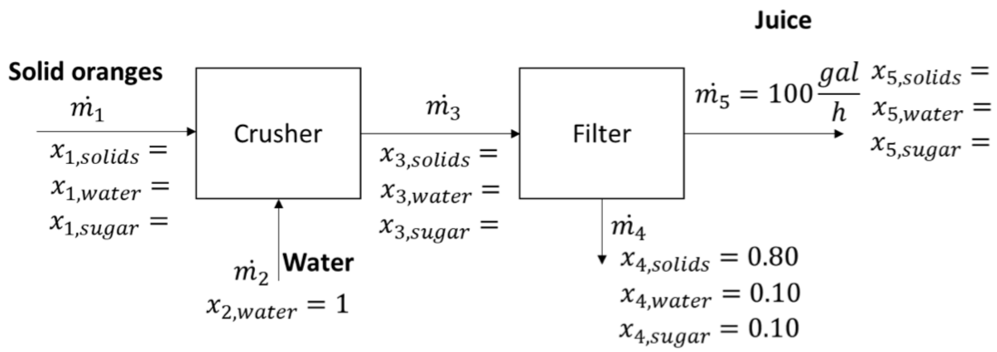
Conceptual Questions: Problems 1-4

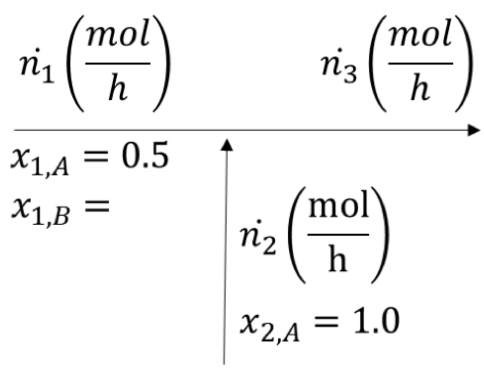
1. **(4 points)** Consider the orange juice production process, below. **True or False**: When performing a degree of freedom analysis around the crusher, it is appropriate to assume a basis. *Justify your answer.*



False; $\dot{m}_5 = 100\,\frac{gal}{h}$, which is not a composition! If a problem has an actual mass/mass flow rate, even in a different subsystem, assuming a basis can violate the law of conservation of mass, as the incorrect basis can result in the equation being unbalanced, equivalent to stating, for example, in = out → 50 = 100.

2. **(4 points)** In the process shown below, the mole fraction of A in stream 3 will be ______________ the mole fraction of A in stream 1.

   a. Greater than
   b. Less than
   c. Equal to



Law of Conservation of Mass

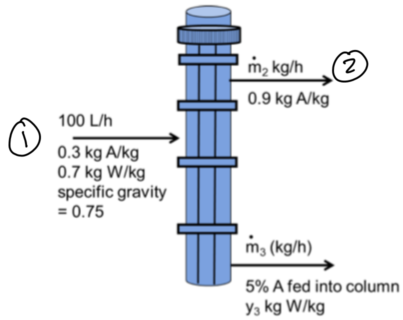
in − out + $\cancel{\text{gen}}^{0}$ − $\cancel{\text{cons}}^{0}$ = accumulation   Assume know accumulation 'a'

no chemical reaction

There is no chemical reaction occurring, and $x_{2,A} > x_{1,A}$, so it is safe to assume, regardless of accumulation factor and $\dot{n}_1$ and $\dot{n}_2$, that $x_{3,A}$ will always be greater than $x_{1,A}$.

3. **(4 points)** Consider the distillation column below. The mass ratio of the top product (stream 2) to feed (stream 1) is _______ one. *Justify your answer.*

a. Greater than
b. Less than
c. Equal to
d. Need more information



$$\text{Mass Ratio} = \frac{\text{Mass Top Product}}{\text{Mass Feed}} = \frac{\dot{m}_2}{\dot{m}_1}$$

1: $0.3 \frac{kg\ A}{kg}$, $0.7 \frac{kg\ W}{kg}$ — Column separates A and W

2: $0.9 \frac{kg\ A}{kg}$, $0.1 \frac{kg\ A}{kg}$ ← stream 2 rich with A but low flowrate as its evaporated

3: $y_3 \frac{kg\ W}{kg}$ ← Should be much lower in [A]

