Conceptual Questions

1. False - you may not assume a basis because a flowrate is specified elsewhere in the process. Doing so may violate the law of conservation of mass.

2. a. Greater than

3. less than. law of conservation of mass - $\dot{m}_2$ has to be less than $\dot{m}_1$

4. There are 4 species (CS_2, N_2, O_2, benzene) so we can write 4 independent material balances

Problem 5: Hemodialysis

1. Draw + label PFD

Dialysate

$\dot{n}_{2H_2O} = \frac{\dot{V}_1 \cdot \rho_{H_2O}}{MW_{H_2O}}$

$\dot{n}_{2E} = C_{2E}\dot{V}_2$

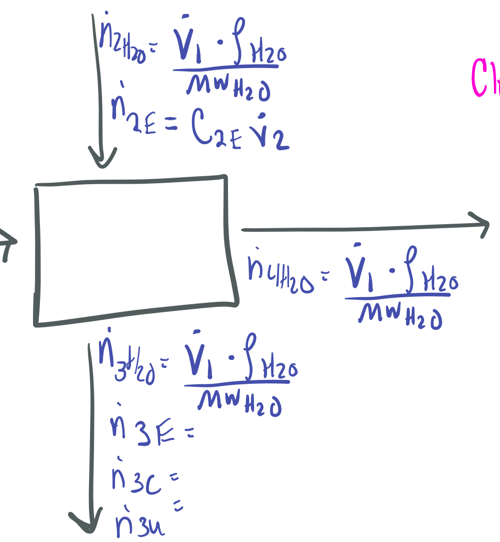
Fresh Blood

$\dot{n}_{1H_2O} = \frac{\dot{V}_1 \cdot \rho_{H_2O}}{MW_{H_2O}}$

$\dot{n}_{1E} = C_{1E}\dot{V}_1$

$\dot{n}_{1u} = C_{1u}\dot{V}_1$

$\dot{n}_{1c} = C_{1c}\dot{V}_1$



Clean blood

$\dot{n}_{4H_2O} = \frac{\dot{V}_1 \cdot \rho_{H_2O}}{MW_{H_2O}}$

$\dot{n}_{4E} =$

$\dot{n}_{4u} =$

$\dot{n}_{4c}$

$\dot{n}_{3H_2O} = \frac{\dot{V}_1 \cdot \rho_{H_2O}}{MW_{H_2O}}$

$\dot{n}_{3E} =$

$\dot{n}_{3c} =$

$\dot{n}_{3u} =$

used dialysate

Want to know

(A) $x_{4i} = \frac{\dot{n}_{4i}}{\dot{n}_{4E} + \dot{n}_{4u} + \dot{n}_{4c} + \dot{n}_{4w}}$, (B) $x_{3i} = \frac{\dot{n}_{3i}}{\dot{n}_{3E} + \dot{n}_{3c} + \dot{n}_{3u} + \dot{n}_{3w}}$

Additional Info

$\dot{V}_1 = \dot{V}_2 = \dot{V}_3 = \dot{V}_4$ 400 mL/min *flowrate of H_2O

$\rho_{blood} = \rho_{dialysate} = \rho_{water}$ (g/mL)

Stream 1: $C_{1E} = 250 \frac{mmol\ E}{L}$, $C_{1u} = 10 \frac{mmol\ u}{L}$, $4 \frac{mmol\ C}{L} = C_{1c}$

Stream 2: $250 \frac{mmol\ E}{L} = C_{1E}$

(*) $0.80\,\dot{m}_{1c} = \dot{m}_{3c}$ (**) $0.10\,\dot{m}_{1u} = \dot{m}_{4u}$

DOF Analysis

6 unknowns ($\dot{n}_{4E}$ $\dot{n}_{4u}$ $\dot{n}_{4c}$ $\dot{n}_{3E}$ $\dot{n}_{3c}$ $\dot{n}_{3u}$)

\- 4 independent material balances (because we have 4 species E, u, c, w)

\- 2 additional equations (* and **)

0 DOF ^^ we can solve!

Material Balances

E: $n_{1E} + n_{2E} = n_{3E} + n_{4E}$

u: $n_{1u} = n_{3u} + n_{4u}$

C: $n_{1c} = n_{3c} + n_{4c}$

W: $n_{1w} + n_{2w} = n_{3w} + n_{4w}$

total: $n_{1E} + n_{1u} + n_{1c} + n_{1w} + n_{2E} + n_{2w} = n_{3E} + n_{4E} + n_{3u} + n_{4u} + n_{3c} + n_{4c} + n_{3w} + n_{4w}$

