP}{4n_1}\left(1+f_A-3+3f_A\right) = -\frac{kP}{4n_1}\left(4f_A-2\right)$$

(+5)

$$= -\frac{kP}{2n_1}\left(2f_A-1\right)$$

Rearrange: $\int\frac{df_A}{1-2f_A} = \frac{kP}{2n_1}\int dV \rightarrow -\frac{1}{2}\ln\left(1-2f_A\right) = \frac{kP}{2n_1}V + C$

@ V=0, $f_A=0$, so C=0 (+1)

$$\boxed{V = -\frac{n_1}{kP}\ln\left(1-2f_A\right)}$$ (+2)

$f_A = \frac{1}{2} - \frac{1}{2}\exp\left(-\frac{kPV}{n_1}\right)$

i) same as version 1&2:

$$\boxed{F_A = \frac{2f_A}{1+f_A}}$$

4-½

i) $F_A = \frac{n_1 - n_{A,5}}{n_1}$?

(+1)

$n_{3A} = 2n_{5A}$ from split balance

$\dot{n}_{3A} = n_{2A}(1-f_A)$ and $n_{2A} = \frac{2\dot{n}_1}{1+f_A}$ so $\dot{n}_{3A} = 2\dot{n}_1 \frac{(1-f_A)}{(1+f_A)} = 2n_{5A}$

$\dot{n}_{5A} = \dot{n}_1 \frac{(1-f_A)}{(1+f_A)}$ (+2)

$$\therefore F_A = \frac{n_1}{n_1}\left[\frac{1-\frac{(1-f_A)}{(1+f_A)}}{1}\right] = 1 - y_{A,3}$$

(+2) $$F_A = 1 - \frac{(1-f_A)}{(1+f_A)} = \frac{1+f_A-1+f_A}{1+f_A} = \boxed{\frac{2f_A}{1+f_A} = F_A}$$