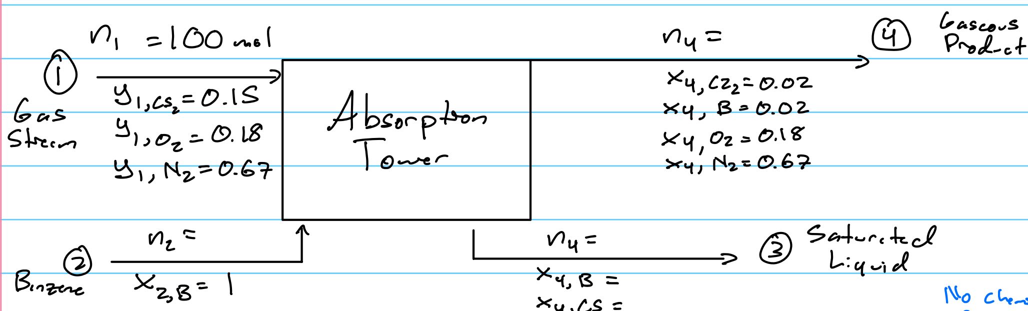
Distillation usually separates more volatile component. A is not as concentrated in feed, so there should be a lower mass flow rate in 2; $\boxed{\dot{m}_2 < \dot{m}_1}$

4. **(4 points)** Consider 100 moles of a gas stream containing 15 mol% CS_2, 18 mol% O_2, and 67 mol% N_2. The gas is fed to a continuous absorption tower, where it contacts liquid benzene, which absorbs CS_2, but not O_2 or N_2. Benzene is fed to a column in a 2:1 mole ratio to the feed gas. Some of the benzene entering as liquid evaporates and leaves the top of the tower as vapor. The gas leaving the absorber contains 2 mol% CS_2 and 2 mol% benzene. How many independent material balances can you write?

a. 2
b. 3
c. 4 ← You can write 4
d. 5
e. Need more information.

You can write 4, but they will all have accumulation as an unknown variable!

Note
No Mixing/Splitting, can write 4 even with accumulations



Mathematical Relations

$$\frac{n_2}{n_1} = \frac{2}{1}$$

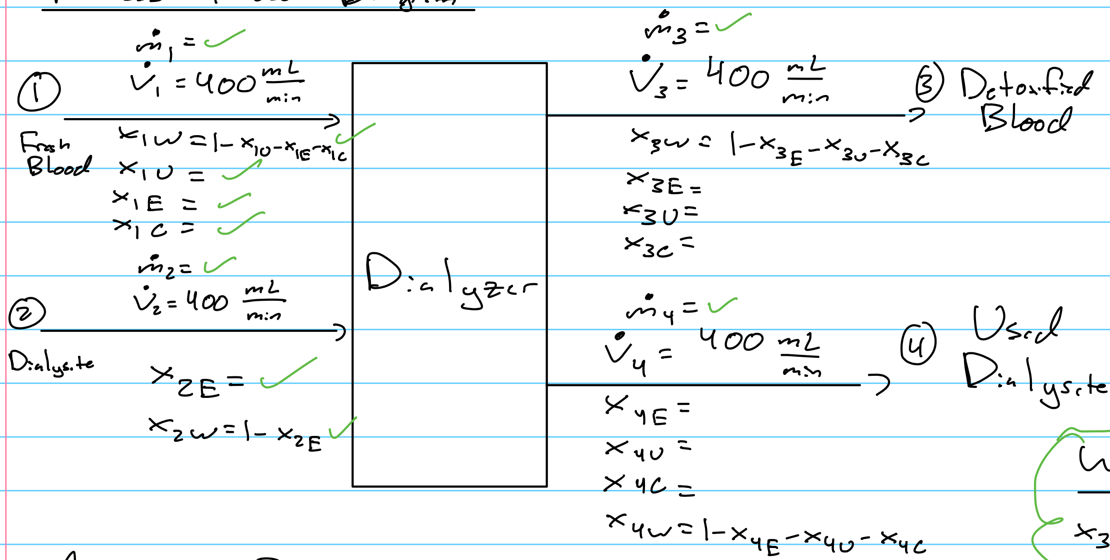
Law of Conservation of Mass: In − Out + ~~Generation − Consumption~~ = Accumulation (No Chemical Reaction) (Not stated if its steady-state)

In − Out = Accumulation

Given whether or not there is any accumulation, you could write 4 independent material balances, one for each species.