(*) $0.8\dot{n}_{1c} = \dot{n}_{3c}$

(**) $0.10\dot{n}_{1u} = \dot{n}_{4u}$

How to solve

1. Calculate all $\dot{n}_{1w}$ $\dot{n}_{2w}$ $\dot{n}_{3w}$ $\dot{n}_{4w}$ using ρ, MW as shown on PFD
2. Calculate all $\dot{n}_{1i}$ and $\dot{n}_{2i}$ using $\dot{n}_{1i} = C_{1i} \cdot \dot{V}_1$ and $\dot{n}_{2i} = C_{2i}\dot{V}_2$

   Now we have species molar flowrates for streams 1 and 2

3. Equations (*) and (**) can be written with $\dot{n}$ or $\dot{m}$, because they are ratios.

4. use $\circledast$ to calc $\dot{n}_{3u}$
5. use $\circledast\circledast$ to calc $\dot{n}_{4u}$
6. use u balance to calc $\dot{n}_{3u}$
7. use c balance to calc $\dot{n}_{4c}$
8. Solve E balance in terms of n_{3E} - plug into total. Solve for n_{4E}
9. Plug n_{4E} into E balance, Calc n_{3E}
10. We now know all species molar flowrates for streams 3 and 4 - can calculate the mole fractions! Equations A and B

ungraded

Why does the E composition need to stay the same? So we don't remove the healthy electrolytes from the blood!

Problem 6: CO_2 absorption

A) How many lbs. of CO_2 are fed to the absorber daily?

$$\frac{9.6\times10^6\ \text{kWh}}{\text{day}}\left|\frac{2.30\ \text{lbs. } CO_2}{\text{kWh}}\right. = 22.08\times10^6\ \frac{\text{lbs } CO_2}{\text{day}}$$

$$\boxed{22\times10^6\ \frac{\text{lbs } CO_2}{\text{day}}}$$

B) How many cars are "removed" from the road by reducing emissions by 90%?

Convert annual CO_2 emissions to daily emissions

$$\frac{4.6\ \text{metric tons}}{\text{car}\cdot\text{year}}\left|\frac{1\ \text{year}}{365\ \text{days}}\right|\frac{1000\ \text{kg}}{1\ \text{metric ton}}\left|\frac{2.2\ \text{lbs.}}{1\ \text{kg}}\right. = 28\ \frac{\text{lbs } CO_2}{\text{day}\cdot\text{car}}$$

$$\frac{0.9\,(22\times10^6\ \text{lbs } CO_2)}{\text{day}}\left|\frac{\text{car}\cdot\text{day}}{28\ \text{lbs}}\right. = 707{,}000$$