Problem 5: Kidney Hemodialysis

Process Flow Diagram



Naming Scheme

Subscript	Name
U	Urea
E	Electo.
C	Creatinine
W	Water

Want to Know

$x_{3E}, x_{3U}, x_{3C}, x_{4E}, x_{4U}, x_{4C}$

Additional Equations

ⓐ $\dot{m}_4 x_{4C} = 0.80 \dot{m}_1 x_{1C}$

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

DoF Analysis

6 Unknowns $(x_{3E}, x_{3U}, x_{3C}, x_{4E}, x_{4U}, x_{4C})$

− 4 Material Balances (4 indp species)

− 2 additional Equations (ⓐ & ⓑ)

0 DoF Soluble

Convert to Same Basis

$$\text{Conc.} = \frac{mol}{vol} = \frac{mmol}{L} \times \dot{V} = \dot{n}$$

$$\dot{n}_{1W} = \dot{n}_{2W} = \frac{400\,mL}{min} \times \frac{1\,g}{1\,mL} \times \frac{1\,mol}{18.02\,g} \times \frac{1000\,mmol}{1\,mol} = 22197.56 \frac{mmol}{min}$$

$$\dot{n}_{1U} = \frac{0.4\,L}{min} \times \frac{10\,mmol}{L} = 4 \frac{mmol}{min}$$

$$\dot{n}_{1E} = \frac{0.4\,L}{min} \times \frac{250\,mmol}{L} = 100 \frac{mmol}{min}$$

$$\dot{n}_{1C} = \frac{0.4\,L}{min} \times \frac{4\,mmol}{L} = 1.6 \frac{mmol}{min}$$

$$\dot{n}_{2E} = \frac{0.4\,L}{min} \times \frac{250\,mmol}{L} = 100 \frac{mmol}{min}$$

$$\left. \begin{aligned} x_{1U} &= \frac{\dot{n}_{1U}}{\dot{n}_{1E} + \dot{n}_{1C} + \dot{n}_{1W} + \dot{n}_{1U}} \\ x_{1E} &= \frac{\dot{n}_{1E}}{\dot{n}_{1E} + \dot{n}_{1C} + \dot{n}_{1W} + \dot{n}_{1U}} \\ x_{1C} &= \frac{\dot{n}_{1C}}{\dot{n}_{1E} + \dot{n}_{1C} + \dot{n}_{1W} + \dot{n}_{1U}} \\ x_{2E} &= \frac{\dot{n}_{2E}}{\dot{n}_{2E} + \dot{n}_{2W}} \end{aligned} \right\} \text{All Known}$$

$$\dot{m}_1 = \dot{m}_2 = \dot{m}_3 = \dot{m}_4 = 400 \frac{mL}{min} \times \frac{1\,g}{1\,mL} = 400 \frac{g}{min} \Big\} \text{ all } \dot{m}_i \text{ are Known}$$

Given that all concentrations of electrolytes are the same in each stream, but I contend with this in Plan of Attack.

Problem 5: Kidney Hemodialysis (continued)

Material Balances

No reactions! All flowrates equivalent

$in - out + \cancel{generation - consumption} = \cancel{accumulation} \rightarrow in = out$

U: $\dot{m}_1 x_{1U} = \dot{m}_3 x_{3U} + \dot{m}_4 x_{4U}$

C: $\dot{m}_1 x_{1C} = \dot{m}_3 x_{3C} + \dot{m}_4 x_{4C}$

E: $\dot{m}_1 x_{1E} + \dot{m}_2 x_{2E} = \dot{m}_3 x_{3E} + \dot{m}_4 x_{4E}$

W: $\dot{m}_1 x_{1W} + \dot{m}_2 x_{2W} = \dot{m}_3 x_{3W} + \dot{m}_4 x_{4W}$

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

Originally known are in green

Known based on definition of a mass fraction

Plan of Attack

(i) Solve $\star$ for x_{4U}

(ii) Plug (i) into U balance to solve for x_{3U}

(iii) Solve $\star$ for x_{4C}

(iv) Plug (iii) into C balance to solve for x_{3C}

Redundant (v) Use given that $x_{1E} = x_{2E} = x_{3E} = x_{4E}$ to get x_{3E} and x_{4E}

(vi) Solve for x_{3W} and x_{4W} with appropriate results

This allows us to report $\boxed{\underbrace{x_{3E}, x_{3U}, x_{3C}}_{\text{Concentration of Blood exiting the dialyzer}}, \underbrace{x_{4E}, x_{4U}, x_{4C}}_{\text{Concentration of dialysate exiting the dialyzer}}}$ as requested

Having equal concentrations of electrolytes is crucial for the health of the patient as imbalances can cause issues from muscle fatigue to serious heart issues or cardiac arrest in serious situations

Problem 6 (Labeled 7): CO2 Absorption

- 500 MW coal-fired Plant Produces 9.6 mil kWh/day — 11,000 bulbs/day
- Coal Fired Plants produce 2.30 lbs CO_2/kWh → EPA requiring 90% reduction
- Cooled flue gas leaves as mixture of CO_2, and N_2/O_2 to go to absorber
  - ↳ 12.3% CO_2 by volume, rest is N_2/O_2
- Amine Solvent directly into absorber
  - ↳ mass fraction of 0.30 in water
- Feed Ratio of amine : CO_2 is 10:1 by mass
- Density $CO_2 = 1.96$ g/L & density of O_2/N_2 is 1.27 g/L

A. Pounds of CO2 per Day from Plant

$$9.6\times10^6 \frac{\text{kWh}}{\text{day}} \times 2.30 \frac{\text{lbs } CO_2}{\text{kWh}} = 22{,}080{,}000 = \boxed{2.2\times10^7 \frac{\text{lbs } CO_2}{\text{day}}}$$

B. "Car Equivalent" CO2 Emissions for Removal

- 4.60 $\frac{\text{metric tons } CO_2}{\text{year}}$ from Cars

Determine 90% of Plant Emissions

$$0.90\times\left(2.2\times10^7 \frac{\text{lbs } CO_2}{\text{day}}\right) = 19.8\times10^6 \frac{\text{lbs } CO_2}{\text{day}}$$

Determine Car emissions in $\frac{\text{lbs } CO_2}{\text{day}}$

$$4.60 \frac{\text{metric tons } CO_2}{\text{year}} \times \frac{1 \text{ year}}{365 \text{ day}} \times \frac{2204.62262 \text{ lbs}}{1 \text{ metric ton}} = 27.78 \frac{\text{lbs } CO_2}{\text{day}}$$

Determine Number of Cars Needed

Round to Sig Figs

Will go to 3 sig figs as given is at 3 in (B).

$$\# \text{ cars} = \frac{19.8\times10^6 \frac{\text{lbs } CO_2}{\text{Day}}}{27.78 \frac{\text{lbs } CO_2}{\text{Day}}} = 712633.06 \text{ Cars}$$

$$\boxed{7.12\times10^5 \text{ Cars}}$$

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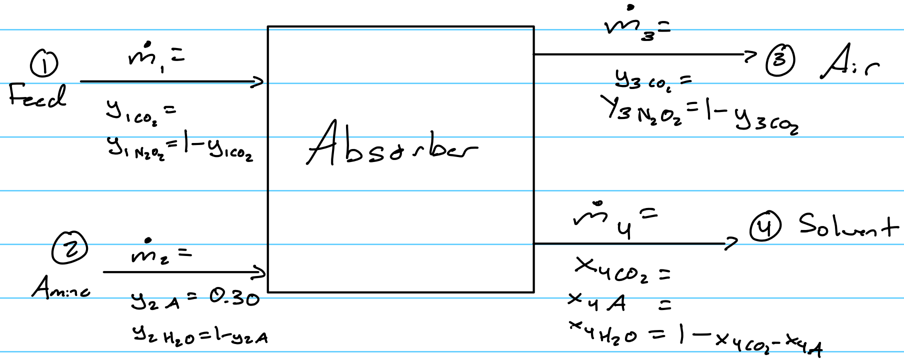
C. Absorber Exiting Solvent Composition



Not derived from law of conservation of mass

Additional EQs

1. $\frac{\dot{m}_2}{\dot{m}_1} = \frac{10}{1}$
2. $\dot{m}_4 = 0.90\dot{m}_1$
3. $\dot{m}_1 = \frac{\dot{m}_{1CO_2}}{y_{1CO_2}}$
4. $y_{1CO_2} = \frac{P_{CO_2}\dot{V}_{CO_2}}{P_{CO_2}\dot{V}_{CO_2} + P_{N_2O_2}\dot{V}_{N_2O_2}}$

$\hookrightarrow y_{1CO_2} = \frac{\dot{m}_{CO_2}}{\dot{m}_{CO_2} + \dot{m}_{N_2O_2}}$