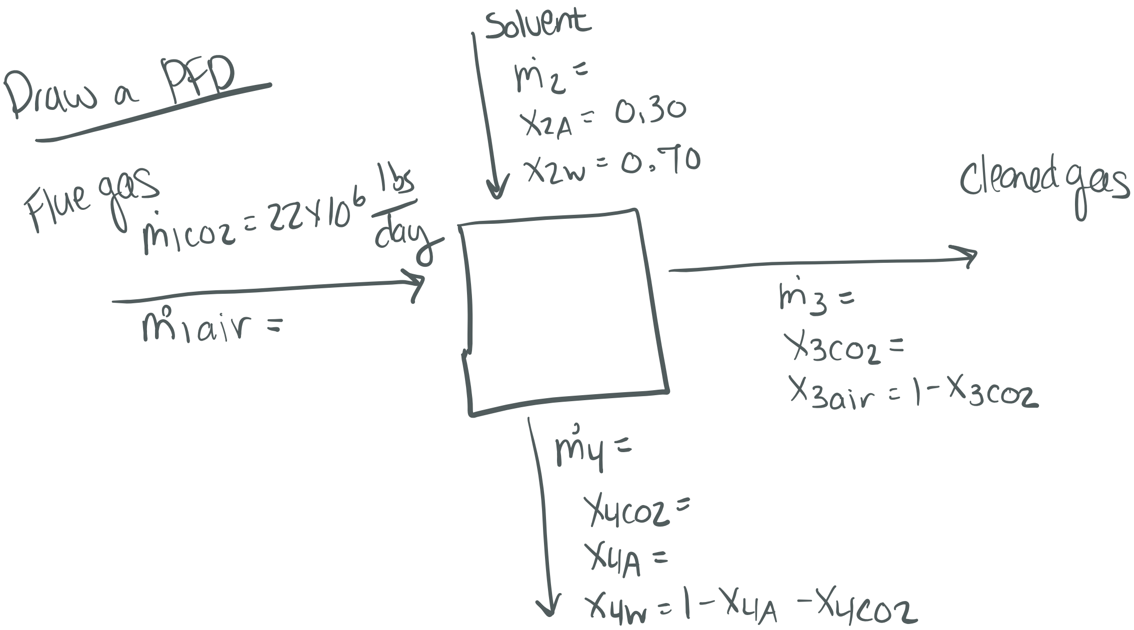
with sig figs

$$\boxed{710{,}000\ \text{cars}}$$

that is more than 2x the number of people in Cleveland!

c) want to know x_{4CO_2} x_{4A} x_{4W}

Draw a PFD



want to know: x_{4CO_2}, x_{4A}, x_{4W}

Additional Information

*** $V_{1CO_2} = 0.12 \left(\frac{V_{CO_2}}{V_{mix}}\right)$

ρ_{CO_2} @STP $= 1.96$ g/L

ρ_{air} @STP $= 1.27$ g/L

90% of CO_2 is removed $\rightarrow$ $0.90(\dot m_1 x_{1CO_2}) = \dot m_4 x_{4CO_2}$ *

Feed ratio: $\frac{m_1 x_{1CO_2}}{m_2 x_{2A}} = \frac{1}{10}$ **

DOF analysis

7 unknowns ($\dot m_{1air}$, $\dot m_2$, $\dot m_3$, $\dot m_4$, x_{3CO_2}, x_{4CO_2}, x_{4A})

\- 4 mat balances (CO_2, A, air, w)

3 additional equations (*, **, ***)

0 DOF - can solve!

Material Balances

CO_2: $\dot{m}_{1CO_2} = \dot{m}_4 x_{4CO_2} + \dot{m}_3 x_{3CO_2}$

A: $\dot{m}_2 x_{2A} = \dot{m}_4 x_{4A}$

W: $\dot{m}_2 x_{2W} = \dot{m}_4 x_{4W} = \dot{m}_4 (1 - x_{4A} - x_{4CO_2})$

air: $\dot{m}_1 x_{1air} = \dot{m}_3 x_{3air} = \dot{m}_3 (1 - x_{3CO_2})$

total: $\dot{m}_1 + \dot{m}_2 = \dot{m}_3 + \dot{m}_4$

$0.90 \dot{m}_1 x_{1CO_2} = \dot{m}_4 x_{4CO_2}$

$\frac{\dot{m}_1 x_{1CO_2}}{\dot{m}_2 x_{2A}} = \frac{1}{10}$

1. Calculate mass fraction of CO_2 in stream 1 assuming a basis of 1 L + using the densities of CO_2 + air.

$$1\text{ L flue gas} \left(\frac{0.12\text{ L }CO_2}{1\text{ L flue}}\right)\left(\frac{1.96\text{ g }CO_2}{1\text{ L }CO_2}\right) = \dot{m}_{CO_2}$$

$$1\text{ L flue gas} \left(\frac{0.88\text{ L air}}{\text{L flue}}\right)\left(\frac{1.27\text{ g air}}{\text{L air}}\right) = \dot{m}_{air}$$

$$x_{1CO_2} = \frac{\dot{m}_{CO_2}}{\dot{m}_{CO_2} + \dot{m}_{air}}$$

2. use X_{1CO_2} to calculate $X_{air} = 1 - X_{1CO_2}$
3. Calculate $\dot{m}_1$ from $\dot{m}_{1CO_2} = \dot{m}_1 X_{1CO_2}$
4. use ** to calculate $\dot{m}_2$
5. Plug * into CO_2 balance
6. Solve the CO_2 balance for m_3 and plug into air balance $\rightarrow$ solve for X_{3CO_2}
7. Use X_{3CO_2} in CO_2 balance to calculate m_3
8. use total to calculate $\dot{m}_4$
9. A balance to calc X_{4A}
10. W balance to calc X_{4W}
11. CO_2 balance to calc X_{4CO_2}