Given Quantities

$P_{CO_2} = 1.96\ g/L$

$P_{N_2O_2} = 1.27\ g/L$

$\dot{m}_{1CO_2} = 2.2 \times 10^7\ \frac{\text{lbs } CO_2}{\text{day}}$

Want to Know

x_{4CO_2}, x_{4A}

Naming Scheme

- $y_{1N_2O_2}$ is Concentration of N_2/O_2
- y_{iA} is Concentration of Amine

Others are Self-explanatory

Convert to same Basis

$\dot{m}_{1CO_2} = 2.2 \times 10^7$ lbs CO_2/day

Need $\dot{m}_{N_2O_2}$ to find $\dot{m}_1$

Assume a basis of 1L

$0.123 \times 1L \times 1.96\ g/L = 0.24108\ g$

$0.877 \times 1L \times 1.27\ g/L = 1.11379\ g$

$$y_{1CO_2} = \frac{0.24108}{0.24108 + 1.11379} = 0.1779$$

$$\dot{m}_{1CO_2} = y_{1CO_2}\dot{m}_1 \rightarrow \dot{m}_1 = \frac{\dot{m}_{1CO_2}}{y_{1CO_2}}$$

DoF Analysis

8 Unknowns ($\dot{m}_1, y_{1CO_2}, \dot{m}_2, \dot{m}_3, y_{3CO_2}, \dot{m}_4, x_{4CO_2}, x_{4A}$)

4 material balances (4 independent species, no mixing)

4 additional EQs (1, 2, 3 and 4)

0 DoF Soluble

C. Absorber Exiting Solvent Composition (Continued)

Material Balances

No reaction

in − out + ~~generation~~ − ~~consumption~~ = ~~accumulation~~ → in = out

CO_2: $\dot{m}_1 y_{1CO_2} = \dot{m}_2 y_{3CO_2} + \dot{m}_4 x_{4CO_2}$

N_2/O_2: $\dot{m}_1 y_{1N_2O_2} = \dot{m}_3 y_{3N_2O_2}$

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

H_2O: $\dot{m}_2 y_{2H_2O} = \dot{m}_4 x_{4H_2O}$

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

Originally known are in green

Plan of Attack

(i) Find y_{1CO_2} by ☆ using a basis of 1L as shown on prev. page

(ii) Calculate $\dot{m}_1$ by using equation ☆

(iii) Solve ☆ for $\dot{m}_2$

(iv) Solve ☆ balance for $\dot{m}_4$

(v) Solve Amine balance for x_{4A}

(vi) Plug x_{4A} into $x_{4H_2O} = 1 - x_{4CO_2} - x_{4A}$ and substitute into H_2O balance. Results in $\dot{m}_2 y_{2H_2O} = \dot{m}_4 (1 - x_{4CO_2} - x_{4A})$ which has 1 unknown. Solve this for x_{4CO_2}

(vii) Solve CO_2 balance for y_{3CO_2}

(viii) Solve Total Balance for $\dot{m}_3$

This allows us to report y_{3CO_2}, $y_{3N_2O_2}$, x_{4CO_2}, x_{4A}, and x_{4H_2O} as requested.

Problem 7 (Labeled 8): Unit 2A Reflection

(4 points) We have now concluded unit 1 & part of unit 2 which covered unit conversions, dimensional homogeneity and the general procedure for nonreactive single- and multi-unit processes.

a. Is there anything about the content that you still find confusing?
b. What (if anything) about the way the class is taught prohibiting your learning?
c. What (if anything) about the way the class is taught helping your learning?

I am still confused about setting up process flow diagrams when the information given doesn't have any quantities that aren't necessarily what you would directly in an equation. I found a lot of trouble with problem 6 (**hemodialysis**) as I was unsure how to handle the molar flow rate given, when there was concentrations that I as trying to solve for and have in my PFD. This extended into the **CO2 absorber** question, though my confusion on that problem was a mixture of being stuck on the PFD and also applying previous parts to the solution. I do not find the topics of single unit processes or dimensional homogeneity confusing. I attended office hours to assist in the completion of the homework, which was helpful as I could converse with both the TAs and fellow classmates, so the frequent office hours is definitely beneficial to my learning. As for the class directly, I think the heavy emphasis on examples is a double edged sword. While having so many practice problems does help me know what steps to take on the homework, it felt as though they were a gross simplification of what is expected on the homework assignment. I do really appreciate the emphasis on engagement, collaboration, and examples in the classroom, but spending some time on more difficult problems would definitely be beneficial to my learning in this course. I believe this contributes to some confusion I face on the homework, as I am looking for patterns in the example problems that I simply can't follow/make use of when I do a problem on my own. Also, clarifications/more descriptive wording would be very beneficial in the future, as the announcement sent out on Wednesday of the week this assignment was due cleared a lot of things up, even if they should've been implied in the problem statement. I would also like to note that my concerns and confusion may just be a result of this being the first proper homework assignment that wasn't relying on previous topics, and that I'm just getting used to the way problems are approached in this environment.